COST OPTIMAL SURGE PROTECTIVE SYSTEM FOR LOW VOLTAGE INSTALLATIONS

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Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science

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April 2017

DECLARATION

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ABSTRACT

Surge protective devices (SPDs) have become an integral part of residential, commercial and industrial power quality applications. A wide selection of surge SPDs are promoted by greater number of manufactures for the protection of electrical and electronic systems damaging effects of electrical transients and lightning. The selection of the appropriate cost effective SPD is great difficult due to some manufactures use different technologies and many manufactures specify their SPD performance differently.

One of the difficult tasks encountered when specifying a SPD is identifying and understanding the ratings associated with its application. There are many performance values and ratings associated with an SPD, such as Maximum Continuous Operating Voltage (MCOV), Voltage Protection Rating (VPR), Nominal Discharge Current (In), and Short Circuit Current Rating (SCCR). The most important and misunderstood rating is the Surge Current Rating. In today's market there are numerous SPDs with surge current ratings ranging from 10 kA through 1000 kA with different prices.

The research presents a methodology to select cost optimal surge protection devices for low voltage installations. The procedure for the selection of SPD is considered the steps of risk assessment, IES standard, manufacture technical details, the applied technology and the data bank of SPD available in local market. The cost optimal solution has been obtained by user friendly software considering the risk assessment result, area lightning density, location and the geographical factors.

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SYMBOLS AND ABBREVIATIONS

Ad - Collection area for flashes to an isolated structure

Ai - Collection area for flashes near a service

Al - Collection area for flashes to a service

Cd - Location factor Ce Environmental factor

Ct - Correction factor for a HV/LV transformer on the service

D1 - Injury to living beings

D2 - Physical damage

D3 - Failure of electrical and electronic systems

hz- Factor increasing the loss when a special hazard is present

H - Height of the structure

Ha - Height of the structure connected at end "a" of a service

Hb- Height of the structure connected at end "b" of a service

Hc- Height of the service conductors above ground

Kd- Factor relevant to the characteristics of a service

KMS - Factor relevant to the performance of protection measures against LEMP

Kp- Factor relevant to adopted protection measures in a service

KS1 - Factor relevant to the screening effectiveness of the structure

KS2 - Factor relevant to the screening effectiveness of shields internal to the structure

KS3 - Factor relevant to the characteristics of internal wiring

KS4 - Factor relevant to the impulse withstand voltage of a system

L - Length of structure

La - Length of the structure connected at end "a" of a service

LA - Loss related to injury to living beings

LB - Loss in a structure related to physical damage (flashes to structure)

L′B - Loss in a service related to physical damage (flashes to service)

Lc- Length of service section

LC - Loss related to failure of internal systems (flashes to structure)

L′C - Loss related to failure of service equipment (flashes to structure)

Lf - Loss in a structure due to physical damage

LZ - Loss related to failure of service equipment (flashes near a service)

L1 - Loss of human life in a structure

L2 - Loss of service to the public in a structure

L2 - Loss of service to the public in a service

L3 - Loss of cultural heritage in a structure

L4 - Loss of economic value in a structure

L4 - Loss of economic value in a service

NX - Number of dangerous events per annum

ND - Number of dangerous events due to flashes to a structure

NDa - Number of dangerous events due to flashes to a structure at

Ng - Lightning ground flash density

NI - Number of dangerous events due to flashes near a service

NL - Number of dangerous events due to flashes to a service

NM - Number of dangerous events due to flashes near a structure

P - Probability of damage

PA - Probability of injury to living beings (flashes to a structure)

PB - Probability of physical damage to a structure (flashes to a structure)

PC - Probability of failure of internal systems (flashes to a structure)

PLD - Probability of failure of internal systems (flashes to a connected service)

PLI - Probability of failure of internal systems (flashes near a connected service)

PM - Probability of failure of internal systems (flashes near a structure)

PMS - Probability of failure of internal systems (with protection measures)

PSPD- Probability of failure of internal systems or a service when SPDs are installed

PU Probability of injury to living beings (flashes to a connected service)

PV - Probability of physical damage to a structure (flashes to a connected service)

PW - Probability of failure of internal systems (flashes to a connected service)

PX - Probability of damage to a structure

PZ - Probability of failure of internal systems

ra - Reduction factor associated with the type of surface of soil

ru- Reduction factor associated with the type of surface of floor

rp- Factor reducing the loss due to provisions against fire

R - Risk

RA - Risk component (injury to living beings – flashes to a structure)

RB - Risk component (physical damage to a structure – flashes to a structure)

RC - Risk component (failure of internal systems -flashes to a structure)

RD - Risk for a structure due to flashes to the structure

rf- Factor reducing loss depending on risk of fire

RF - Risk due to physical damage to a structure

RI - Risk for a structure due to flashes not striking the structure

RM - Risk RM when protection measures are adopted

RO - Risk due to failure of internal systems

Rs- Shield resistance per unit length of a cable

RS - Risk due to injury to living beings

RT - Tolerable risk

RU - Risk component (injury to living being – flashes to a connected service)

RV - Risk component (physical damage to structure – flashes to a connected service)

RW - Risk component (failure of internal systems – flashes to the connected service)

RX - Risk component for a structure

RZ - Risk component (failure of internal systems – flashes near a service)

R1 - Risk of loss of human life in a structure

R2 - Risk of loss of service to the public in a structure

R3 - Risk of loss of cultural heritage in a structure

R4 - Risk of loss of economic value in a structure

1.0 INTRODUCTION

1.1 Background

The annual property damaged due to lightning and switching transient in Sri Lanka is exceeding 250 million Sri Lankan Rupees. Out of these losses 75% is due to the damaged electrical and electronic systems. The loss due to both lightening and switching transients can be minimized by installing Surge Protective devices (SPDs) in the power system and the communication /data line systems. A wide selection of surge protective devices (SPDs) and technologies are available on the market for the protection of electrical and electronic systems from the damage effects of electrical transients and lighting. Some manufactures use different technologies and only specify their SPD performance differently. To get the most effective protection at the best value, you need to make a selection based on the most important technical specifications. The size, performance and specification of SPD depend on following characteristics [1] & [2].

Current characteristic of SPD

- I: Surge current rating (kA)
- In: Nominal Discharge Current (In)
- Imax: Maximum discharge current (Imax)
- Short Circuit Current Rating (SCCR)

Voltage characteristic of SPD

- Uc: Maximum Continuous Operating Voltage (MCOV)
- Up: Voltage Protection Rating (VPR) or surge voltage rating (SVR) or Clamping Voltage
- TOV: Temporary Over Voltage

All electronics are susceptible to damage due to voltage and current transients generated, basically by lightning and also by switching operations and power anomalies. The degree of damage depends on the characteristics of the surge and the response of the electronics. Reducing the risk of damage on electrical systems due to lightning is an absolutely necessary objective in the electrical utility. Therefore, it is very essential to identify the accurate technical data for selecting parameters on SPD system since there are numerous SPD systems available in local market with different technical details and manufactures. Selecting appropriate surge protection device is essential for implementing a robust and reliable surge protection solution. Evaluating the risk of a low voltage system enables overvoltage protection requirement to be identified. The choice of surge arresters is made according to several characteristics [1].

- The protection level (Up)
- The maximum discharge capability (Iimp 0r Imax)
- Network earthling system
- The operating voltage (Uc, Ut)
- The options (end of life indicator, pluggable,)
- The short circuit current (Ip) of a power supply in the installation

1.2 Motivation

Selection of precise surge protective device is a critical task with the technical specifications of manufactures, since there are wide selections of surge protective devices and technologies are available on the market for the protection of electrical and electronic systems from the damage effects of electrical transients and lightning. Further, the Competition between SPD manufacturers has seen ever increasing surge ratings being offered to the market, where surges of this magnitude are unlikely to ever occur in nature. A number of sources provide information on the statistical distribution of the current discharge of the direct lightning strike. Many studies have shown that peak lightning discharges above 100kA are likely to occur less than 5% of the time. Combined with the fact that most discharges do not strike the power line directly but are magnetically or capacitive coupled to it. Even under a direct lightning discharge, the energy will split in either direction and also be attenuated by the distribution arresters and line losses.

As an Engineer, the author was motivated to select this topic to investigate and forward the recommendations for selecting precise cost effective SPD system for low voltage systems.

1.3 Objective

The objective of this study is to propose a selecting procedure for cost optimum SPD for low voltage systems according to the manufacture's technical data with consideration to damage probability and cost of SPD's without violating to standards. Further develop user friendly software for selecting SPDs.

1.4 Scope of the Work

The scope of the work to select the precise SPD system for low voltage system is as follows.

- The collection of data
- Analyse the manufacturer's technical details of SPD's available in local market and prepare a data base of critical parameters including cost of equipment
- Study of IEC/IEEE standard, risk analysis, SPD categories, level of protection zone, SPD selection criteria, damage probability, cost of damage
- Theoretical calculation and analysis of aforesaid technical details and identify the precise technical values
- Evaluate for cost optimal solution for low voltage surge protection system and develop user friendly software

2.0 THEORETICAL DEVELOPMENT

2.1 Surge Protective Device

Surge is a temporary overvoltage that can cause damage to electrical equipment. Surge has a very short duration with most of the energy dissipated within 1 millisecond. These over voltage can occur as a result of lightning discharge surges, electrical system switching or electrostatic discharge. Other terms often used to describe a surge are spike, transient voltage or lightning impulse [3]. The surge protection device (SPD) is designed to limit the surge exposure of electrical and electronic equipment. The purpose of the SPD is to provide an alternate, low impedance path for the surge current.

2.1.1 Principle of Surge Protection Operation

SPDs are designed to limit transient over voltages due to lightning or switching and divert the associated surge currents to earth, so as to limit these over voltages to levels that are unlikely to damage the electrical installation or equipment [4].

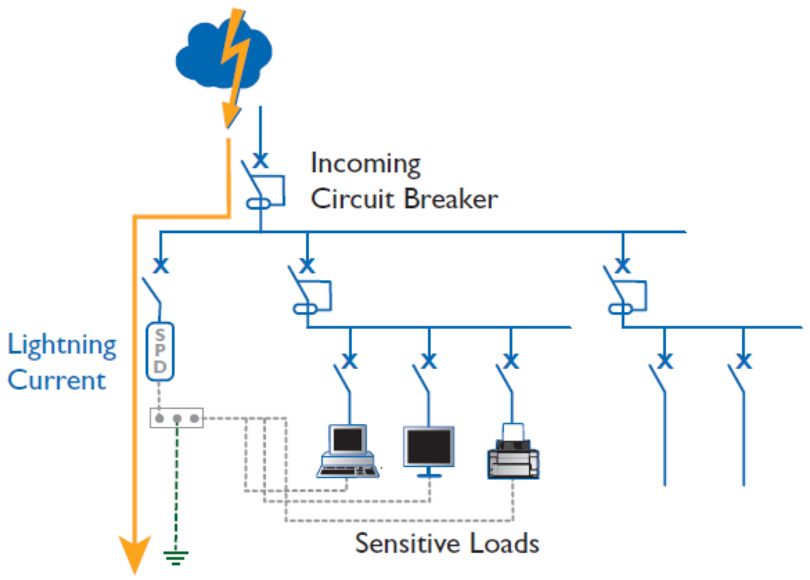


Figure 1: Principle of protection system in parallel

2.2 Transient overvoltage

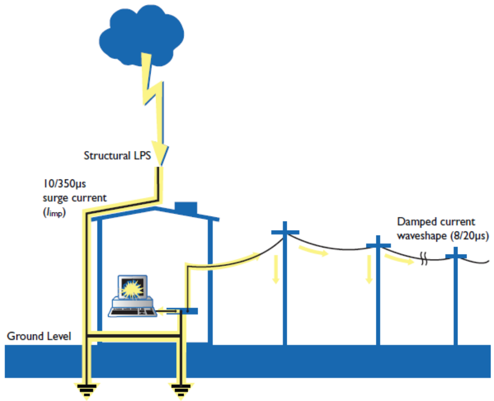
Transient overvoltage is generally caused by lightning and electrical switching events. Transient overvoltage can be generated by lightning, through resistive, inductive or capacitive coupling or by electrical switching events. About 35% of all transients come from outside the facility from such sources 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.

Lightning activity can cause transient overvoltage on mains power supplies and data communication, signal or telephone lines [3] & [5]. 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. When 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 overvoltage 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 overvoltage through [6]

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

2.3 Direct strikes

Strikes to power lines are quite common. It is often thought that the high voltage to low voltage transformer action eliminates the resultant transient overvoltage. When lightning strike on 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.



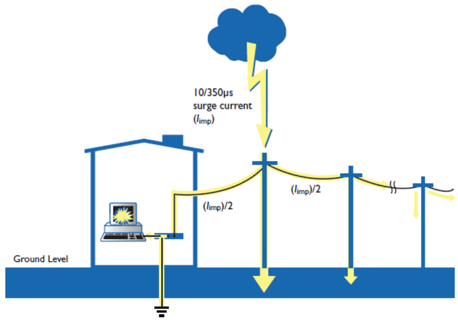
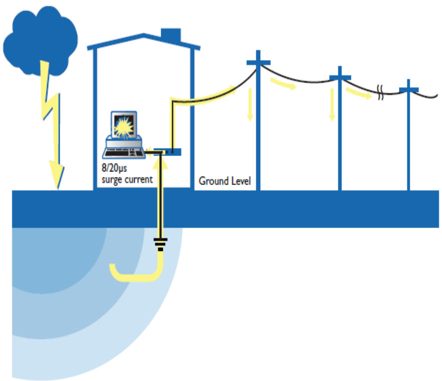


Figure 2: Direct strike to structure Figure 3: Direct strike to service



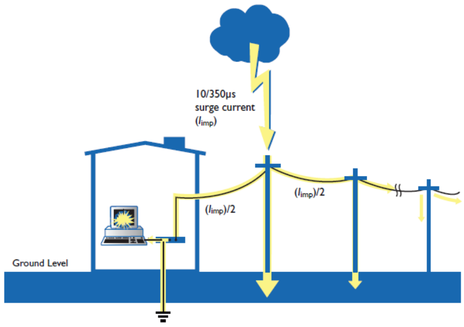


Figure 4: Indirect strike near structure Figure 5: Indirect strike to nearby service

2.4 Resistive coupling

Resistive coupling is the most common cause of transient overvoltage 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

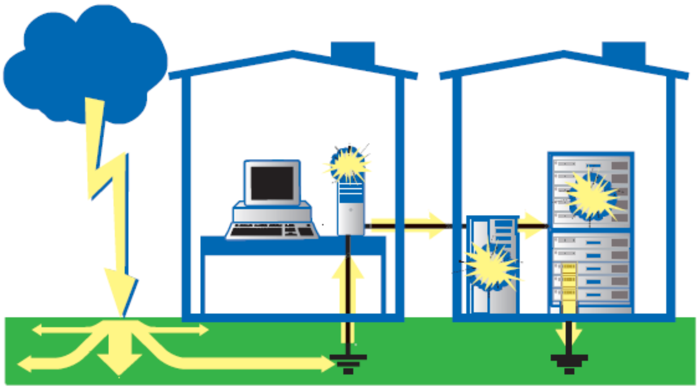


Figure 6: Resistive coupling

2.5 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.

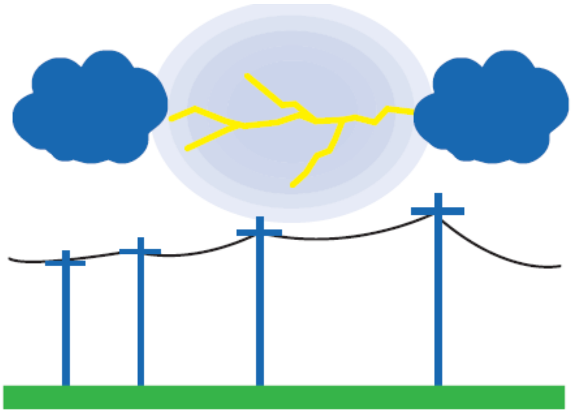


Figure 7: Inductive coupling

2.6 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.

2.7 Electrical switching events

Transient over voltages caused by electrical switching event 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. The figures below illustrate the common current and voltage waveforms that are used to test SPDs for mains, signal and telecom lines.

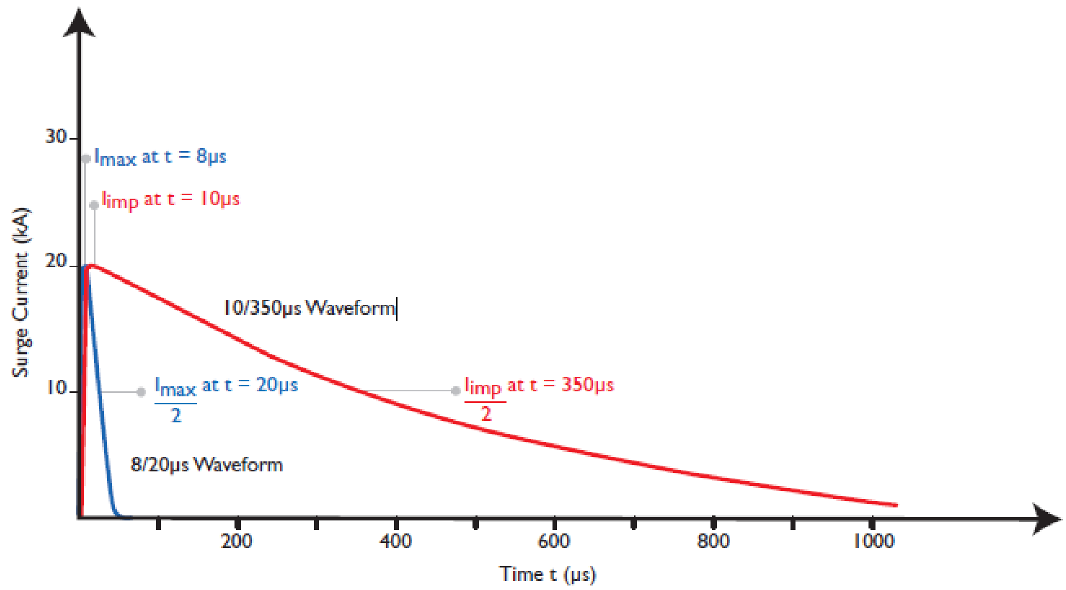


Figure 8: Current wave form

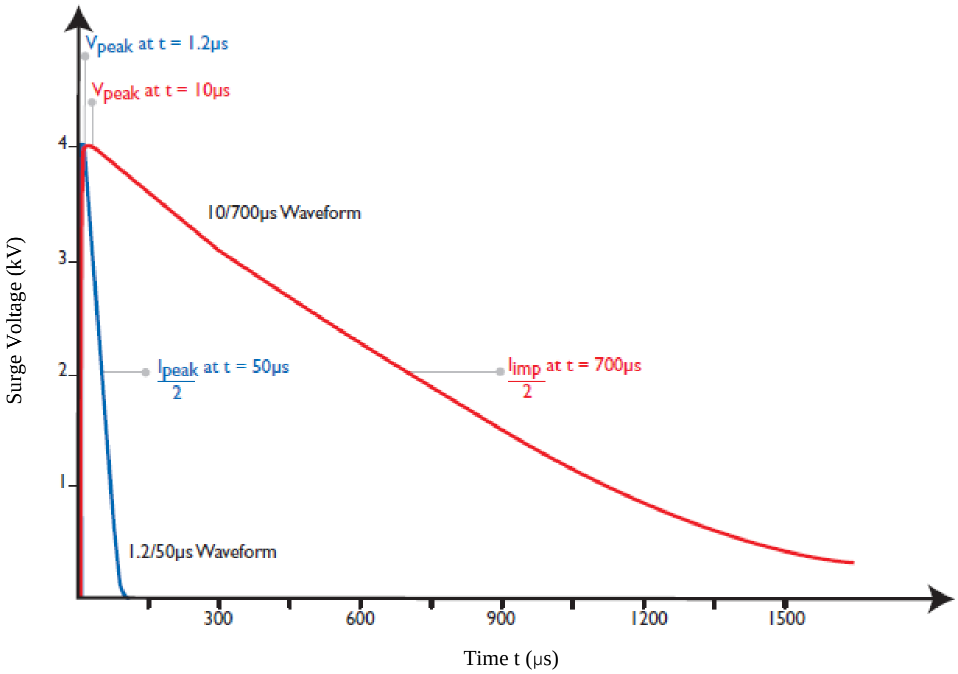


Figure 9: Voltage wave form

2.8 Lightning Protection Zone (LPZ) concept

Protection against Lightning Electromagnetic Impulse (LEMP) is based on a concept of the Lightning Protection Zone (LPZ) that divides the structure into a number of zones according to the level of threat posed by the LEMP [7]. The general idea is to identify or create zones within the structure where there is less exposure to some or all of the effects of lightning and to coordinate these with the immunity characteristics of the electrical or electronic equipment installed within the zone. Successive zones are characterized by significant reductions in LEMP severity as a result of bonding, shielding or the use of SPDs. Figure below illustrates the basic LPZ concept defined by protection measures against LEMP as detailed [5]

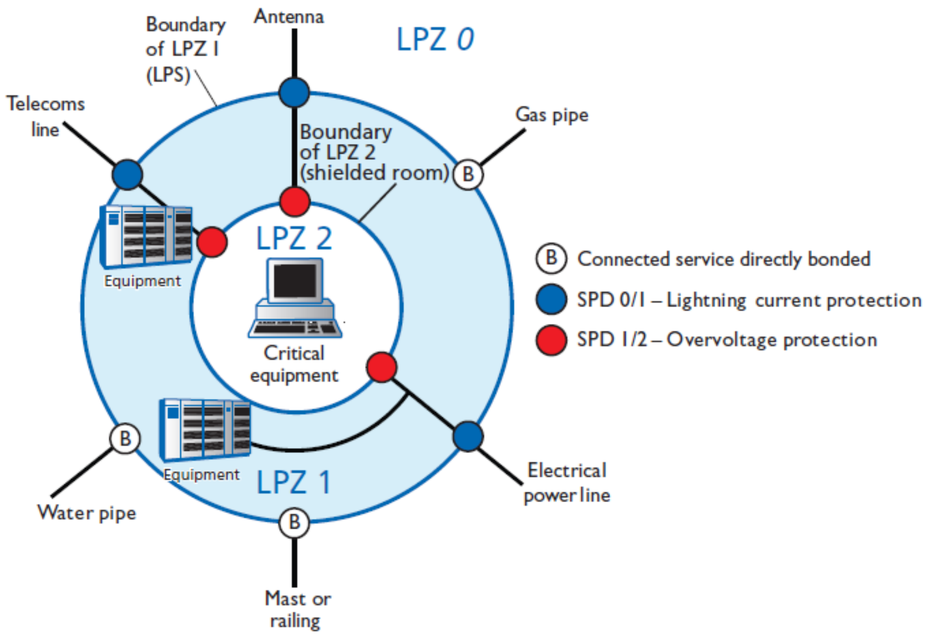


Figure 10: Lightning protection zone concept

The LPZs can be split into two categories, external zones and internal zones although further zones can be introduced for a further reduction of the electromagnetic field and lightning current if required.

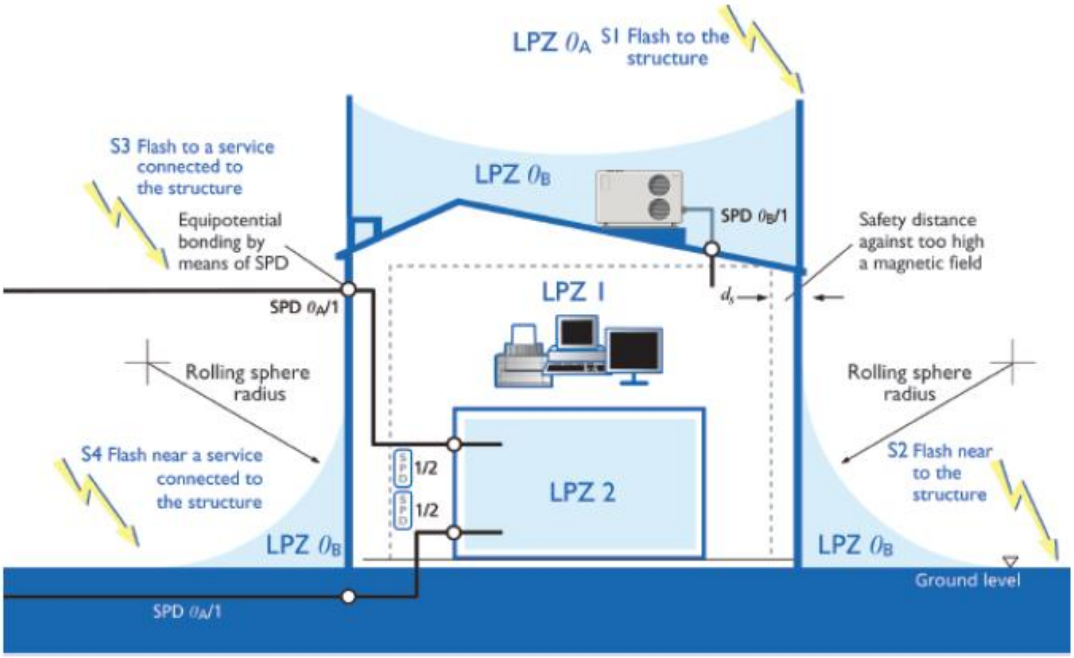


Figure 11: Lightning protection zone categories

2.8.1 External zones:

LPZ 0A 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 [5]. The full electromagnetic field occurs here.

LPZ 0B 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.

2.8.2 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 0A, LPZ 0B 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 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 12.

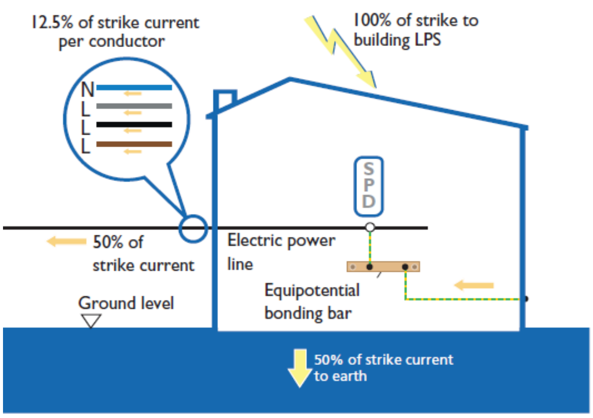


Figure 12: Lightning current flow diagram

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 100kA/4).Similarly, for LPL II and III/IV the maximum Type 1 SPD current capabilities would be 18.75kA (10/350µs) and 12.5kA (10/350µs) respectively. In practice, 18.75kA (10/350µs) Type 1 SPDs are uncommon so 25kA (10/350s) Type 1 SPDs cover both LPL I and II. This worst case current of 25kA (10/350µs) is significantly higher than the worst case current of 10kA (8/20µs) 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 13. 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.

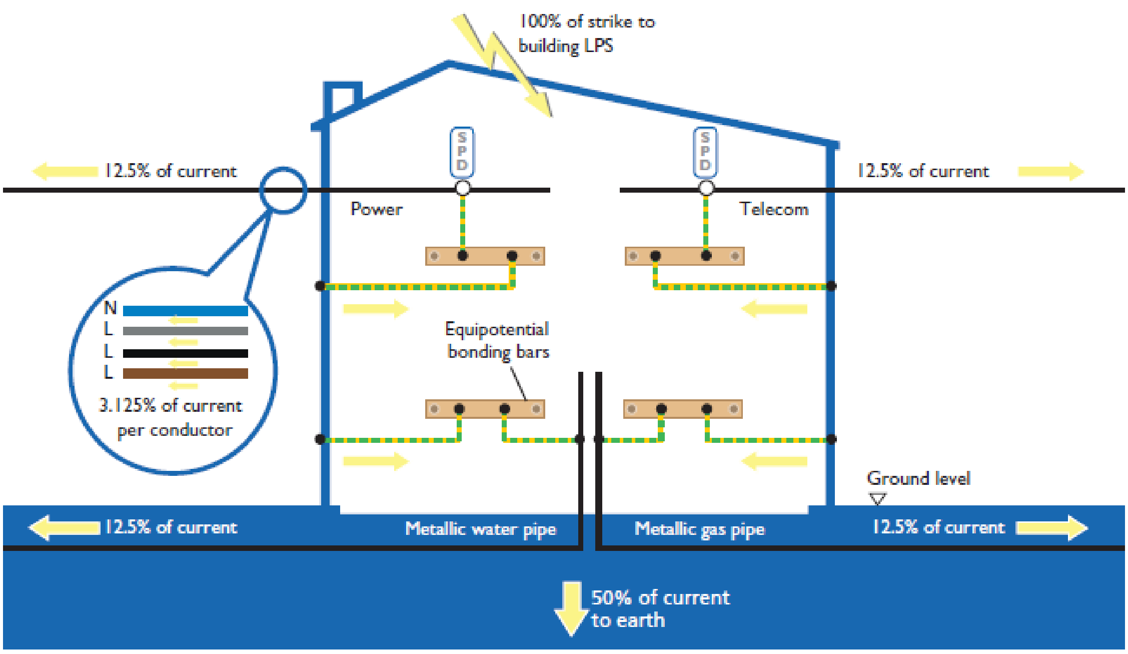


Figure 13: Lightning current discharge distribution

2.9 Surge protection category

There are three types of SPD according to international standards [3] & [8]:

- Type 1 SPD

  The Type 1 SPD is designed to provide protection against transient overvoltage due to Direct Lightning Strokes, which 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 characterized by a **10/350µs** current wave.

- Type 2 SPD

  The Type 2 SPD is designed to provide protect against transient Over voltages due to Switching and Indirect Lightning Strokes which is the main protection system for all low voltage electrical installations. Installed in each electrical switchboard, it prevents the spread of over voltages in the Electrical installations and protects the loads. Type 2 SPD is characterized by an **8/20µs** current wave.

- Type 3 SPD

  The Type 2 SPD is designed to provide 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

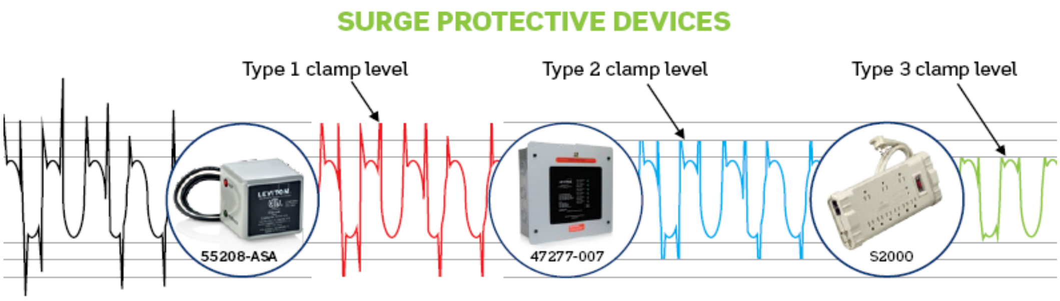


Figure 14: Clam level of SPD types

There are two classes of SPD components.
Voltage limiting SPDs include metal oxide varistors and suppressor diodes [9]. These have high impedance when no surge is present but can reduce impedance with increased surge current and voltage. These are also called clamping devices, These can be used for main switchboard primary protection, distribution board and final circuit protection. As voltage limiting components there is no follow on current and with suitable fusing these are easy to install and operate.

Voltage switching SPDs include spark gaps, gas discharge tubes, thyristors and triacs [10]. These have a high impedance when no surge is present but can have a sudden change to a low impedance in response to a voltage surge. These are called crowbar devices. Spark gaps have high surge ratings and are suitable for point of entry protection in installations with Highly exposed overhead LV power lines with no local transformer in high lightning areas. As voltage switching SPDs, spark gaps have a crowbar effect and effectively place a short circuit across the line once fired. Thus high levels of AC follow on current will flow. Unless properly configured to be compatible with the AC fault rating of the supply and suitably fused, spark gaps can cause nuisance tripping of supply circuit breakers and extreme voltage disturbances whilst the follow on current flows.

3.0 PLANNING OF PROTECTION

The loss due to both lightning and switching transients can be minimized by installing Surge Protective Devices in the power systems and communication/ data line systems. However before planning the installation of SPDs it is required to ensure that

- the wiring system is according to the codes of practice starting from the main panel,
- Electrical safety devices such as earth fault tripping devices, over current devices and voltage stabilizing devices are properly installed and they are in good condition.
- the electrical system has a single earthling point (close to the main panel) with DC earth resistance less than about 5 Ω at the earth pit,
- load distribution is balanced and optimized,
- power feeds to outdoor systems are confined into dedicated distribution boards,

If the infrastructure of the building is at pre-design stage then it should be planed the locations of equipment in a zonal lay-out. i.e. Robust and unsophisticated electrical items of large motors, machines, power tools etc should be placed closer to the main panel and more sophisticated equipment of computers, medical equipment, communication equipment etc. should be located at inner rooms where power is provided from more inward power distribution boards. For a productive and cost effective surge protection scheme the following steps should be taken

- System analysis and risk assessment,
- Strategic location selection for protective devices
- Selection of appropriately coordinated protective devices
- Proper installation and commissioning

The lightning may affect our system when there is a

- direct strike or side flash to a building
- direct strike or side flash to a service line or
- strike to a location near to a service line

Lightning may cause equipment or system damage in several ways. In each of the above case the lightning energy may enter the systems by one or more of the 3 coupling mechanisms; resistive, inductive and capacitive coupling.

When lightning strikes a building, the current may be entered the power lines by insulation breakdown of air and the wires (arcing) or by back-routing via earthling systems. This is basically a resistive coupling. As the current flows through steel reinforcement, down conductors etc, a part of the energy is injected into the power lines through inductive coupling (via electromagnetic induction).

A lightning strike to a LV power line is a resistive coupling. A strike to an MV line may transfer part of the energy through both inductive and capacitive coupling at the transformer (between the primary and secondary coils). There can also be a resistive coupling if there is an insulation breakdown between the coils. A nearby strike basically induces voltage impulses in service lines through inductive coupling while strikes near to the utility may cause a potential rise in the earthing system which leads to resistive coupling.

3.1 Protection Scenario

The low voltage power line SPDs are most often connected in shunt. In a TT wiring system,

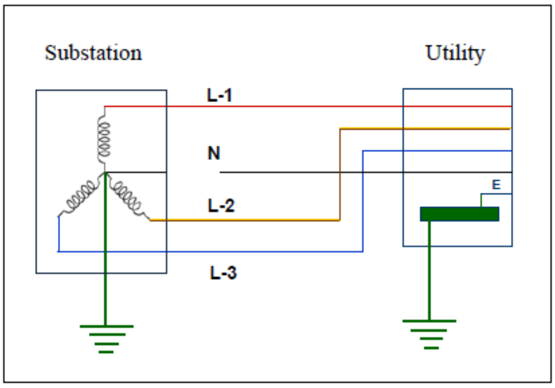


Figure 15: TT wiring system

The SPDs are recommended to be connected in one of the two arrangements as shown in Figure 15. Out of the two arrangements the connection type 2 has a wider usage among many engineers.

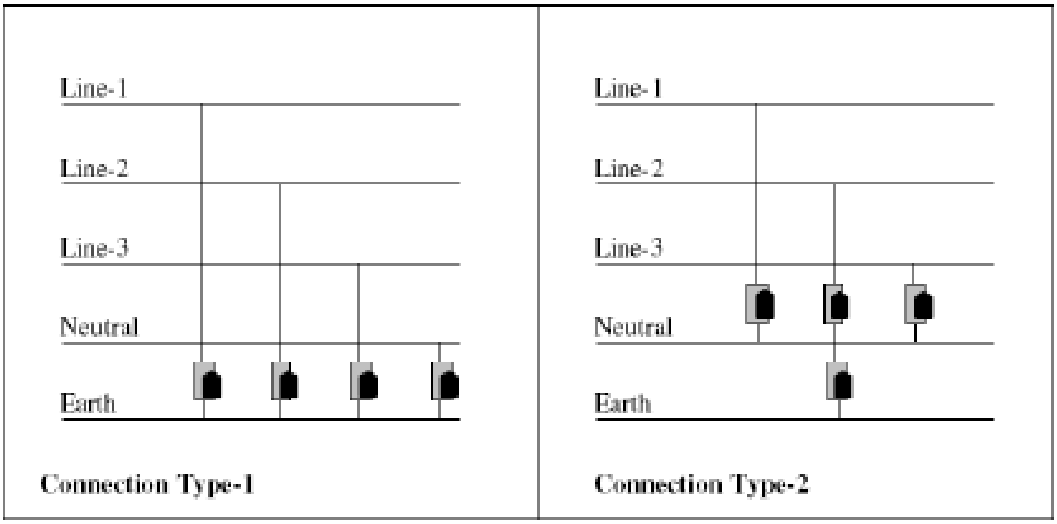


Figure 16: Type of connection arrangement in TT system

The role of surge protective devices is twofold. As a transient propagates in a line, the SPDs should switch itself from high impedance mode to low impedance mode for a short duration allowing the transient to pass into earth. After that it should be switched back to the high impedance mode. In the event of a ground potential rise (eg. A nearby lightning to ground) the SPDs should be switched into low impedance (ideally short circuit) mode equalizing the earth, neutral and line potentials.

Due to several reasons SPDs are needed to be connected to the LV system at several stages in a given building. This scenario of connecting SPDs in several stages is known as the “Zonal Concept” [5]. The most exposed zone; closer to the power entry point (usually the main power panel) and power outreaching points; is termed Zone-1. The Zone-2 is usually the sub panels to which only partial lightning currents or reduced voltage impulses reach and Zone-3 is the power socket level which experiences even lower lightning energy.

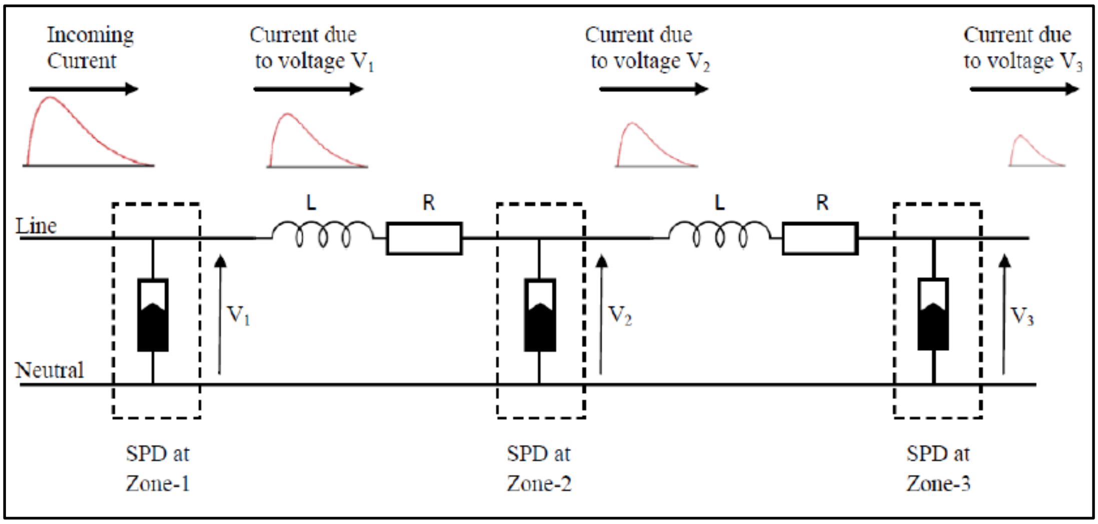


Figure 17: Zonal concept vise voltage and current distribution

3.2 Selection of Surge Protective Devices

3.2.1 Impulse Current

The surge protective devices are usually referred by their impulse current handling capacity, although, the more logical way is to refer them by the zone at which they should be connected. The IEC 62305 (2006) Standards [3] & [5] specify two current impulse waveforms for the testing of surge protective devices. The waveforms are specified by their rise time and half peak width. The two specified waveforms are (10 µs/350µs) and (8µs/20µs); where the first number refers to the rise time (approximately) and the second to the half peak width [11].

In the selection of SPDs, the most exposed zone or Zone-1 needs SPDs with higher rating of impulse current handling. The Zone-2 and Zone-3 need sequentially reducing values of current handling capacity. The values of the current rating should be determined by following an appropriate standard and also taking into account the geographical location, thunderstorm density, equipment to be protected etc.

The success of a network of surge protection depends on several factors; the current handling capacity is one of the important parameters. Also note that the values in the Table-1 are the current handling capacity of each SPD connected between a line and the neutral. The SPD between the neutral and earth should have a current handling capacity of above 75% of 3 times the value of one SPD between line and neutral. For an example at the main panel of a high risk location in an area of low lightning density (3 Phase system);

Iimp of each SPD from line to neutral = 40 kA

Iimp of SPD from neutral to earth = (40 × 3) × 75 / 100 = 90 kA

These are minimum values for the above installation. It has been found that several leading manufacturers indicate the current handling capacity of their SPDs as 3 times the capacity of a single SPD (eg. 120 kA in the above case). Few manufacturers indicate the capacity of SPDs even including the capacity of neutral to earth SPD (eg. 210 kA in the above case). Such indications mislead the customers so that the engineer should be careful in their selections.

Table 1: current handling capacities of SPD zonal vice

Location	High lightning density areas (Current in kA/Phase)	Low lightning density areas (Current in kA/Phase)
Main panel * (Zone-1)	40 (Low risk)	30 (Low risk)
	60 (High risk)	40 (High risk)
Sub-panels ** (Zone-1)	30 (Low risk)	15 (Low risk)
	40 (High risk)	20 (High risk)
power feeder level ** (Zone-3)	07 (Low risk)	03 (Low risk)
	15 (High risk)	07 (High risk)

Low Risk: domestic, offices, factories, non-essential service providers etc.

High Risk: hospitals, power generation and distribution, communication, broadcasting and other essential service providers

High lightning density areas: Areas where isokeraunic level is greater than 80 thunder days/year

Low lightning density areas: Areas where isokeraunic level is less than 80 thunder days/year

* For 10 / 350 μs current impulse

** For 8 / 20 μs current impulse

3.1.2 Voltage Protection Level

One of the most important factors that should be considered in selecting SPDs is the "Voltage Protection Level" or simply the "Protection Level". This is the minimum let-through voltage that will appear across the line and neutral (differential mode voltage) and that between the neutral/line and the earth (common mode voltage). Any given electronic equipment has a certain impulse withstanding voltage beyond which the equipment will undergo permanent damage or temporary malfunctioning. This tolerable level should significantly be higher than the voltage protection level of the SPDs that one selects to protect the equipment [11]. Therefore, SPDs with lower value of voltage protection level is better than that with a higher value.

The manufacturer should specify the voltage

3.2.3 Response Time

Lightning Impulses may have rise times that are in the order of sub-microseconds. Therefore the SPD should have appreciable speed in switching from high impedance to low impedance mode. The response time of a SPD depends basically on its constituent components. SPDs are primarily made by one or more of the following components [1]

- Spark gaps or gas discharge tubes (GDT)
- Metal Oxide Varistors (MOV)
- Zener Diodes or Silicon Avalanche Diodes (SAD)

In addition some other linear and non-linear devices such as, capacitors, inductors and positive temperature coefficient resistors (PTCR) etc. are also included in the circuits to improve the performance.

The three basic components have their own advantages and drawbacks. For examples; the current handling capacity and the response time increase in the order of SAD, MOV and GDT. The increment of the former characteristic is an advantage while that of the latter is a disadvantage. Hence, in most of the products the components are combined to improve the overall performance. Thus, the end-product response time may be different from the response time of any of the individual components.

3.2.4 Maximum Continuous Operating Voltage

Under no-impulse conditions, the SPD remains almost open circuited (except for a leakage current in the order of micro amperes in MOV/SAD based SPDs). However, if the operating voltage (e.g. 230 V rms) is increased to a higher value for few cycles (due to some fault) there is a chance that the SPD may switch into low impedance mode (note that the SPD goes through this transition at few kilo Volts under impulse conditions but at much lower voltage at 50 Hz). If such transition takes place, a large current under nearly operating voltage will flow through the SPD which is not made to withstand such high energy. As a result the SPD may be totally damaged.

The maximum of such operating voltage, only, under which the SPD is safe, is termed the maximum continuous operating voltage (MCOV). As per the standards [5] the MCOV should be above 110% of the operating voltage. In most of the European countries an MCOV of 270 V is recommended for MOV based SPDs. However, in countries where the power quality is not very reliable (significantly fluctuating voltage) a value of 300 V or 320 V is more appropriate. It can be shown that the larger the value of MCOV, the greater the let-through voltage of the SPD [5, 6]. Therefore, it is always advisable to select an SPD with the least MCOV that can withstand a power quality of a given region.

3.2.5 Temporary overvoltage (TOV)

Temporary overvoltage (TOV) is the maximum rms value the surge protector can withstand for 5 seconds without destruction. It is used to describe temporary surge which can arise as a fault of faults within medium and low voltage. UT=1.45 x Uo. For 230/400V system UT= 1.45x30 = 3

4.0 Flow chart for cost optimal selection of SPD

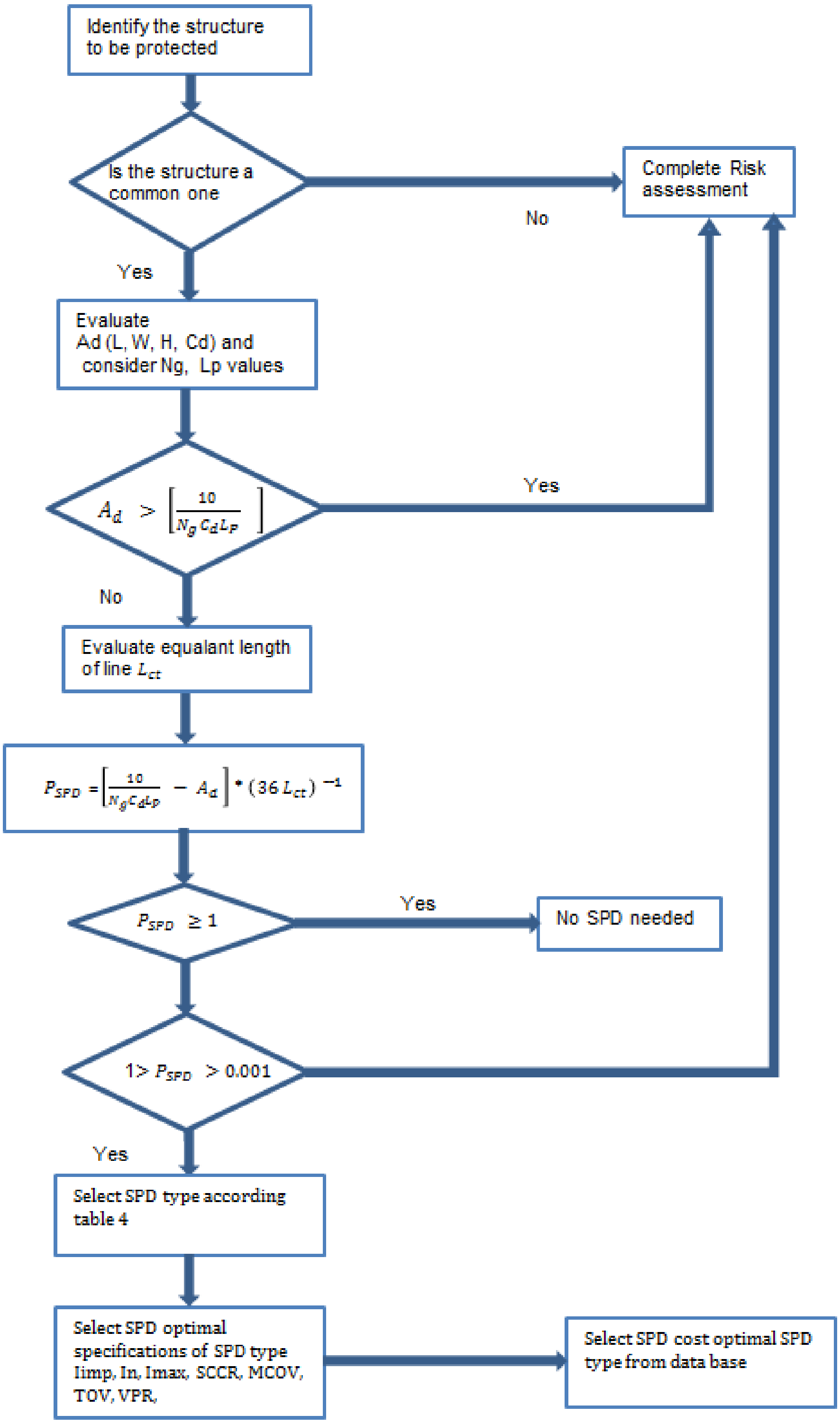


Figure 18: Flow chart for cost optimal selection of SPD

The cost of the SPD is increasing with the impulse current handling capacities and varying with selection of technology therefore, selection of correct and appropriate impulse current capacity and technology of a SPD is very important for the cost optimizing.

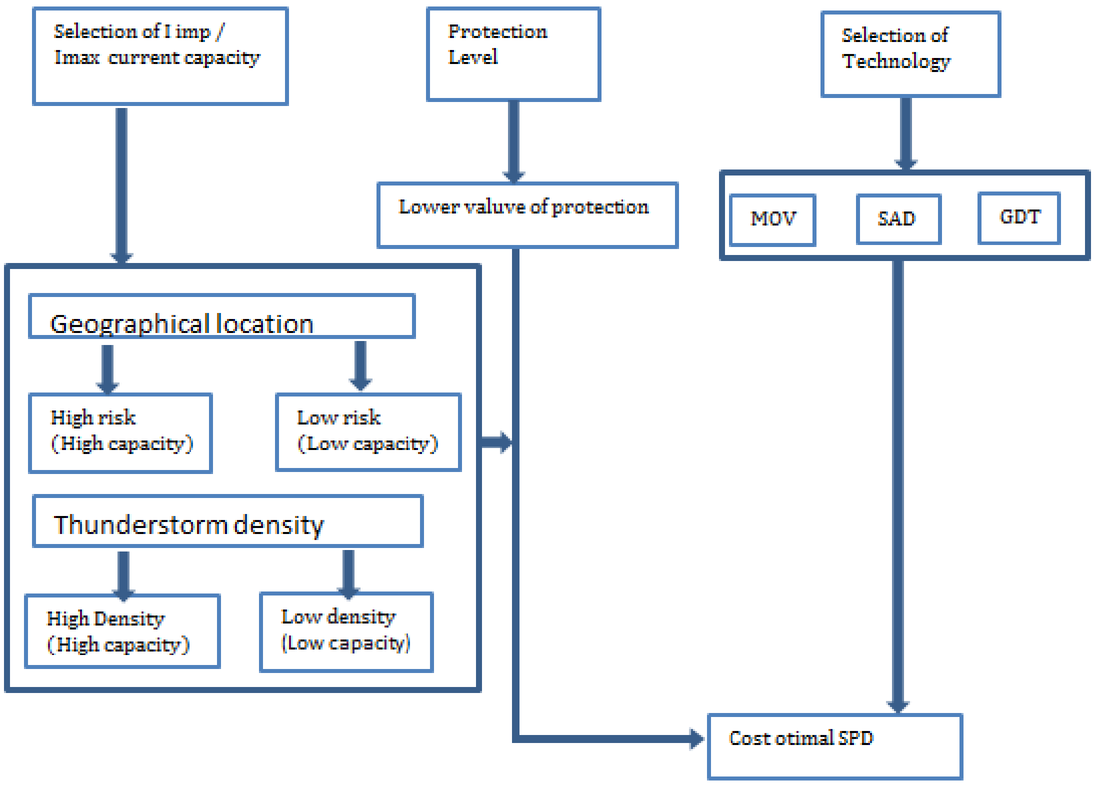


Figure 19: Block diagram of Cost optimal selection method

There is very little published data or even recommendations on what level of surge current (kA) rating should be used in the different categories or locations. IEEE has provided some input on what surge ratings are, and how to interpret them, but does not publish recommendations. Also, there is not a proven equation or calculator available to input system requirements and receive a solution. Any information a manufacturer provides, via calculators or other means is merely their recommendation.

The cost of SPD system depends upon the type of SPD, impulse currant capacity, technology used, mode of protection and level of protection. Therefore, it is required to appropriate selection of aforesaid factor for optimizing the cost of SPD.

4.1 Cost optimal SPD selection algorithm

- Proper selection of type of SPD considering risk assessment and lightning density level of area
- Optimal selection of impulse current capacity, maximum current and nominal current capacity considering appropriate standard, Geographical location, Thunderstorm density and equipment to be protected
- Selection of technology considering equipment to be protected and the location of installation or zone concept
- The mode of protection is to be common and differential mode and the level of protection is to be minimised.

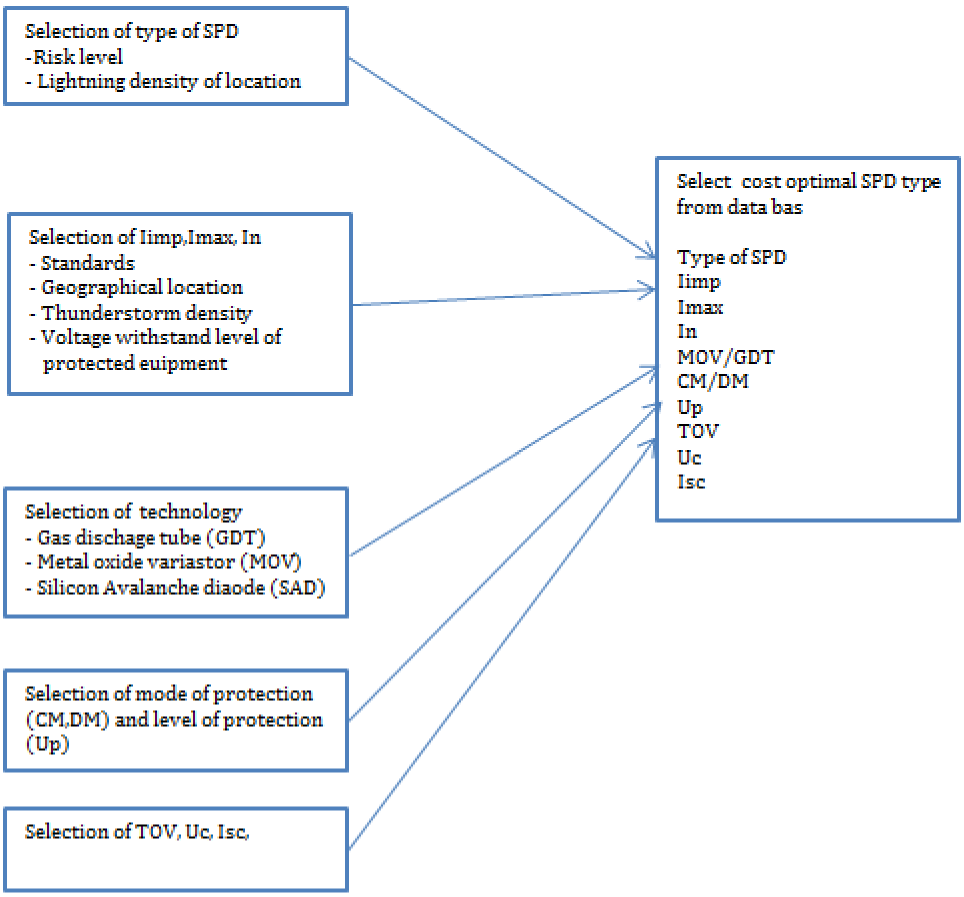


Figure 20: Method of cost optimal SPD selection from database

4.2.1 Procedure to determine of SPD for common structure

Surge Protective Devices (SPDs) are installed for the protection of electrical installations, internal to a structure, against lightning overvoltage transmitted by supply lines. Simple relations are proposed which allow to electrical contractors to evaluate if SPDs are required for safety in electrical installations in buildings located in rural or urban area. However, complete risk assessment need to be carried out for the special structures of hospital and structures with explosion hazard. Requirements for SPDs selections are given as well as values are proposed of probability of damage Pspd associated to SPD to be installed for different values of impulse and nominal discharge current.

Therefore, where it is required to save primary goods as the human life, essential services to the public or the cultural heritage, the internal installations have to be protected against the effects of lightning to limit to a tolerable value the risk of

- Failure of installation and then loss of service performed by the installation
- Damage to the structure, its content and to the persons, due to lightening mediated by the internal installation.

In agreement with the standard IEC 62305-2 [12] the risk analysis involves the evaluation of

- The risk of loss of human life (R1)
- The risk of loss of essential services to the public (R2)
- The risk of loss of cultural heritage (R3)
- The risk of economic loss (R4)

For a practical approach to the problem it is convenient to distinguish the special structures and common structures.

Special structures

Some type of structures such as

- Structure with risk of explosion
- Hospital and other structures where failure of internal installations immediately endangers life
- Structures with risk of loss essential services to the public

- Structures where the damage may also involve surrounding structures or the environment

To evaluate the risk in such structures is often a complicated matter due the type of risks involved and the number of risk components to be considered. As result a complete risk analysis should be performed according to the standard IEC 62305-2 and if required, protection against lightning shall be designed following the requirement of IEC 62305 series standard. If the risk evaluation is not available or cannot be performed due to lack of input parameters, protection measures with LPL 1 should be adopted in any case, irrespective of the result of risk assessment.

in the greatest majority of cases, structures have no particular characteristics and the risk analysis to evaluate whether protection measures and needed or not for the safety of persons is limited to calculation of risk of loss human life (R1), which involves four components only

$$R_1 = R_A + R_B + R_U + R_V \quad (1)$$

$$R_A = N_g \; x \; A_d \; x \; C_d x \; P_A x \; r_a \; x \; L_t \text{x } 10^{-6} \quad (2)$$

$$R_B = N_g \; x \; A_d x \; C_d \; x \; P_B x \; h \; x \; r \; x \; r_f \; x \; L_f \text{x } 10^{-6} \quad (3)$$

$$R_U = N_g \; x \; A_l x \; C_d \; x \; C_t x \; P_U \; x \; r_u \; x \; L_t \text{x } 10^{-6} \quad (4)$$

$$R_V = N_g \; x \; A_l x \; C_d \; x \; C_t x \; P_V x \; h \; x \; r \; x \; r_f \; x \; L_f \text{x } 10^{-6} \quad (5)$$

In an unprotected structure PA =PB= PU =PV =1

$$R_A + R_B = N_g \; A_d \; C_d \; 10^{-6} (r_a \; L_t + r \; h \; r_f \; L_f) \quad (6)$$

$$R_U + R_V = N_g \; A_d \; C_d \; C_t \; 10^{-6} (r_u \; L_t + r \; h \; r_f \; L_f) \quad (7)$$

By replacing (6) and (7) in (1) is obtained

$$R_U + R_V = N_g \; A_d \; C_d \; C_t \; 10^{-6} (r_u \; L_t + r \; h \; r_f \; L_f) \quad (7)$$

$$R_1 = R_U + R_V = N_g \; C_d \; 10^{-6} \; r \; h \; r_f \; L_f \; (A_d + A_l \; C_t) \leq 10^{-5} \quad (8)$$

and then

$$R_1 = R_U + R_V = N_g \; C_d \; 10^{-6} \; r \; h \; r_f \; L_f \; (A_d + A_l \; C_t) \leq 10^{-5} \quad (9)$$

By indicating with L_p=r h $r_f L_f$ formula (9) more simply may be written

$C_d \;\; L_p \;\; (A_d + A_l \;\; C_t \;\;) \;\; \leq \;\; 10 \;\; / \;\; N_g$ (10)

$if\ the\ risk\ componet$ R_B assume itself high value in comparison with the component R_v and reaches a value higher or equal to tolerable risk.

$R_B \;\; > \;\; R_T$ And then from (10)

A_d >10/($N_g C_d L_p$) (12)

Therefore, only If the condition 12 is not verified, it is possible to conclude that there is a possibility to reduce the risk by suitable SPD only installed at the entry point of the line.

Characteristics of SPD at the entry point of the line into structure

To stablish the characteristic of SPD at the entry point of the line it is necessary to recall relation 10 in which also the probability P_{SPD} is inserted.

$C_d \;\; L_p \;\; (A_d + P_{SPD} A_l \;\; C_t \;\;) \;\; \leq \;\; 10 \;\; / \;\; N_g$ (13)

Starting from (13) it is possible to obtained

$P_{SPD} = \left[(10 \;\; / \;\; N_g \; C_d \;\; L_p \;) \; - \;\;\; A_d \;\; \right] / \;\; A_l \;\; C_t$ (14)

Relation (14) may be also expressed as follows

$P_{SPD} = \left[(10 \;\; / \;\; N_g \; C_d \;\; L_p \;) \; - \;\;\; A_d \;\; \right] / \;\; K_d \;\; L_c$ (15)

Being L_c- lenght of line connectoed to the structure in (m)

K_d - a coefficient related to the line characteristics

Values of the coefficient K_d for diffeerent characteristics of the line

Table 2: Values of the coefficient K_d

Flash to line	Overhead	Buried
Low voltage (Ct = 1)	36	18
High voltage (Ct= 0.2)	7.2	3.6

$P_{SPD} \; = \; \left[(10 \;\; / \;\; N_g * \; C_d \; * \;\; L_p \;) \; - \;\;\; A_d \;\; \right] / \;\; 36 \, L_c$ (15)

PSPD =[(10/ Ng * Cd*Lp) - Ad]/36 * Lc

$\boldsymbol{A_d}$ **= L x W + 6 x H x (L +W) + 9 x** $\boldsymbol{\pi \; x \;\; H^2}$

Example:

Length	20
Width	10
Height	3.5
Ad	1176.5

Table 3: Calculation of 10/(Ng*Cd*Lp)

Lightning ground flash density	15
Location factor	0.25
Loss coefficient related to characteristics of structure	0.0004
10/(Ng*Cd*Lp)	6666.667

$A_d \; > \; \left[\frac{10}{N_g C_d L_P}\;\right]$ Need complete risk assessment

Ad	1176.5	10/(Ng*Cd*Lp)	6666.667

Table 4: Calculation of probability

Lightning ground flash density	15
Location factor	0.25
Loss coefficient related to characteristics of structure	0.0004
Collection area	1176.5
Length of line	1000
Probability	0.152505

Location factor Cd of structure and line

Table 5: Location factor

Structure/line location	Cd
Urban	0.25
Suburban	0.5
Rural	1

Table 6: Values of the factor Lp

Structure	r_p	h_z	r_f	L_f	L_p
Small house	1	1	1.00E-03	1.00E-01	1.00E-04
Multi-apartment house	1	5	1.00E-03	1.00E-01	5.00E-04
Small church	1	2	1.00E-03	2.00E-02	4.00E-05
Large church	1	5	1.00E-03	2.00E-02	1.00E-04
Small school	0.5	5	1.00E-03	5.00E-02	1.25E-04
Large school	0.5	10	1.00E-03	5.00E-02	2.50E-04
Public entertainment (small)	0.2	5	1.00E-02	2.00E-02	2.00E-04
Public entertainment(Large)	0.2	10	1.00E-02	2.00E-02	4.00E-04
Commercial (small)	0.5	2	1.00E-02	5.00E-02	5.00E-04
Commercial (Large)	0.5	5	1.00E-02	5.00E-02	1.25E-03
Industry (Small)	0.5	1	1.00E-02	5.00E-02	2.50E-04
Industry (Large)	0.5	2	1.00E-02	5.00E-02	5.00E-04
Small hotel	0.5	2	1.00E-02	1.00E-01	1.00E-03
Large hotel	0.5	5	1.00E-02	1.00E-01	2.50E-03

Table 7: probability PSPD

P_{SPD}	SPD tested with class I test	SPD tested with class I test
	(Iimp kA;10/350µs)	(In kA; 8/20µs)
1	No SPD provided	No SPD provided
0.03	5	2.5
0.01	10	5
0.005 -0.001	Enhanced protection(*)	

The lightning ground flash density (Ng) [13]

Table 8: lightning ground flash density

Location	Thunder day per year (Td)	(Ng)
Anuradhapura	132	13.2
Badulla	129	12.9
Bandarawela	174	17.4
Baticaloa	84	8.4
Colombo	159	15.9
Galle	105	10.5
Hambanthota	96	9.6
Katugastota	168	16.8
Katunayake	147	14.7
kurunagala	138	13.8
Maha Illuppallama	114	11.4
Mannar	90	9
Nuwar Eliya	108	10.8
Pottuvil	36	3.6
Puttalama	120	12
Rathmalana	165	16.5
Rathnapura	162	16.2
Trincomalee	84	8.4
Vavuniya	99	9.9
Jaffna	51	5.1
Kankasanthurai	60	6

5.0 SELECTION OF SURGE PROTECTOR DEVICES

Several protection levels of SPD allow the energy to be distributed among several SPDs, the three types of SPD are provided for:

- Type 1: when the building is fitted with a lightning protection system and located at the incoming end of the installation, it absorbs a very large quantity of energy;
- Type 2: absorbs residual overvoltage
- Type 3: provides "fine" protection if necessary for the most sensitive equipment located very close to the loads.

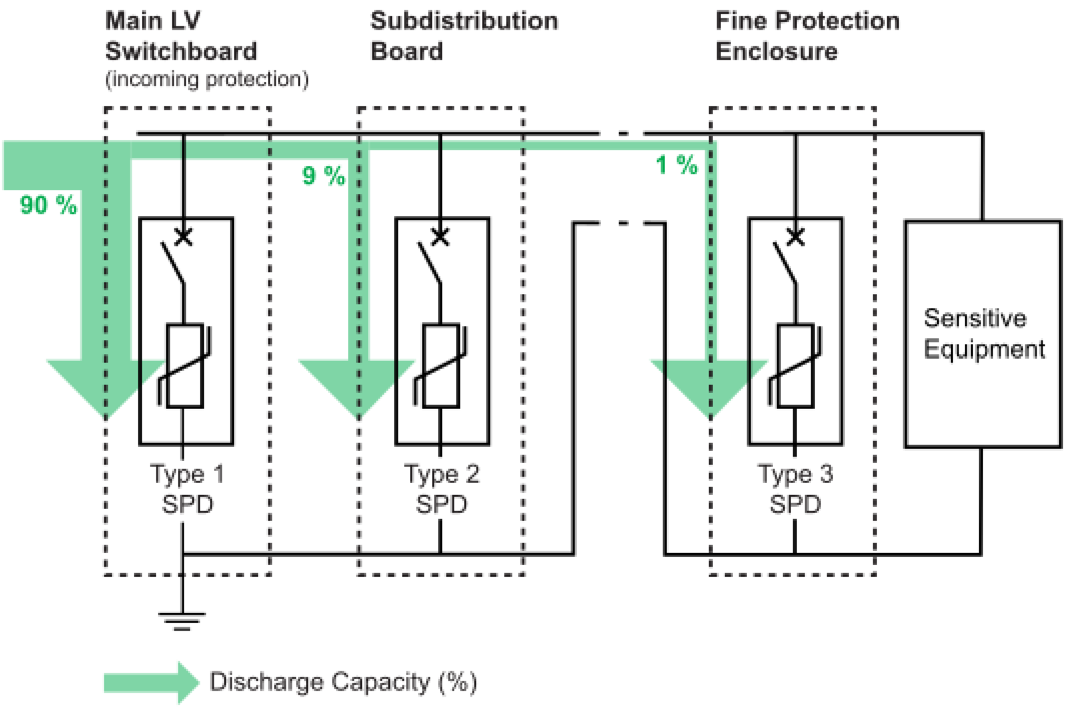


Figure 21: Protection distribution level

The choice of surge arrester is made according to several characteristics:

- The protection level (Up).
- The maximum discharge capability: Iimp or Imax (10/350 or 8/20 impulse wave).
- The network's earthling system.
- The operating voltages (Uc, UT).

- The options (end of life indicator, pluggable, Safety reserve, TS, Optical monitoring block).
- The short-circuit current (Ip) of a power supply in the installation.

Depending on the system earthling arrangement, the maximum continuous operating voltage Uc of SPD must be equal to or greater than the values shown in the table

Table 9 : Operating voltage Uc

System configuration of distribution network			
	TT	TN-C	TN-S
Line conductor and neutral conductor	1.1 Uo	NA	1.1 Uo
SPDs connected between	1.1 Uo	NA	1.1 Uo
Neutral conductor and PE conductor	Uo	NA	Uo
Each line conductor and PEN conductor	NA	1.1 Uo	NA

5.1 Voltage Protection Level Up (at In)

Selection of equipment in the installation helps with the choice of the protection level Up for the SPD in function of the loads to be protected. The table of Figure indicates the impulse withstand capability of each kind of equipment as indicated in the following table according to IEC 60364-4-44, IEC 60664-1 and IEC 60730-1.

Table 10: Voltage Protection Level Up (at In)

Categories	U_n 230 /400 V	U_n 400 /690 V	Examples
I	1500 V	2500 V	Equipment containing particularly sensitive electronic circuits : – computer workstations, computers, TV, HiFi, Video, Alarms, etc; – household appliances with electronic programmers, etc.
II	2500 V	4000 V	Domestic electrical equipment with mechanical programmers, portable tools, etc.
III	4000 V	6000 V	Distribution panels, switchgear (circuit-breakers, isolators, power socket bases, etc.), ducting and its accessories (cables, busbars, junction boxes, etc.).
IV	6000 V	8000 V	Equipment for industrial use and equipment such as fixed motors permanently connected to the fixed installation, Electrical meters, principle overcurrent protection equipment, remote measurement devices, etc.

Equipment of overvoltage category I is only suitable for use in the fixed installation of buildings where protective means are applied outside the equipment – to limit transient overvoltage to the specified level. Examples of such equipment are those containing electronic circuits like computers, appliances with electronic programmes, etc.

Equipment of overvoltage category II is suitable for connection to the fixed electrical installation, providing a normal degree of availability normally required for current-using equipment. Examples of such equipment are household appliances and similar loads.

Equipment of overvoltage category III is for use in the fixed installation downstream of, and including the main distribution board, providing a high degree of availability. Examples of such equipment are distribution boards, circuit-breakers, wiring systems including cables, bus-bars, junction boxes, switches, socket-outlets) in the fixed installation, and equipment for industrial use and some other equipment, e.g. stationary motors with permanent connection to the fixed installation.

Equipment of overvoltage category IV is suitable for use at, or in the proximity of, the origin of the installation, for example upstream of the main distribution board. Examples of such equipment are electricity meters, primary overcurrent protection devices and ripple control units.

5.2 Selection Of Type I SPD

5.2.1 Impulse current Iimp

Table 11: Protection level

Protection level as per EN 62305-2	External lightning protection system designed to handle direct flash of:	Minimum required Iimp for Type 1 SPD for line-neutral network
I	200kA	25kA/pole
II	150	18.75 kA/pole
III/IV	100	12.5kA/pole

The run-off capacity of a surge arrester is determined by its electrical characteristics, and must be chosen according to the level of risk. The choice of **Iimp** for Type 1 surge arrester in case of a 200 kA direct lightning strike (around 95% of strikes are less than 200 kA: IEC 61 024-1-1 Annex A, Basic values of lightning current parameters), is 25 kA for each power line.

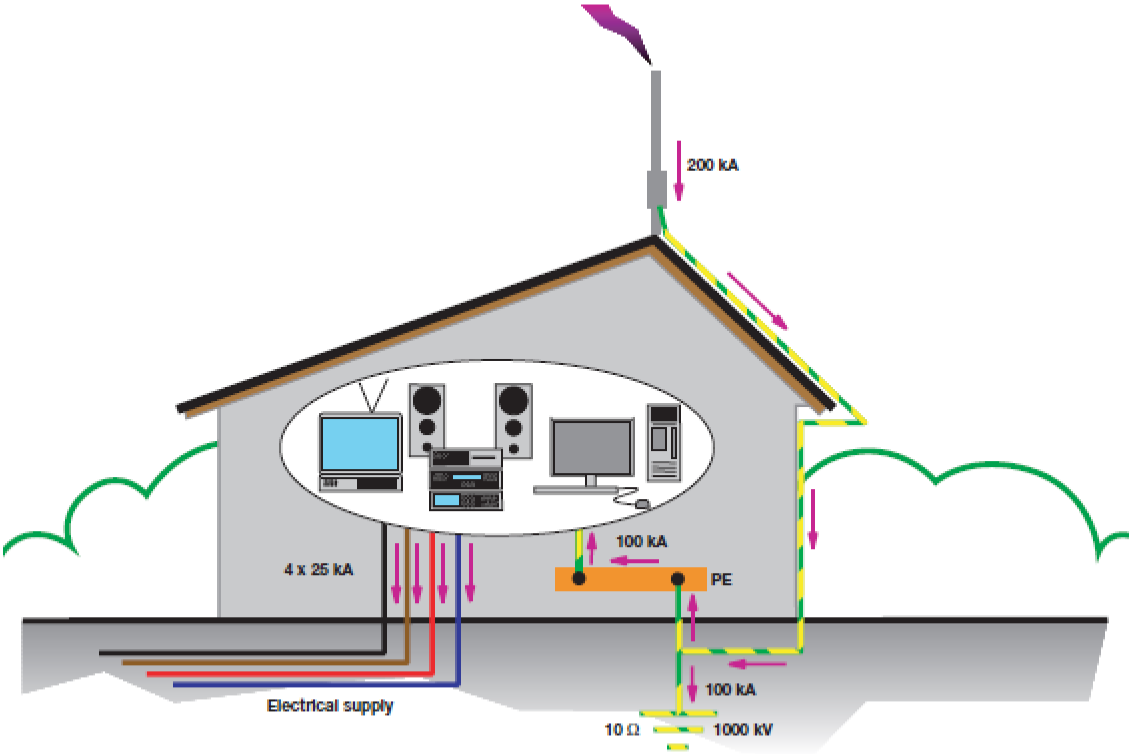


Figure 22: Distribution of current within the building

Recommends a minimum Iimp of 25 kA for Type 1 surge arresters based on the following calculation:

- Prospective direct lightning strike current I: 200 kA (only 1% of discharges > 200 kA).
- Distribution of current within the building: 50 % to ground and 50 % to the electrical network (according to international standards IEC 61 643-12 Annex I-1-2).
- Equal distribution of the current in each of the conductors (3 L + N):
- Iimp =100 kA/4= 25 kA.

5.3 SELECTION OF A TYPE 2 SPD

5.3.1 Maximum discharge current Imax

The maximum discharge current Imax is defined according to the estimated exposure level relative to the building's location. The value of the maximum discharge current (Imax) is determined by a risk analysis (table in).

Table 12: Maximum discharge current Imax

	Exposure level		
	Low	Medium	High
Building environment	Building located in an urban or suburban area of grouped housing	Building located in a plain	Building where there is a specific risk: pylon, tree, mountainous region, wet area or pond, etc.
Recommended Imax value (kA)	20	40	65

Table 13: Imax for Type 2 surge arresters

Optimization of Imax for Type 2 surge arresters				
Ng	< 2	2 < Ng < 3	3 < Ng <4	4 < Ng
In (kA)	5	15	20	30
Imax (kA)	15	40	65	100

5.3.2 Current handling capacity of SPDs.

- Low Risk: domestic, offices, factories, non-essential service providers etc.
- High Risk: hospitals, power generation and distribution, communication, broadcasting and other essential service providers
- High lightning density areas: Areas where isokeraunic level is greater than 80 thunder days/year
- Low lightning density areas: Areas where isokeraunic level is less than 80 thunder days/year
- For 10 / 350 µs current impulse
- ** For 8 / 20 µs current impulse

Table14: current handling capacity of SPDs

Location	High lightning density areas (Current in kA/Phase)	Low lightning density areas (Current in kA/Phase)
Main panel * (Zone-1)	40 (Low risk)	30 (Low risk)
	60 (High risk)	40 (High risk)
Sub-panels ** (Zone-1)	30 (Low risk)	15 (Low risk)
	40 (High risk)	20 (High risk)
power feeder level ** (Zone-3)	07 (Low risk)	03 (Low risk)
	15 (High risk)	07 (High risk)

The current handling capacity is one of the important parameters. Also note that the values in the Table-1 are the current handling capacity of each SPD connected between a line and the neutral. The SPD between the neutral and earth should have a current handling capacity of above 75% of 3 times the value of one SPD between line and neutral. For an example at the main panel of a high risk location in an area of low lightning density (3 Phase system); Iimp of each SPD from line to neutral is 40 kA, Iimp of SPD from neutral to earth is $(40 \times 3) \times 75 / 100 = 90$ kA

These are minimum values for the above installation.

It has been found that several leading manufacturers indicate the current handling capacity of their SPDs as 3 times the capacity of a single SPD (eg. 120 kA in the above case). Few manufacturers indicate the capacity of SPDs even including the capacity of neutral to earth SPD (eg. 210 kA in the above case). Such indications mislead the customers so that the engineer should be careful in their selections.

The criteria taken into consideration in this section are the evaluation of the risk of a direct lightning strike on or nearby the building, including the financial aspect caused by destruction or operating losses. Even if protection is not indispensable, it should be noted that since zero risk does not exist, a means of protection may always be useful.

5.4 Surge Protection Technologies

There are 3 primary methods in common use for providing surge protection, where each method has certain advantages and disadvantages in their ability to provide surge protection [14] & [1]. These are

- Silicon Diodes (SAD's)
- Metal Oxide Varistors (MOV's)
- Spark Gaps Diverters (SGD's)

Table15: Comparison of common technologies

Device	High Energy High Current	Low let-through Voltage	No follow-on current (non crowbar)
Silicon Devices	✗✗	✓✓	✓
MOVs	✓	✓	✓
Traditional Spark Gaps	✓✓	✗	✗✗

5.4.1 Silicon Avalanche Diode

The Silicon Avalanche Diode (SAD) devices include such devices as Trans Zorbs, Zeners, Sid actors, etc. They are typically characterized by a predictable low let-through voltage, a fast response time, a very low surge rating, and a very high cost. Silicon devices typically have a lower clamping voltage and better clamping ratio for the same MCOV of a MOV device. For a 220-240V rated piece of equipment a let-through of 600V-1000V is desired. As a MOV based device can adequately protect to this level, there is a strong argument as to whether the extra cost premium for silicon based protection device may be better spent on MOV based protection.

Additionally as most Silicon components on the market are generally in the 30-50V range, Silicon SPDs for mains voltage protectors are made up of series strings. If excessive lead lengths are used in the internal construction, the internal voltage drop due to the lead length can be excessive, thereby negating the advantages of using the silicon devices. Silicon devices are well known for their low surge ratings. This is partially overcome by paralleling many devices together, but obviously with a corresponding increase in price. Another well documented problem with Silicon based devices is that they are not robust – whereby exceeding their energy rating by more than 10-20% will give a 100% failure. With the series/parallel matrix of components, once one component is stressed and fails, a chain reaction will commonly occur, failing the entire device. MOVs and spark gaps on the other hand, are robust and can commonly exceed their surge rating by over 50%, and in many instances tested samples have exceeded their expected life by a factor of 2-4 times.

Many manufacturers of the silicon devices promote the high speed of the products, which in many instances can be misleading and irrelevant in the proper selection of Surge Protective Devices. Claims of speeds from 5ns to <1ns are commonly quoted. Although some manufacturers will claim these fast clamping devices are a better product, close inspection will show that the poor installation practices and the layout of long internal leads of many of these products will often cause larger let-through voltages to be provided due to inductance. .

An advantage of silicon is that is does not degrade and will last for a very long time. However, they will fail if the energy rating of the device is slightly exceeded. As the energy ratings of the silicon devices are comparatively low, there is a high risk that a failure will occur due to excessive energy of one impulse, rather than an excessive total number of smaller impulses. .

5.4.2 Metal Oxide Varistors

MOVs are generally well accepted in the industry as being the low cost, all round best performer. It is important to install suitable surge rated which have been considered to suit the environment, geographical location and criticality of the application. If not sufficiently rated higher enough, one of the main disadvantages of the MOV can be the life. MOVs have a life that is limited by the number and intensity of the transients that are diverted. The relationship of which is non-linear. Well-designed MOV products usually have excessive capacity to give a high single shot rating, not as this is commonly expected to be required, but to give a much longer length of life with the more numerous smaller impulses. They will also usually have some form of an indication system that not only detects the complete failure of the SPD, but also a partial reduction of the internal capacity allowing the owner to replace the unit before the equipment is left with no protection, where the critical loads might possibly be damaged.

5.4.3 Spark Gaps

Spark gaps are naturally ventilated air gaps and gas arresters which have the gap enclosed and contain a low pressure inert gas to lower the firing voltage. Due to encapsulation, Gas Arresters normally have a lower surge rating, and are not commonly used for power Surge Protection devices. Spark Gaps are predominantly promoted by European manufacturers, and are typically characterized by high surge ratings, much higher let-through voltages and long life.

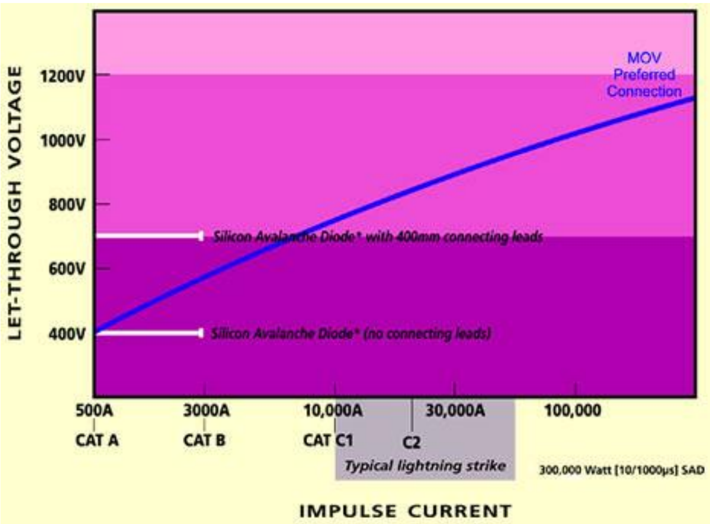


Figure 23: Comparison of SAD and MOV surge rating and let-through voltage

The surge rating is high, as after the high firing voltage (3000-4000V), the arc voltage falls to approx 30V, meaning that little energy is dissipated across the device as most is diverted back to the source or to ground. This low arc voltage can however crowbar the supply, causing the mains voltage to be short circuited (follow-on current), blowing upstream fuses and removing power to the site. The follow-on current can cause premature aging of the gap, especially on high short circuit capacity supplies.

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5.4.4 Choice of technology according to application

In the main distribution board we need high capacity in 10/350 and withstand voltage fluctuation on the electrical network. Therefore Spark gap is ideal. In the sub distribution board we need low surge capacity, Up (Less than 1.5kV) under low surge. Therefore, MOV is ideal. However, a MOV based device can adequately protect to this level and MOVs are generally well accepted in the industry as being the low cost, all round best performer. MOVs are ideally suited as voltage limiting devices due to their economical cost and their ability to handle large surge currents. However MOVs are a consumable item and exhibit an operational life which is proportional to the number and amplitude of surges and transients. MOV life characteristic is non-linear, so doubling of the surge rating provides a far greater length of life (typically 3-5 times) for the same size surge

Component	Gas Discharge Tube (GDT)	Encapsulated spark gap	Zinc oxide varistor	GDT and varistor in series	Encapsulated spark gap and varistor in parallel
Characteristics					
Operating mode	Voltage switching	Voltage switching	Voltage limiting	Voltage-switching and -limiting in series	Voltage-switching and -limiting in parallel
Operating curves	u I		u I		
Application	■ Telecom network ■ LV network (associated with varistor)	LV network	LV network	LV network	LV network
SPD Type	Type 2	Type 1	Type 1 ou Type 2	Type 1+ Type 2	Type 1+ Type 2

Figure 24: Comparison of technology

MOV are widely used in power protection system, are almost unsuitable in signal protection systems due to its large stray capacitance. Most often, SPD for signal systems comprised only of Gas discharge Tubes or GDT and SAD with series inductor.

5.5 Environmental criteria

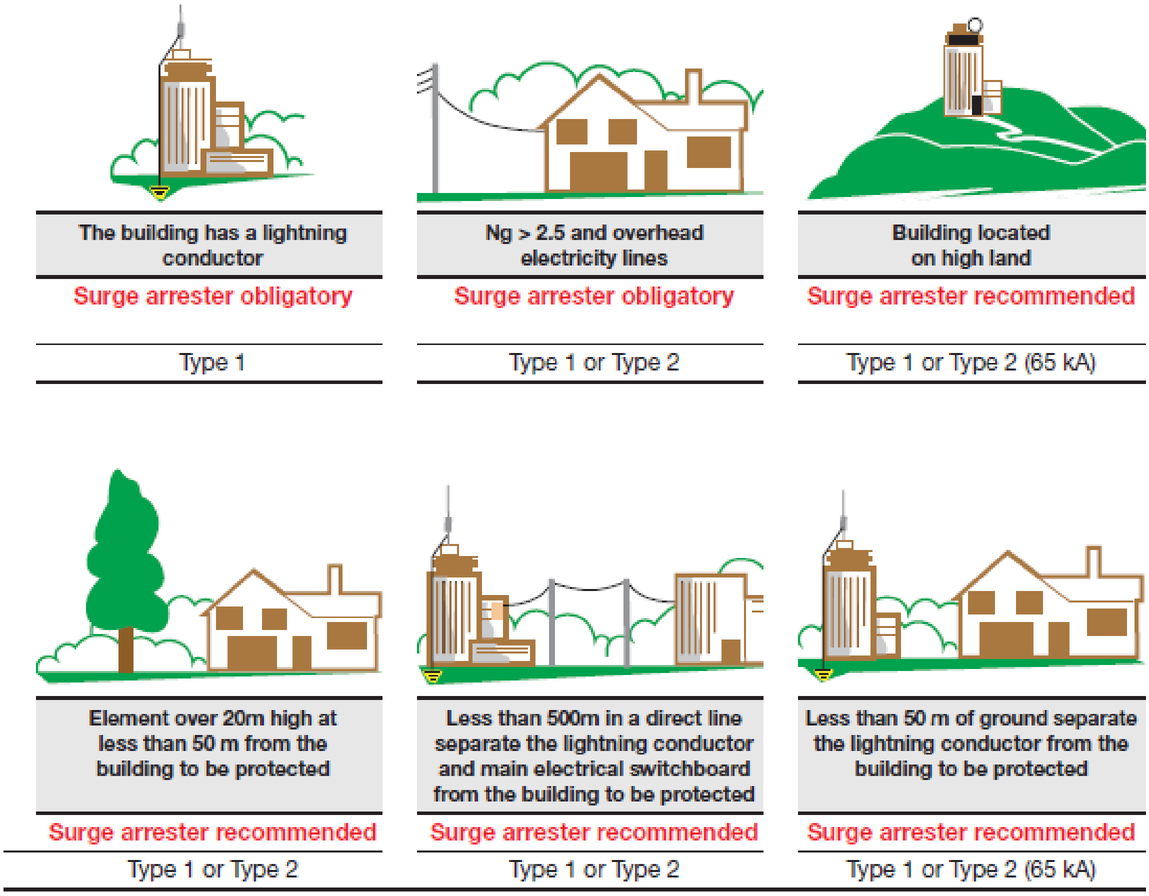

Figure 25: Environmental criteria

5.6 Operational Criteria

Recommended	Highly recommended	Very highly recommended	Selection criteria
			Continuity of supply is the priority (for reasons of operating loss costs, safety, etc.):
		●	– factories, offices, banks, airports, police stations, chemists, video surveillance systems, etc.,
		●	– hospitals, retirement homes, dialysis centres.
			Equipment protection is the priority:
		●	– high value > 150,000 Euros;
	●		– medium value > 15,000 Euros;
●			– low value > 150 Euros.
			Risk of lightning strikes in the region:
	●		– Ng ≤ 2.5
		●	– Ng > 2.5
		●	– isolated site.
			Type of electrical supply network feeding the site:
	●		– overhead,
●			– underground.

Figure 26: Operational Criteria

Choice of Uc and UT according to the nominal voltage (Un) of the electrical network

The choice of operating voltage is also vital when selecting a surge arrester. There are two voltage characteristics **Uc** and **UT**. The surge arresters in combination with their breaking devices must resist a temporary 50 Hz overvoltage without incurring any modification to their characteristics or functionalities. For a 230 V (phase-neutral) electrical network, this overvoltage is defined as follows:

UT for 5 secs (+0 / -5 %).

UT is given in the table below.

(e.g. **UT** = 400 V with **UO** = 230V between phase and PE for a TT system).

It is imperative that these values are chosen in compliance with the table below according to the type of earthling system.

Table 16: Value of UT and Uc

Surge arrester connection	TT	
	Uc	UT
Between Phase and Neutral	253V	334V
Between Phase and PE	253V	400V
Between Neutral and PE	230V	NA
Between Phase and PEN	NA	NA

Note: These voltages are minimum voltages) - N.A.: Not Applicable.

6.0 RESULT AND DISCUSSION FOR SELECTION OF COST OPTIMAL SPD SYSTEM

Considering all above indicated details, it is introduced under mentioned optimum selection procedure for the selection of SPD according to the risk analysis, environmental criteria, operational criteria and lightning flash density of area.

Estimate the value of the equipment to be protected, the value is estimated by considering the financial cost of the equipment and the economic impact of equipment downtime

- Domestic equipment

  Audio video equipment, computers, Electrical appliances, Burglar alarm
- Building equipment

  Fire alarm, access control, automated heating, air conditioning, lift
- Business equipment

  Programmable machine, server, sound or light control system
- Heavy equipment

  Medical infrastructure, production infrastructure, heavy computer processing

Determine the type of building, lightening protection can be calculated for an entire building or for part of a building that is electrically independent.

- detached house
- flat small semidetached house
- common area of building
- professional premises

Identify the type power distribution, depending on the size of the building and the extent of its electrical system, one or more surge arresters must be used in the various switchboards in the installation.

- single switchboard or main switchboard,
- sub distribution board,
- Sensitive equipment more than 30 m from the switchboard.

Understand the risk of the impact of lightening on the site

Location of the building:

- in an urban, suburban, grouped, housing area.
- in plain area.
- in an area where there is a special risk (pylon, tree, mountainous region, mountain peak, damp area or pond).
- in an exceptionally exposed area (lightning rod within 50 metres of a building).

6.1 Selecting optimize protective device

6.1.1 Equipment to be protected

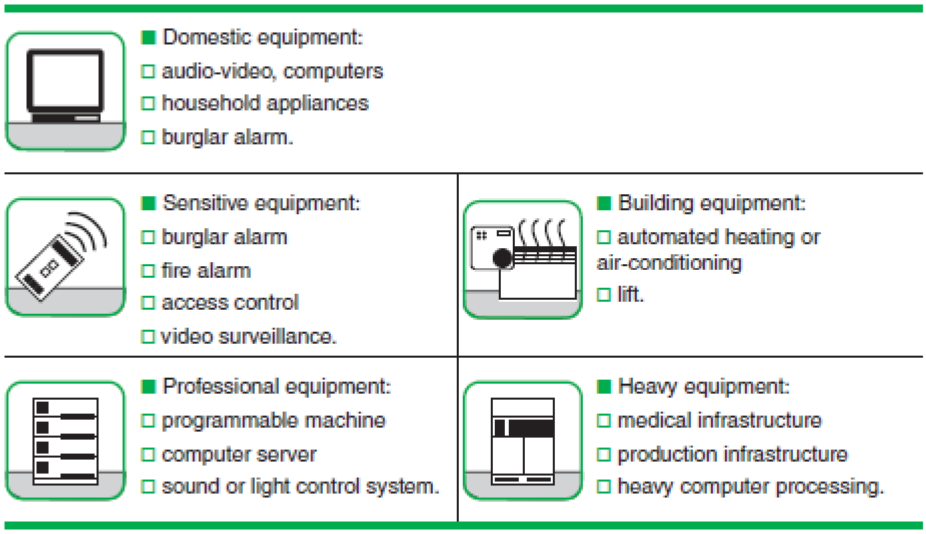

Figure 27: Lightning Density

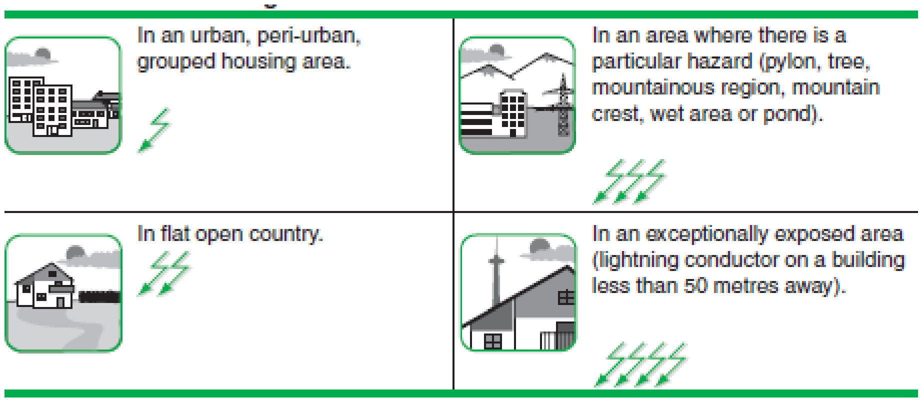

Figure 28: Location of building

Table 17: Imax for Type 2 surge arresters

Optimization of Imax for Type 2 surge arresters				
Ng	< 2	2 < Ng < 3	3 < Ng <4	4 < Ng
In (kA)	5	15	20	30
Imax (kA)	15	40	65	100

6.1.2 Domestic Equipment

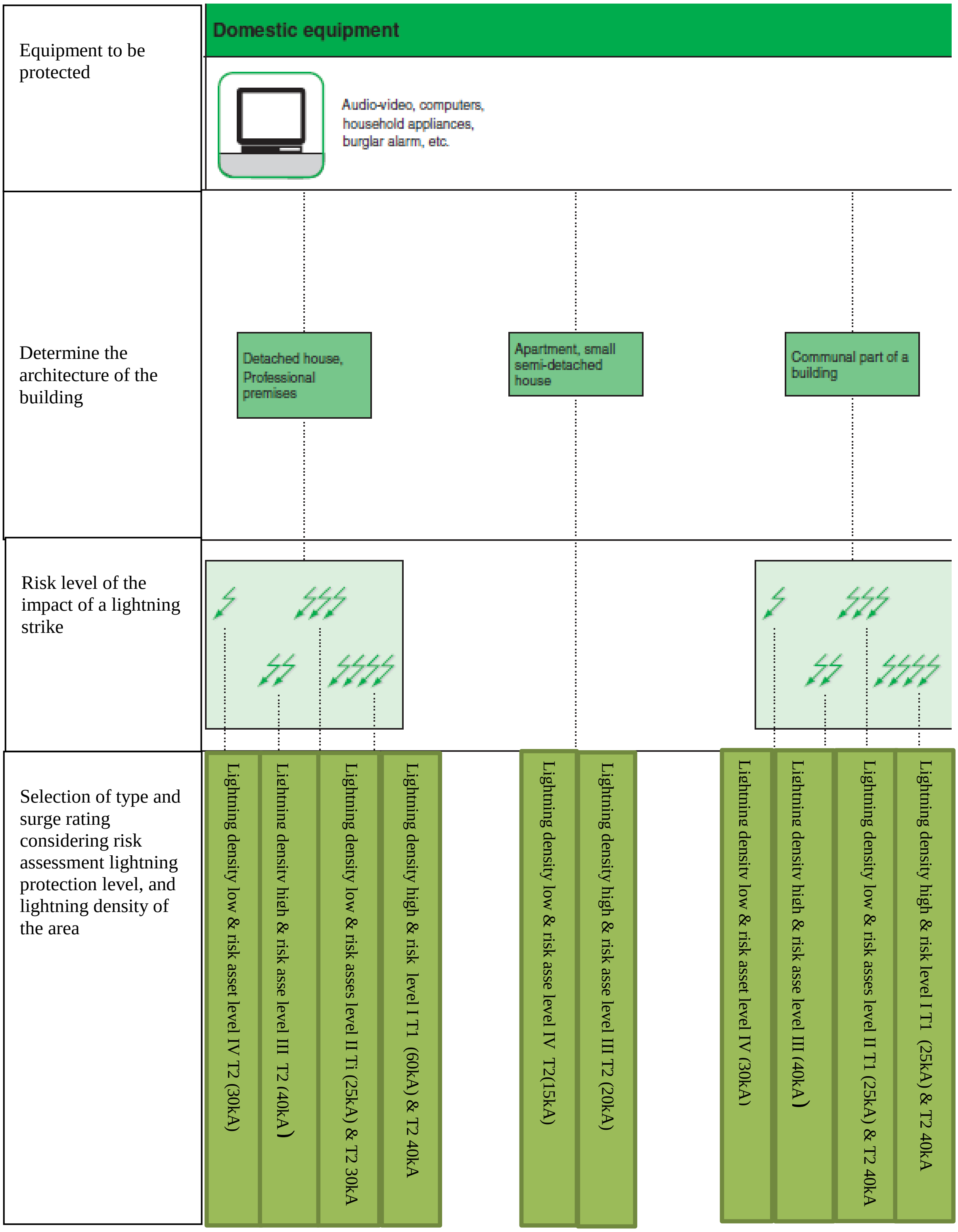

Figure 29: Domestic Equipment

6.1.3 Sensitive and Building equipment

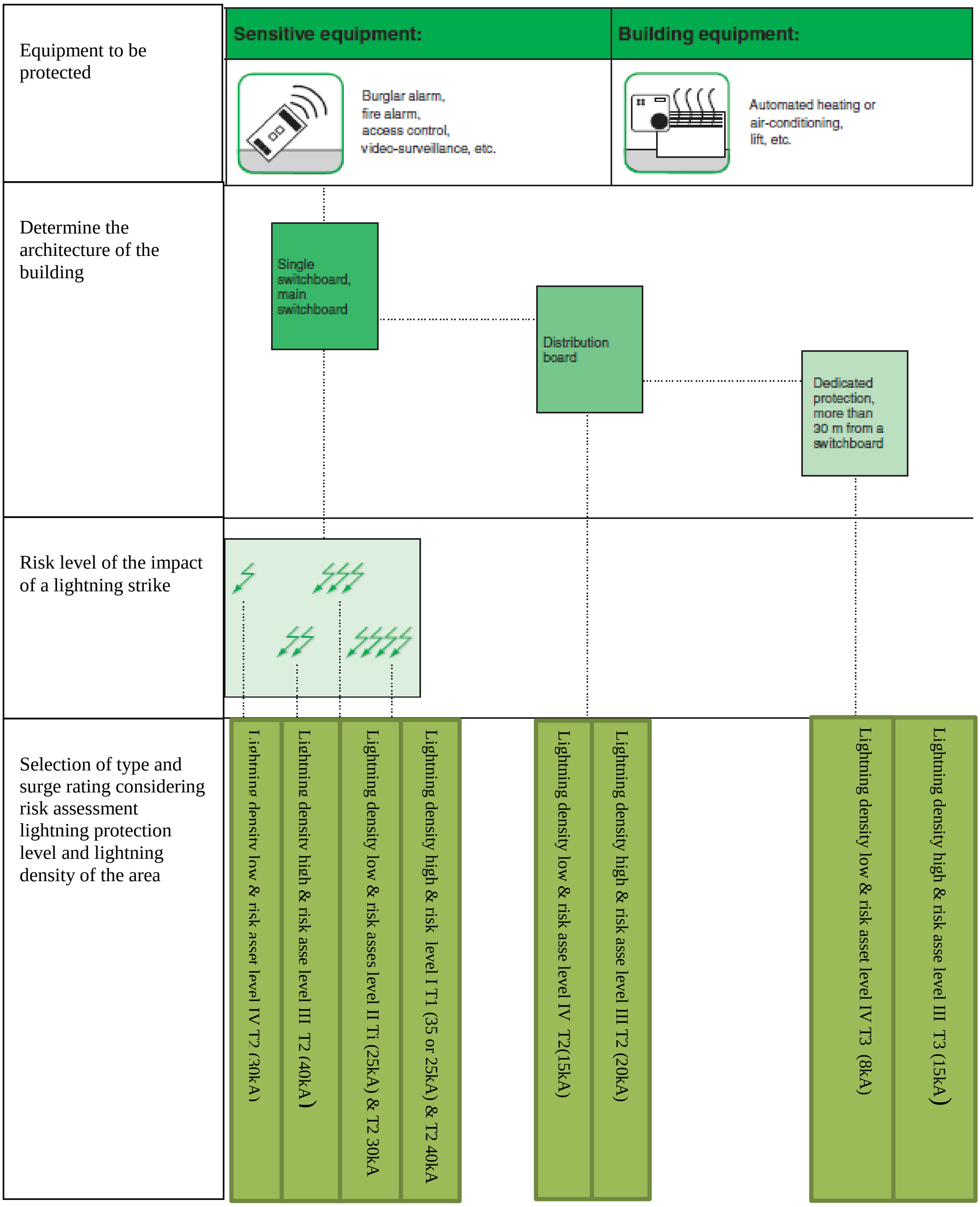

Figure 30: Sensitive and Building equipment

6.1.4 Professional Equipment

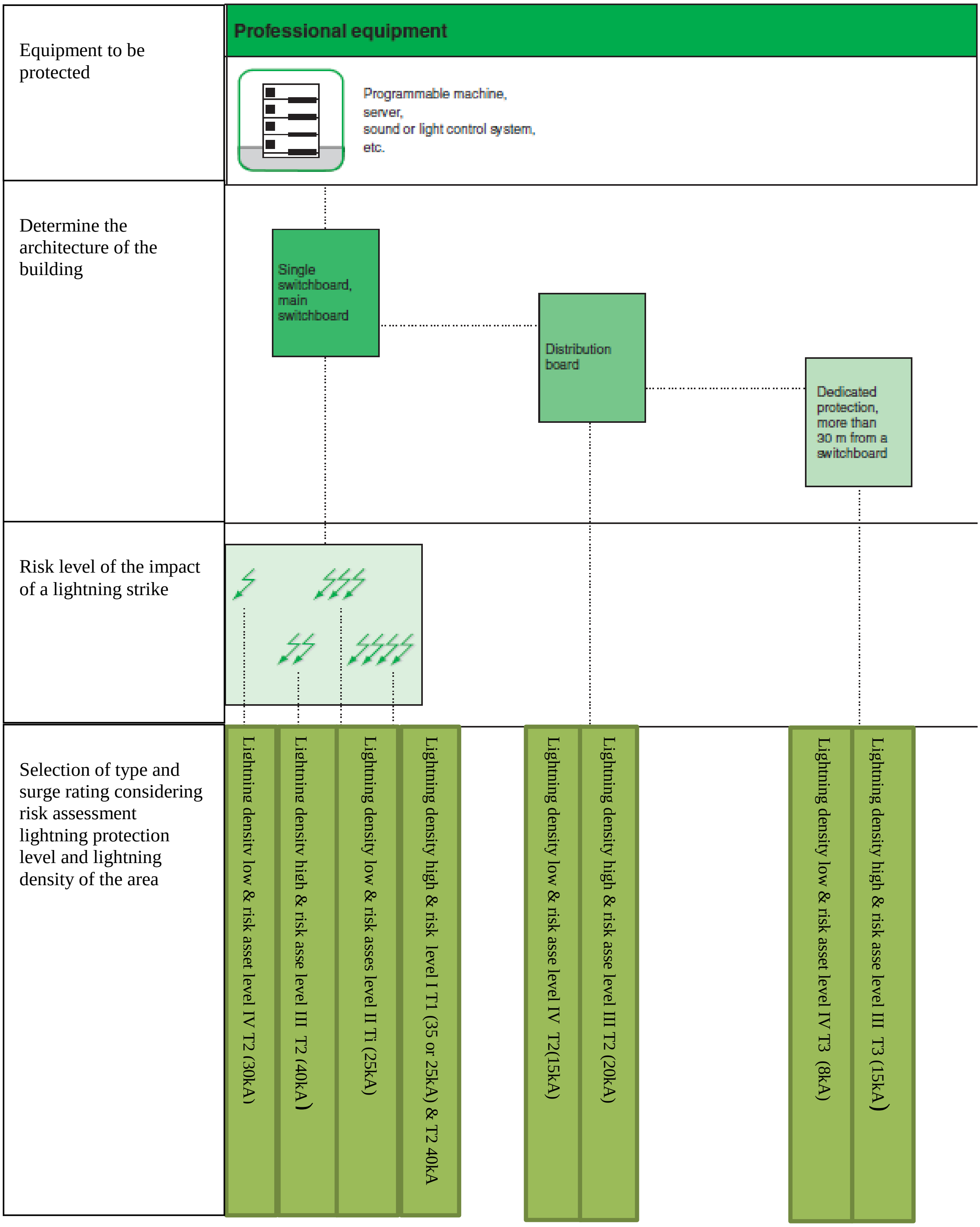

Figure 31: Professional Equipment

6.1.5 Heavy Equipment

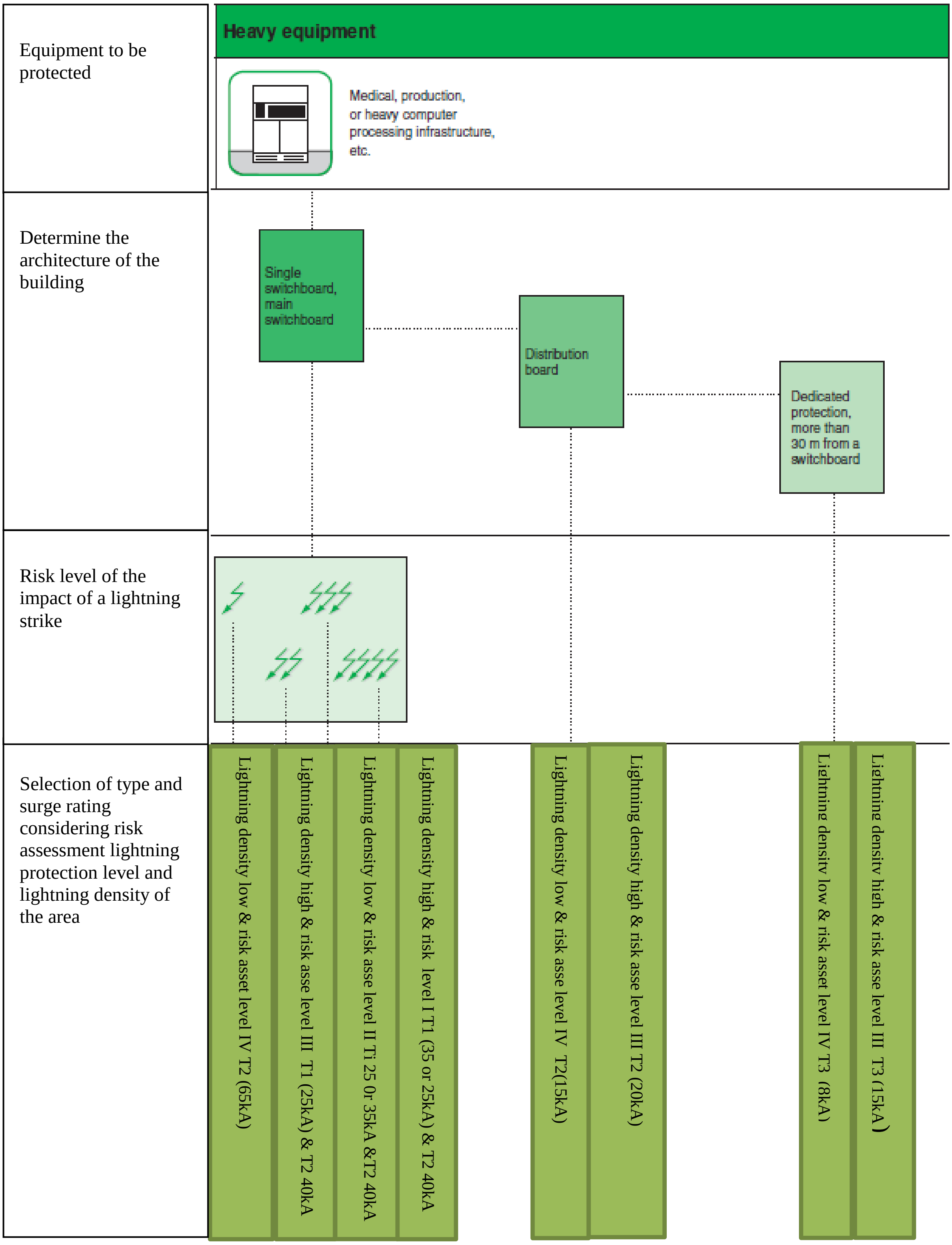

Figure 32: Heavy Equipment

6.1.6 Example 1

Lighting Protection Calculations for Accommodation Building at KDU

Calculations As per IEC 62305 -2

Structure data and characteristics (Table H.1)

Parameter	Comments	Symbol	Value
Dimensions(m)			
Length		Lb	15
Width		Wb	20
Height		Hb	6
Location factor	Higher objects	Cd	1
Structure not protected by LSP	None	PB	1
Shield at structure boundary	None	KS1	1
Shield internal to structure	None	KS2	1
People present outside the house	None		
Lightning flash density	$1/km^2/Year$	Ng	4
Risk of shock of people		Ra	0

Inside the building characteristics (Table H.3)

Parameters	Comment	Symbol	Value
Floor surface type	Marble	ru	0.00001
Risk of fire	Low	r_f	0.001
Special Hazard	None	hz	1
Fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone systems	Yes	Connected to telecom line	
Loss by touch and step voltage	Yes	Lt	0.0001
Loss by physical damages	Yes	LF	0.001

Data and characteristics of lines and connected internal systems (Table H.2)

Parameters	Comment	Symbol	Value
Soil resistivity	Ωm	q	**500**
LV power line and its internal system			
Length (m)		Lc	1000
Height (m)	Buried	Hc	6
Transformer	None	Ct	1
Line location factor	Isolated	Cd	1
Line environment factor	Rural	Ce	1
Line shielding	None	PLD	1
Internal wiring precaution	None	KS3	1
Withstand of internal system	UW = 2.5 kV	KS4	0.6
Coordinated SPD protection	None	PSPD	1
Telecom line and its internal system			
Length (m)		Lc	1000
Height (m)		Hc	6
Line location factor	Isolated	Cd	1
Line environment factor	Rural	Ce	1
Line shielding	None	PLD	1
Internal wiring precaution	None	KS3	1
Withstand of internal system	2.5	KS4	0.6
Coordinated SPD protection	None	PSPD	1

Calculation area of structure and lines (Table H.4)

Symbol of area	Formula for collection area	Value m²
Ad	*To the structure* Ad =[Lb x wb+6Hb x (Lb+Wb)+π x(3Hb)²)]	2578.285714
A1(P)	To the power line A1(P) = √p x [Lc - 3Hb]	21958.18754
Ai(P)	Near the power line Ai(P)= 25 x √p x Lc	559016.9944
Al(T)	To the telecom line Al(T)= 6 Hc x [Lc - 3Hb]	35352
Ai(T)	Near the telecom line Ai(T)= 1000 x Lc	1000000

Expected annual number of dangerous events (H.5)

Symbol of number	Formula for number of flashes	Value (1 Year)
ND	To the structure ND= Ng x Ad x Cd x 10^{-6}	**0.010313143**
NL (P)	To the power line NL (P)= Ng x Al(P)x Cd(P)XCt(P)X10^{-6}	**0.08783275**
Ni(P)	Near the power line Ni(P)= Ngx Ai(P)x Ct(P)xCe(P)x10^{-6}	**2.236067977**
NL (T)	To the telecom line NL (T)= Ng x Alt) X Cd(T) X 10^{-6}	**0.141408**
Ni(T)	Near the telecom line Ni(T) = Ng X Ai(T) X Ce(T) X 10^{-6}	**4**

Risk components involved and their calculation (Table H.6)

Symbol of component	Formula for component with flashes to	Value x 10^{-5}	Risk presentage
RA	The structure resulting in injury to living beings $R_A = N_D x P_A x r_a x L_t$	0	
RB	The structure resulting in physical damages $R_B = N_D x P_B x h_z x r_p x r_f x L_f$	1.03131E-08	4.302605355
RU(Power line)	The power line resulting in shock $R_U = (N_L + N_{Da}) x P_U x r_a x L_t$	0	0
RV(Power line)	The power line resulting in physical damages $R_V = (N_L + N_{Da}) x P_V x h_z x r_p x r_f x L_f$	8.78328E-08	36.64350106
RU(Telecom line)	The phone line resulting shock $R_U = (N_L + N_{Da}) x P_U x r_a x L_t$	1.41408E-10	0.058994899
RV(Telecom line)	The phone line resulting in physical damage $R_V = (N_L + N_{Da}) x P_V x h_z x r_p x r_f x L_f$	1.41408E-07	58.99489869
Total R_1	$R_A + R_B + R_{U(Power\,line)} + R_{V(Power\,Line)}$ $+ R_{U(Telecom\,line)} + R_{V(Telecom\,Line)}$	2.39695E-07	
R_T	Tolerable risk	10^{-5}	

R_1=2.4 X 10^{-5} $\quad R_T = 10^{-5}$

If $R_1 > R_T$ Need lightning protection

Component		Value x 10^{-5}
R_D	Risk due to flashes striking the structure	1.03131E-08
R_1	Risk due to striking influence the structure	2.39
R_S	Risk due to injury to leving being	0
R_O	Risk due to physical damage	2.39
R_F	Risk due to failure of internal system	0

R_D	is risk due to flashes striking the structure	$R_A + R_B + R_C$
R_1	is risk due to flashes striking influence it	$R_M + R_U + R_V + R_W + R_Z$
R_S	is the risk due to injury of living being	$R_A + R_U$
R_F	is the risk due to physical damage	$R_B + R_V$
R_O	is the risk due to failure of internal systems	$R_M + R_C + R_W$

According to table H.6

Component RV(Telecom line) Lightening flash to telecom line for 59%

Component RV(Power line) Lightening flash to power line for 37%

Component RB Lightning flash to structure 4%

To reduce the risk R1

a. Installing SPD of LPL IV at the service entrance , reduce the value Pu and PV 1 to 0.03 d lines due to SPD on connected

b. Installing SPD of LPL IV , reduce the value PB from 1 to o.2 and Pu and PV 1 to 0.03 d lines due to SPD on connected

Values of risk components relevant to risk R1

Symbol of component		Case a	Case b
RA	The structure resulting in injury to living beings $R_A = N_D x P_A x r_a x L_t$	0	0
RB	The structure resulting in physical damages $R_B = N_D x P_B x h_z x r_p x r_f x L_f$	0.00000103	0.000000206
RU(Power line)	The power line resulting in shock $R_U = (N_L + N_{Da}) x P_U x r_a x L_t$	0	0
RV(Power line)	The power line resulting in physical damages $R_V = (N_L + N_{Da}) x P_V x h_z x r_p x r_f x L_f$	0.000000263	0.000000263
RU(Telecom line)	The phone line resulting shock $R_U = (N_L + N_{Da}) x P_U x r_a x L_t$	0	0
RV(Telecom line)	The phone line resulting in physical damage $R_V = (N_L + N_{Da}) x P_V x h_z x r_p x r_f x L_f$	0.000000423	0.000000423
Total R_1	$R_A + R_B + R_{U(Power\ line)} + R_{V(Power\ Line)} + R_{U(Telecom\ line)} + R_{V(Telecom\ Line)}$	0.000001717	0.000000892

As per the risk assessment and lightning protection level, it is required to install level III lightening protection, therefore, as per the research findings following are considered

Exposure level

Ratmanla lightning Density is higher level (Greater than 4Ng)

Equipment to be protected - Sensitive and building equipment

Recommend Type a for main panel, Type 2 sub panel and type 3 for places where greater than 10m

Asper the research finding, to be installed with respectively main, sub and

point of use distribution panel Type 2 40kA, Type 2 20 kA, type 3 8kA

$$R_A = N_D x P_A x \ r_a \ x L_t$$

$$R_B = N_D x P_B x \ h_z \ x r_p \ x \ r_f \ x L_f$$

$$R_U = (N_L + N_{Da}) x P_U x \ r_a \ x \ L_t$$

$$R_V = (N_L + N_{Da}) x P_V x \ h_z x \ r_p \ x \ r_f \ x L_f$$

$$R_U = (N_L + N_{Da}) x P_U x \ r_a \ x \ L_t$$

$$R_V = (N_L + N_{Da}) x P_V x \ h_z x \ r_p \ x \ r_f \ x L_f$$

R1= $R_A + R_B + R_{U(Power\ line)} + R_{V(Power\ Line)}$
$+ R_{U(Telecom\ line)} + R_{V(Telecom\ Line)}$

6.1.6 Example 2

Lightning Protection Calculations for Tower building at University Hospital KDU

This case study includes a lightning protection calculation for tower building at university hospital KDU, it consists with 10th stories building and each flow is symmetrical up to the level of 10th flow. The calculation is only done for the 4th flow level onwards. The building itself and surrounding, internal electrical systems and relevant incoming power line and internal electronic systems and relevant incoming telecom line were considered for calculation. The zones of outside building, six bed rooms, nursing stations, doctors' room, IT rooms, electrical room and Intensive care unit were considered as zones.

Calculations As per IEC 62305 -2

Parameter	Comments	Symbol	Value
Dimensions(m)			
Height (m)	m	Hb	46
Width (m)	m	Wb	21
Length (m)	m	Lb	121
Location factor	Same/smaller	Cd	1
LPS	None	PB	1
Shield at structure boundary	None	KS1	1
Shield internal to structure	None	KS2	1
People present outside/inside the house	None	n_t	1000
Lightning flash density	1/km²/Year	Ng	4
Risk of shock of people		R_A	0

Internal power system and connected power line characteristics

Parameters	Comment	Symbol	Value
Soil resistivity	Ωm	ρ	250
LV power line and its internal system			
Length (m)		Lc	500
Height (m)	Aerial	Hc	2

Transformer	Transformer	Ct	0.2
Line location factor	Same/smaller	Cd	0.5
Line environment factor	Suburban	Ce	0.5
Line shielding	None	PLD	0.2
Internal wiring precaution	None	KS3	0.2
Withstand of internal system Uw (kV)	Sensitive	KS4	0.6
Coordinated SPD protection	None	PSPD	1
Telecom line and its internal system			
Length (m)		Lc	300
Height (m)	Buried	Hc	
Line location factor	Isolated	Cd	0.5
Line environment factor	Suburban	Ce	0.5
Line shielding	None	PLD	0.8
Internal wiring precaution	None	KS3	0.02
Withstand of internal system Uw (kV)	Sensitive	KS4	1
Coordinated SPD protection	None	PSPD	1

Entrance area to the building characteristic (Zone Z1)

Parameters	Comments	Symbol	Values
Soil surface type	Agricultural, concrete	ra	0.01
Shock protection	None	PA	1
Loss by touch and step voltages	outside	Lt	0.01
People potentially in danger in the zone			200

Garden zone Z1A

Parameters	Comments	Symbol	Values
Soil surface type	Agricultural, concrete	ra	0.01
Shock protection	None	PA	1
Loss by touch and step voltages	outside	Lt	0.0002
People potentially in danger in the zone			10

6 Beds ward Zone Z2

Parameters	Comments	Symbol	Values
Flow surface type	Marble, ceramic	ru	0.00001
Risk of fire	Low	rf	0.01

Special hazard (relevant to R1)	Low Panic	hz	5
Special hazard (relevant to R4)			1
fire protection	Extinguishers	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages (R1)	inside	Lt	0.0000005
Loss by physical damage (R1)	Hospital, Industrial, museum, agriculture	Lf	0.0005
Loss by failure of internal system (R1)			0.001
People potentially in danger in the zone			5
Loss by touch and step voltages (R4)			
Loss by physical damage (R4)			0.5
Loss by failure of internal system (R4)			0.01

6 Beds ward Zone Z3			
Parameters	Comments	Symbol	Values
Flow surace type	Marble, ceramic	ru	0.00001
Risk of fire	Low	rf	0.01
Special hazard (relevant to R1)	Low Panic	hz	5
Special hazard (relevant to R4)			1
fire protection	Extinguishers	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages (R1)	inside	Lt	0.0000005
Loss by physical damage (R1)	Hospital, Industrial, museum, agriculture	Lf	0.0005
Loss by failure of internal system (R1)			0.001
People potentially in danger in the zone			5
Loss by touch and step voltages (R4)			
Loss by physical damage (R4)			0.5
Loss by failure of internal system (R4)			0.01

Intensive Care unit Zone 4

Parameters	Comments	Symbol	Values
Flow surface type	Asphalt, linoleum, wood	ru	0.00001
Risk of fire	Low	rf	0.001
Special hazard	Low Panic	hz	5
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			5

Nursing Station Zone 5

Parameters	Comments	Symbol	Values
Flow surface type	Asphalt, linoleum, wood	ru	0.00001
Risk of fire	Low	rf	0.001
Special hazard	Low Panic	hz	2
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			14

Doctor room Zone 6

Parameters	Comments	Symbol	Values
Flow surface type	Asphalt, linoleum, wood	ru	0.00001
Risk of fire	Low	rf	0.001

Special hazard	Low Panic	hz	2
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			5

IT room Zone 7			
Parameters	Comments	Symbol	Values
Lss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			2
Flow surface type	Marble, ceramic	ru	0.001
Risk of fire	High	rf	0.1
Special hazard	Low Panic	hz	2
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			4
Electrical room Zone 8			
Parameters	Comments	Symbol	Values
Flow surface type	Asphalt, linoleum, wood	ru	0.00001
Risk of fire	Low	rf	0.001

Special hazard	Low Panic	hz	2
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Electrical room Zone 8			
Parameters	Comments	Symbol	Values
Flow surface type	Asphalt, linoleum, wood	ru	0.00001
Risk of fire	Low	rf	0.001
Special hazard	Low Panic	hz	2
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			2

Electrical room Zone 8

Parameters	Comments	Symbol	Values
Flow surface type	Asphalt, linoleum, wood	ru	0.00001
Risk of fire	Low	rf	0.001
Special hazard	Low Panic	hz	2
fire protection	None	rp	1
Spatial shield	None	KS2	1
Internal power system	Yes	Connected to LV power line	
Internal telephone system	Yes	Connected to telecom line	
Loss by touch and step voltages	inside	Lt	0.0001
Loss by physical damage	Hospital, Industrial, museum, agriculture	Lf	0.001
People potentially in danger in the zone			2

Collection area of structure	101585.5714
Collection area of power line	4344
Collection area of near power line	500000
Collection area of telecom line	2561.444905
Collection area of near telecom line	118585.4123

Expected annual number of dangerous events

	Value (1 Year)
To the structure (ND)	0.406342286
To the power line (NL-Power)	0.0017376
Near the power line (Ni-Power)	0.5
To the telecom line (NL- Telecom)	0.00512289
Near the telecom line (Ni-Telecom)	0.237170825
Structure connected at A end of tel line (Nda)	0.081268457
Flashes near a structure (NM)	

Value of probability P for unprotected structure		
Probability	Z1	Z
P_A	1	
P_B		1
P_C (Power System)		1
P_C (Telecom system)		1
P_C		1
P_M (Power system)		0.75
P_M (Telecom system)		0.009
P_M		0.752
P_U (Power line)		0.2
P_V (power line)		0.2
P_W (power line)		0.2
P_Z (Power line)		0.008
P_U (Telecom line)		0.8
P_V (Telecom line)		0.8
P_W (Telecom line)		0.8
P_Z (Telecom line)		0.04

Equations

$Rd= Ra+Rb+Rc$

$R1= Rm+Ru+Rv+Rw+Rz$

$Rs=Ra+Ru$

$Rf=Rb+Rv$

$ND= Ng\ x\ Ad\ x\ Cd\ x\ 10^{-6}$

$NL\ (P)= Ng\ x\ AI(P)x\ Cd(P)XCt(P)X10^{-6}$

$Ni(P)= Ngx\ Ai(P)x\ Ct(P)xCe(P)x10^{-6}$

$NL\ (T)= Ng\ x\ AIt)\ X\ Cd(T)\ X\ 10^{-6}$

$Ni(T) = Ng\ X\ Ai(T)\ X\ Ce(T)\ X\ 10^{-6}$

$Nda =Ng\ x\ Ad/a\ x\ Cd/a\ x\ Ct\ x\ 10^{-6}$

$NM= Ng\ x\ (Am\text{-}Ad/b\ Cd/b)\ x\ 10^{-6}$

$R_A=N_D x\ P_A x\ r_a\ x\ L_t$

$R_B=N_D x\ P_B x\ h_z\ x\ r_p\ x\ r_f\ x\ L_f$

$R_M=N_M x\ P_M\ x\ L_O$

$R_U = (N_L + N_{Da}) x\ P_U x\ r_a\ x\ L_t$

$R_V = (N_L + N_{Da}) x\ P_V\ x\ h_z\ x\ r_p\ x\ r_f\ x\ L_f$

$R_W = (N_L + N_{Da}) x\ P_W\ x\ L_O$

$R_Z = (N_I - N_L) x\ P_Z\ x\ L_O$

$R_U = (N_L + N_{Da}) x\ P_U x\ r_a\ x\ L_t$

$R_V = (N_L + N_{Da}) x\ P_V\ x\ h_z\ x\ r_p\ x\ r_f\ x\ L_f$

$R_W = (N_L + N_{Da}) x\ P_W\ x\ L_O$

$R_Z = (N_I - N_L) x\ P_Z\ x\ L_O$

$R1 = R_A + R_B + Rc + Rm + R_{U(Power\ line)} + R_{V(Power\ Line)} + +R_{w(Power\ line)} + R_{Z(Power\ Line)} + R_{U(Telecom\ line)} + R_{V(Telecom\ Line)} + R_{W(Telecom\ line)} + R_{Z(Telecom\ Line)}$

A1(P) = Lc - 3(Ha+Hb)6Hc]

Al(T)= 6 Hc x [Lc - 3Hc]

Ad ={Lb x Wb+6Hb x (Lb+Wb)+π x$(3Hb)^2$)}

$Ai(P)= 25 x \sqrt{p} x Lc$

$Ai(T)= 1000 x Lc$

$A1(P) = Lc - 3(Ha+Hb)\sqrt{p}$

$A_d = L x W + 6 x H x (L + W) + 9 x \pi x H^2$

$Al=(Lc - 3(Ha + Hb)) 6Hc$

$Ai=1000 Lc$

Risk components calculation					
Formula for component with flashes to	Z 1	Z2	Z 3	Z 4	Structure
The structure resulting in injury to living beings (RA)	4.0634E-05				4.0634E-05
The structure resulting in physical damages (RB)		1.0159E-05	0.000025	0.000025	2.0317E-08
Failure of internal system (Rc) flashes to a structure			0.0001	0.0001	0.00406342
Failure of internal system (Rm) flashes near structure					
The power line resulting in shock (RU)		3.4752E-08	1.625E-13	1.625E-13	3.4752E-08
The power line resulting in physical damages (RV)		3.5452E-09	4.15E-07	4.15E-07	8.688E-07
Failure of internal system (Rw) flash to service			0.1162537	0.0011625	3.4752E-06
Failure of internal system (Rz) flashes near to service			3.189E-05	3.189E-07	3.9861E-05
The phone line resulting shock (RU)		8.1966E-09	2.049E-09	2.049E-09	2.7802E-09
The phone line resulting in physical damage (RV)			1.025E-07	1.025E-07	3.4752E-08
Failure of internal system (Rw) flash to service			4.098E-05	4.098E-05	1.3901E-05
Failure of internal system (Rz) flashes near to service			9.282E-05	9.282E-05	9.2819E-05
Total Risk component (R1)	4.0634E-05	1.0202E-05	0.1165449	0.1165449	0.00425507
	Rt=0.00001				0.00425507

R1=0.0231741 is higher than the tolerable value Rt= 0.00001, therefore, lightning protection is required. Selection of protection methods

Selection of protection methods

It is introduced lightning protection class I level protection to the risk assessment result and again reevaluate, then you can bring the risk components below the level of tolerable risk. Then you can identify the required type of SPD as type I as per the value of lightning protection level table.

As per the research data, the value of Iimp and I max will be calculated considering the exposure level (plain with building), equipment to be protected (electronic, heavy and sensitive equipment) and the lightning density of the area (Ng is high)

As per the research introduced chart at chapter 6 the values can be taken as Type 1 = 25kA, type 2= 40kA, Type 3= 15kA and Type 3-8kA for more than 30m away from sun distribution panels .Composition of risk R1 components according to zone

composition of risk R1 components according to zone

Symbol	Z1	Z2	Z3	Z4	Structure
Rd	4.063E-05	0.000125	0.000125	0.000125	0.00410408
R1	0	3.83E-08	0.116286	0.00013391	3.9933E-05
Total	4.063E-05	0.000125	0.116411	0.00025891	0.00414401
Rs	4.063E-05	8.197E-09	2.0492E-09	2.0492E-09	4.0637E-05
Rf	0	1.016E-05	2.5102E-05	2.5102E-05	5.5069E-08
Ro	0	0	0.11635369	0.00014098	0.00407732
Total	4.063E-05	1.017E-05	0.1163788	0.00016609	0.00411802

7.0 CONCLUSION & RECOMMENDATIONS

7.1 Conclusion

The following conclusions are made with regards to above analysis.

Many types of surge protective devices (SPDs) and technologies are available on the market. To get the most effective protection at the best value, you need to make a selection based on the most important technical performance specifications.

The task of choosing surge protection for a given facility cannot be determined solely by the ratings or size of the electrical distribution system. Each facility should be assessed based upon factors such as the anticipated surge environment, type of facility, and exposure risk. The choice of a surge protective device depends upon:

- The exposure of the building to lightning transients
- The sensitivity and value of the equipment that requires protection (it is recommended that the contractor should discuss the installations requirements with the customer)
- The location and therefore the exposure level of the installation
- The equipment used within the installation and whether this equipment could generate switching transients

Site location and exposure determines the risk of transients and lightning. The probability of lightning can be calculated using the ground flash density information or thunder day maps (Isokeraunic maps) from the meteorological department or similar sources. This data can be used as a basic to predict the possible direct and induced coupling onto power lines, allowing a surge rating required for protection to be estimated.

SPDs are needed to be connected to the LV system at several stages in a given building. Locations are identified as Zone 1 at Service Entrance which is the most exposed zone, power entering point at main panel board and out reaching point. Zone

2 is the Secondary Distribution level which only partial lightning current or reduced voltage impulse reach. Zone 3 is at Branch and Point of Use or power socket level which experiences even lower lightning energy.

In the selection of SPDs, the most exposed zone or zone 1 needs SPD with higher rating of impulse current handling. The zone 2 and zone 3 need sequentially reducing values of current handling capacity. The values of the current rating should be determined by as appropriate standards, taking in to account geographical location, thunderstorm density, and equipment to be protected.

The cost of SPD system depends upon the type of SPD, impulse currant capacity, technology used, mode of protection and level of protection. Therefore, it is required to appropriate selection of aforesaid factor for optimizing the cost of SPD. Optimal selection of impulse current capacity, maximum current and nominal current capacity should be considered appropriate standards, Risk assessment, Geographical location, Thunderstorm density and equipment to be protected.

Common structure risk assessment could be evaluated with the given simple risk assessment procedure, However, complete risk assessment need to be carried out for the special structures of hospital, higher value equipment installed building , essential services and structures with explosion hazard.

There is very little published data or even recommendations on what level of surge current (kA) rating should be used in the different categories or locations. Also, there is not a proven equation or calculator available to input system requirements and receive a solution.

Choosing the type of surge protector is based on the risk assessments result, location, exposure level and the lightning density of the area. Further if the installation is equipped with lightning protection system, it is to be included type 1 surge protective device followed by type 2 and 3 as necessarily.

Selecting the operating voltage Uc is based on the nominal voltage of the distribution network and type of earthling in distribution system. Uc is to be selected as 255V for 230/400V, TT distribution system.

Choosing impulse current capacity is based on the risk assessment level (as per the calculation), area lightning density (low, medium, and high), location and exposure level. Choosing maximum current is based on lightning of density of area, environment condition, The nominal discharge current and maximum discharge current is directly related to the lightning risk of the installation and capacity is based on lightning density of the area.

Surge protection needs to be selected such that their voltage protection level (Up) is lower than the impulse withstand capability of the equipment to be protected. For a 230/400V installation suggests that the value should not exceed 2.5kV. However to protect sensitive and critical equipment, then consideration should be given to reduce this value to that required equipment 1.5kV. Therefore, SPDs with lower value of voltage protection level is better than that with a higher value.

According to the SPD technology application, The Spark gap is ideal in the main distribution board since we need high capacity in 10/350 and withstand voltage fluctuation on the electrical network. The MOV is ideal in the sub distribution board since we need low surge capacity, Up (Less than 1.5kV) under low surge.

As per the standards, MCOV should be above 10% of the operating voltage. However, in the countries where the power quality is not very reliable, it is advisable to select an SPD with the least MCOV that can withstand a power quality of a given region.

It is to be used Temporary over voltage as UT = 1.45x nominal line to earth voltage. For 230/400V TT system, UTov = 1.45x 230 = 333.33V.

7.2 Recommendations

It is recommended to adopt under mentioned procedure to select cost optimal SPD system with optimal protection.

- For the common structures of housing, offices, buildings where there is not or less sensitive equipment industrial risk have to adopt common risk assessment as per the common risk assessment procedure indicated in chapter 4 of research report to select SPD and use user friendly software to obtain required SPD combination.
- For large industrial plant, data centres, hospitals, essential services and structures with explosion hazard where there is sensitive industrial risk have to adopt the complete risk assessment as per the IEC 62305 and identify the type of SPD and level of protection as per the risk assessment result. Each facility should be assessed based upon factors such as the anticipated surge environment, type of facility, and exposure risk as per the detail given in chapter 5 &6. Identify the optimal solution as per the data available in chapter 6.
- Follow the under mentioned procedures to select critical specifications for 230/400V TT system, and select theses value as much as closure to SPD's available in local market.
  - Select **Iimp**, **Imax** and **In** capacities as indicated in chapter 5 selection criteria.
  - Used **Uc or MCOV** as 255V, **MCOV** as 110% of nominal voltage or next step available in local market. However, this value could be varied and should be selected considering quality of power
  - Surge protection needs to be selected such that their voltage protection level (Up) is lower than the impulse withstand capability of the equipment to be protected. **Up** is applicable to the installed equipment as given in table at chapter 5
  - The technology as **MOV** for type 1 and 2 and **GDT** for type 1.
  - Temporary over voltage as **UT**=1.45x nominal line to earth voltage

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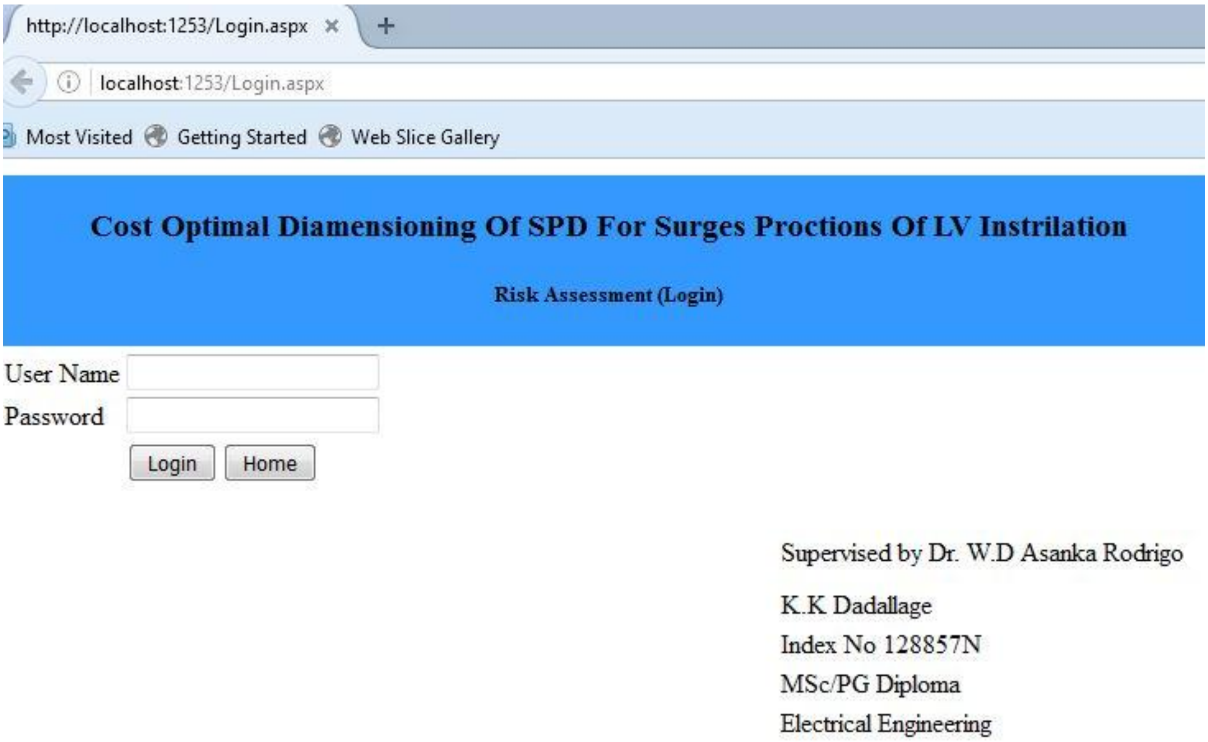
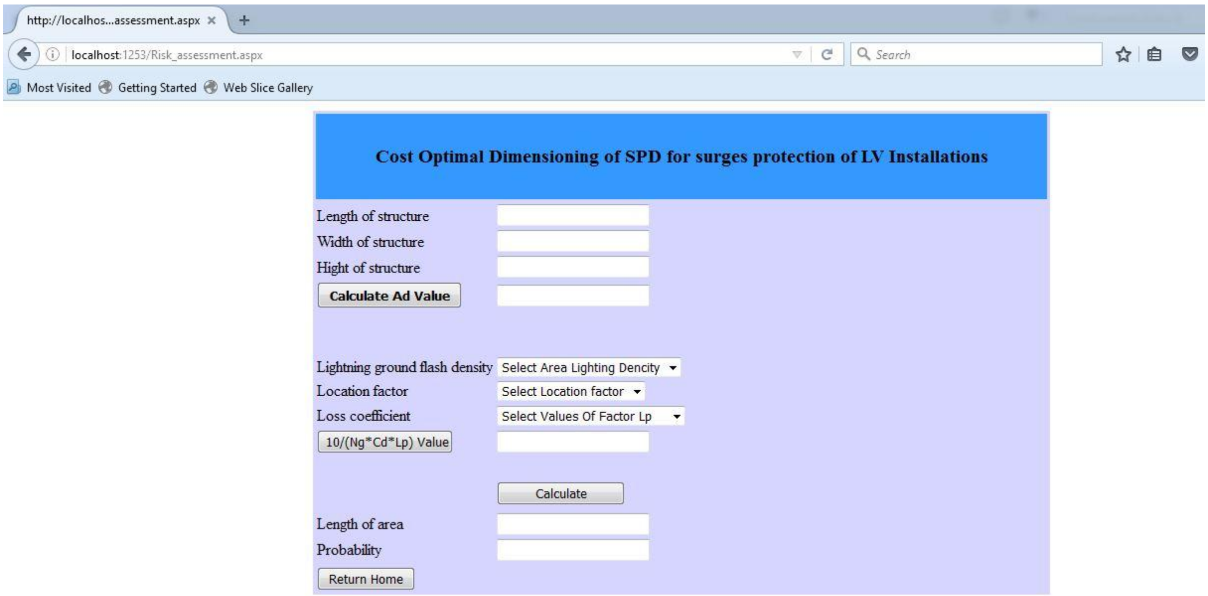
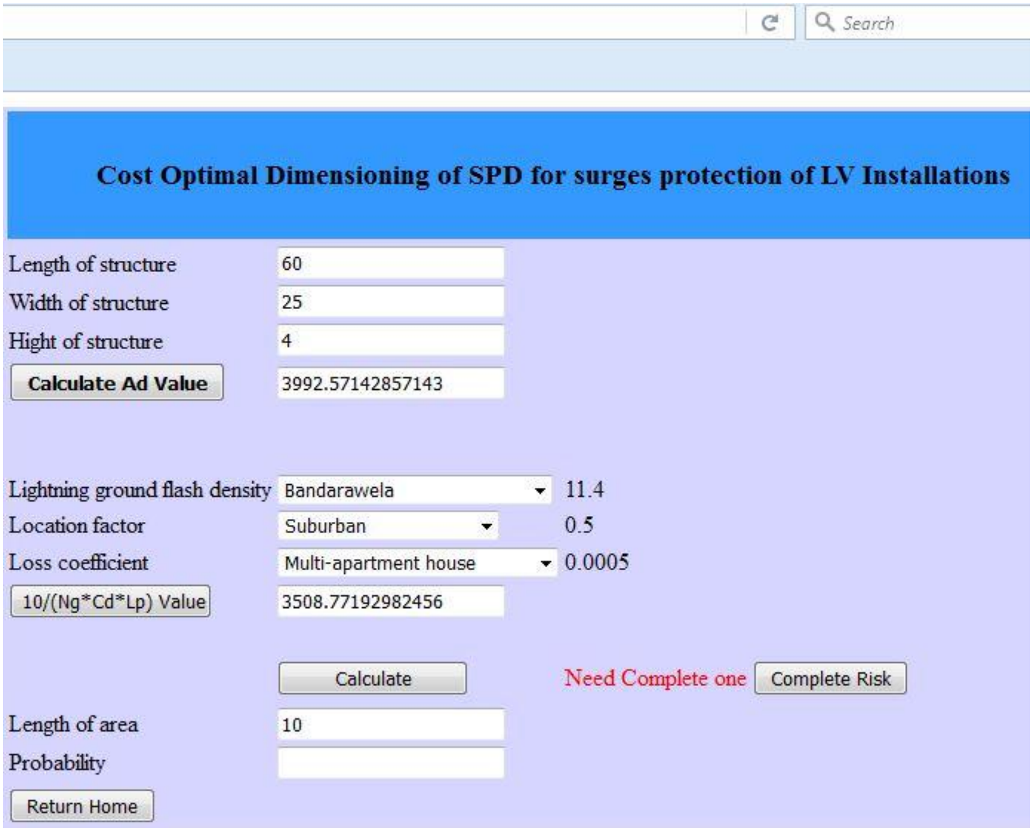
<u>Appendix: A</u>

<u>USER FRIENDLY SOFTWARE SOLUTION</u>



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Cost Optimal Dimensioning of SPD for surges protection of LV Installations
Length of structure
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Width of structure
25
Hight of structure
4
Calculate Ad Value
3992.57142857143
Lightning ground flash density
Bandarawela
11.4
Location factor
Suburban
0.5
Loss coefficient
Multi-apartment house
0.0005
10/(Ng*Cd*Lp) Value
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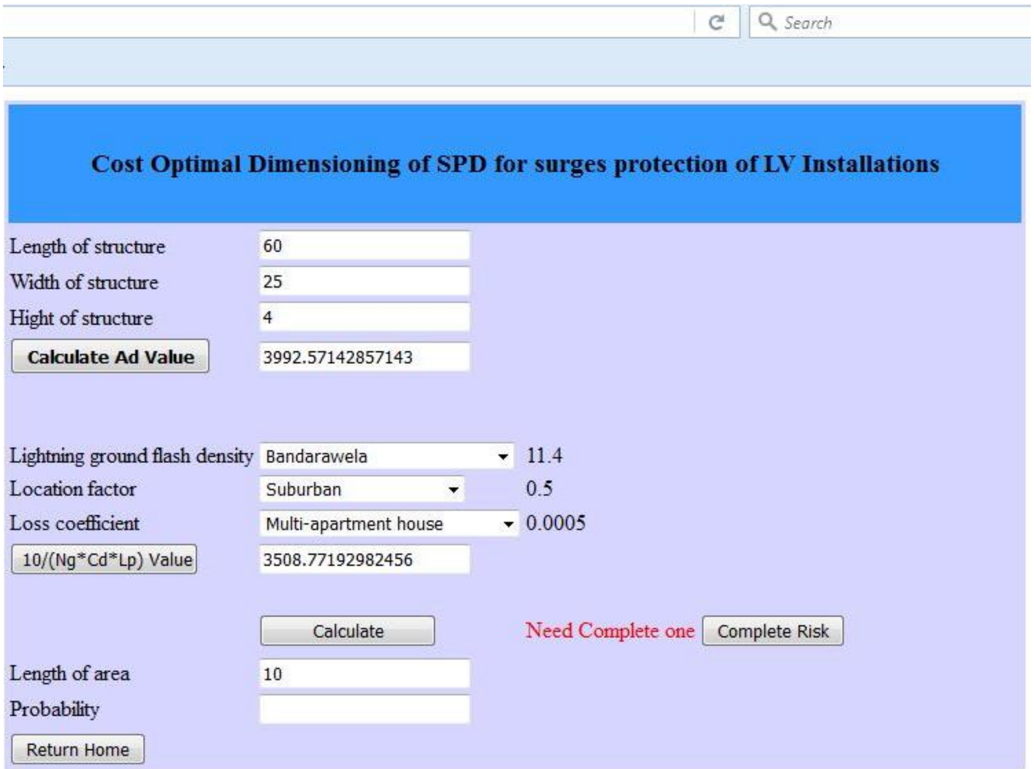
Calculate
Need Complete one
Complete Risk
Length of area
10
Probability
Return Home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Cost Optimal Dimensioning of SPD for surges protection of LV Installations
Length of structure
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Width of structure
25
Hight of structure
4
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Lightning ground flash density
Bandarawela
11.4
Location factor
Suburban
0.5
Loss coefficient
Multi-apartment house
0.0005
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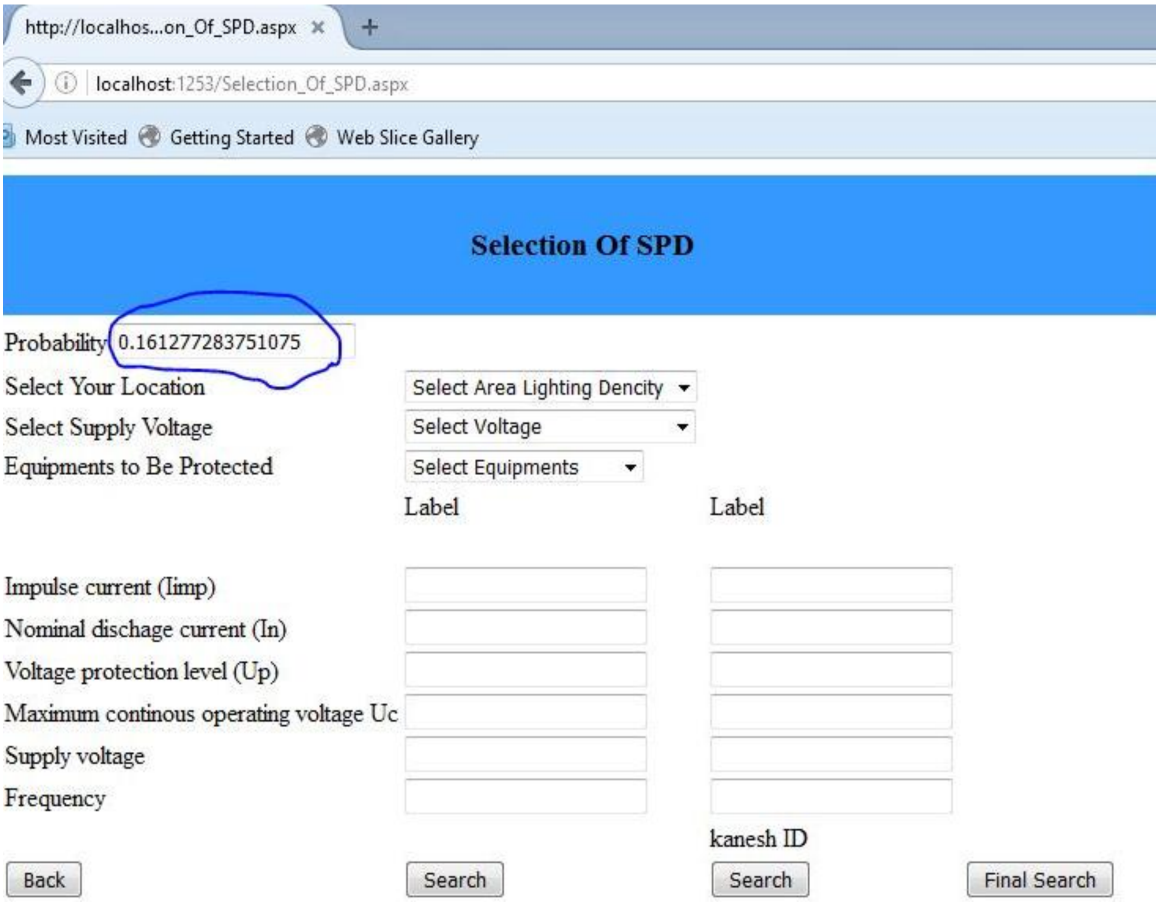
Calculate
Need Complete one
Complete Risk
Length of area
10
Probability
Return Home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Most Visited
Getting Started
Web Slice Gallery
Selection Of SPD
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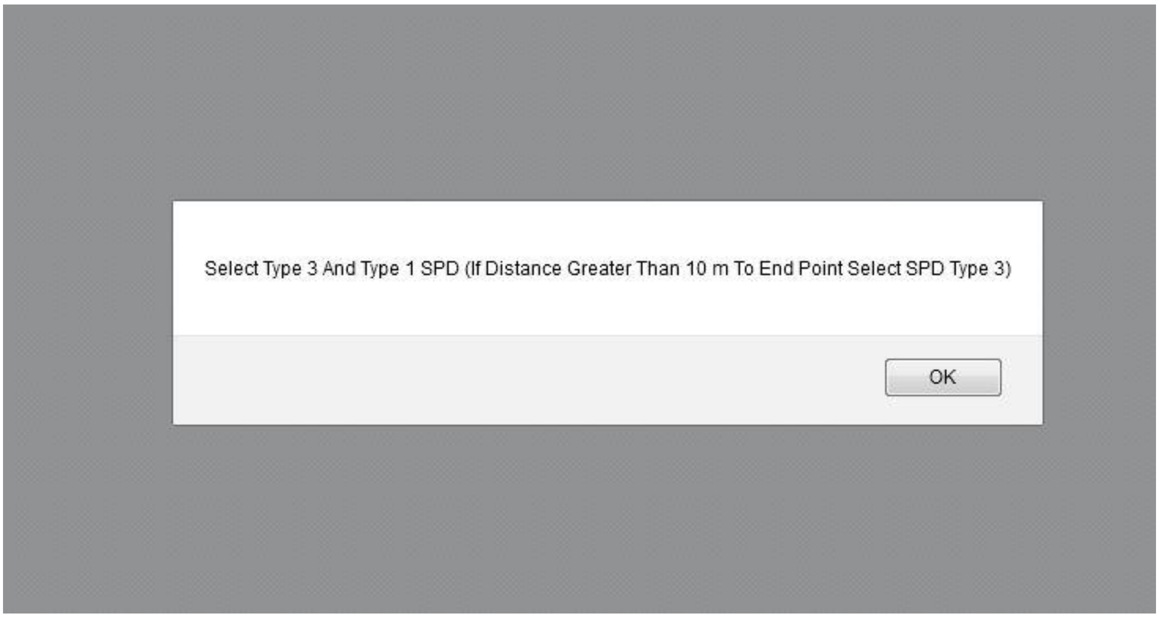
Select Your Location
Select Area Lighting Dencity
Select Supply Voltage
Select Voltage
Equipments to Be Protected
Select Equipments
Label
Label
Impulse current (Iimp)
Nominal dischage current (In)
Voltage protection level (Up)
Maximum continous operating voltage Uc
Supply voltage
Frequency
kanesh ID
Back
Search
Search
Final Search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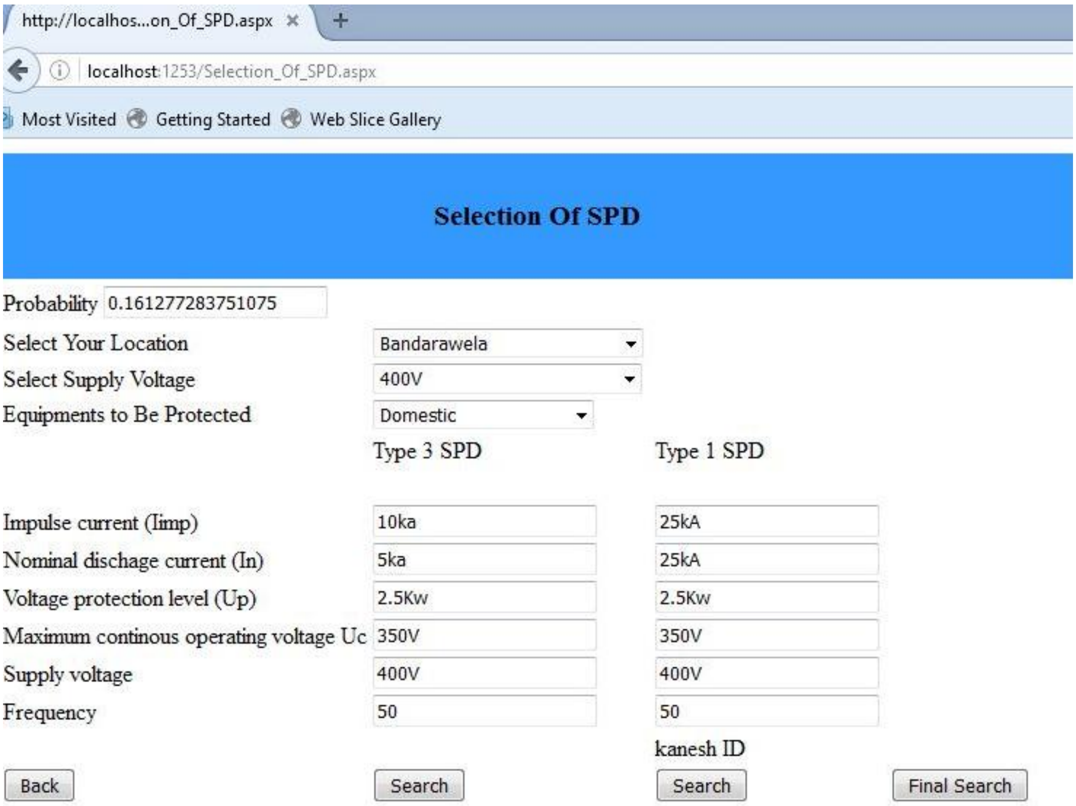
OK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Getting Started
Web Slice Gallery
Selection Of SPD
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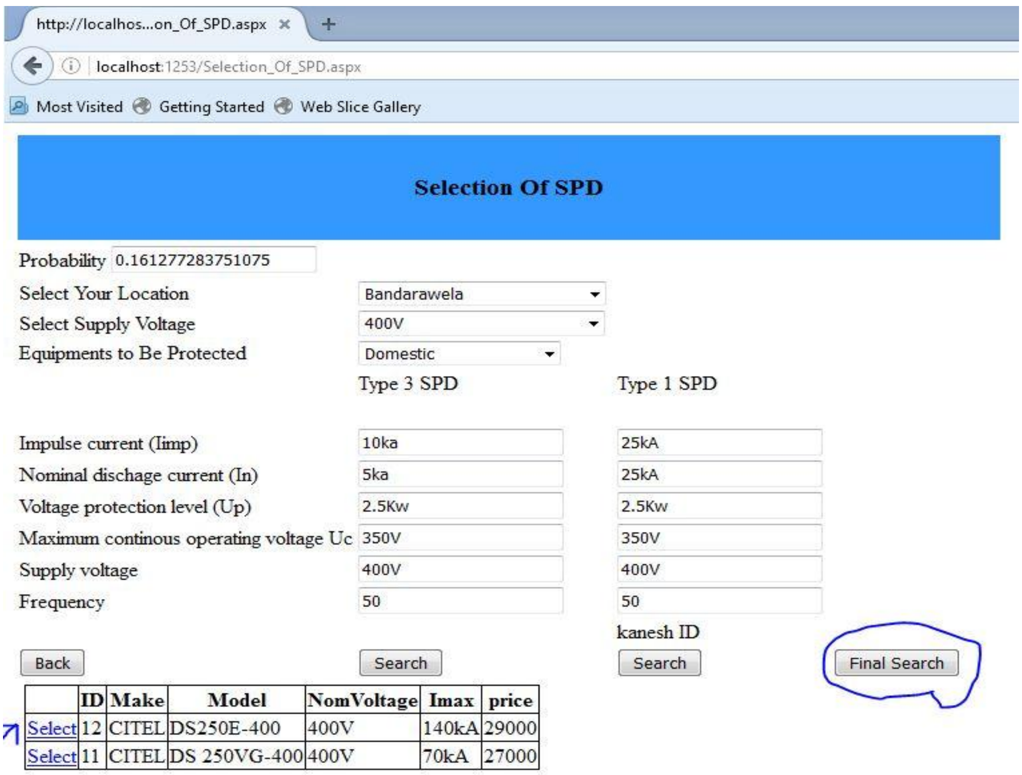
Select Your Location Bandarawela
Select Supply Voltage 400V
Equipments to Be Protected Domestic
Type 3 SPD
Type 1 SPD
Impulse current (Iimp) 10ka 25kA
Nominal dischage current (In) 5ka 25kA
Voltage protection level (Up) 2.5Kw 2.5Kw
Maximum continous operating voltage Uc 350V 350V
Supply voltage 400V 400V
Frequency 50 50
kanesh ID
Back
Search
Search
Final Search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Getting Started
Web Slice Gallery
Selection Of SPD
Probability 0.161277283751075
Select Your Location Bandarawela
Select Supply Voltage 400V
Equipments to Be Protected Domestic
Type 3 SPD
Type 1 SPD
Impulse current (Iimp) 10ka 25kA
Nominal dischage current (In) 5ka 25kA
Voltage protection level (Up) 2.5Kw 2.5Kw
Maximum continous operating voltage Uc 350V 350V
Supply voltage 400V 400V
Frequency 50 50
kanesh ID
Back
Search
Search
Final Search
ID Make Model NomVoltage Imax price
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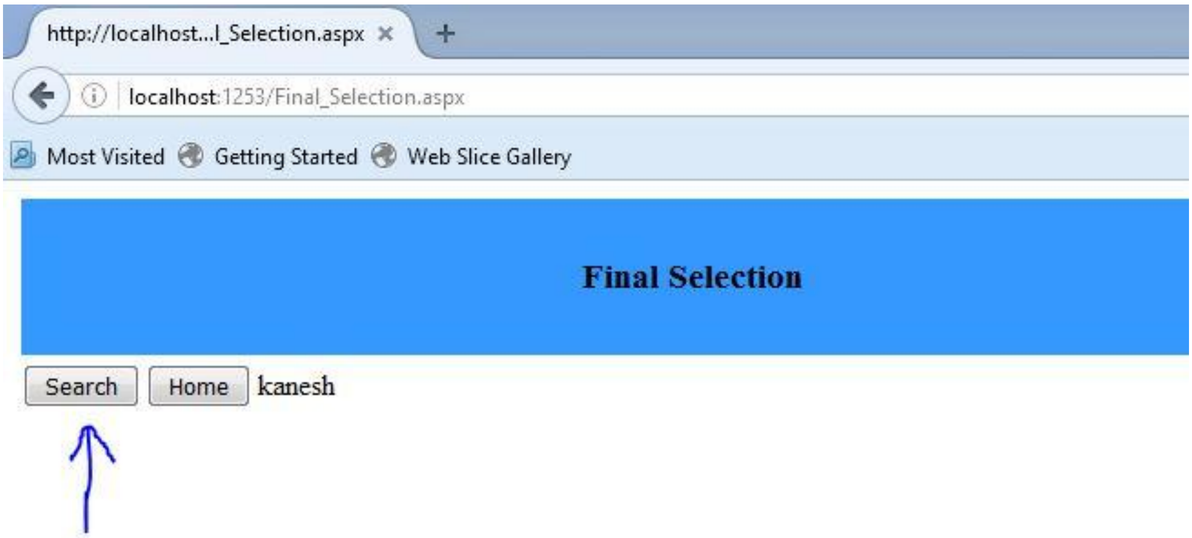
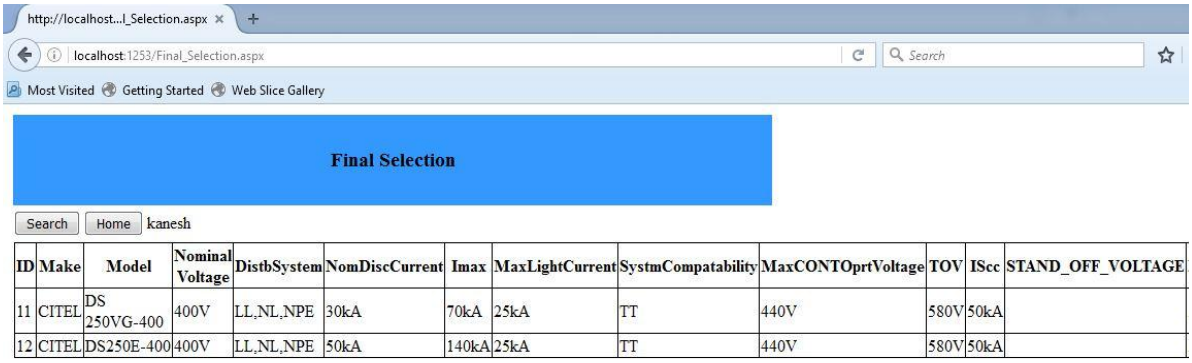
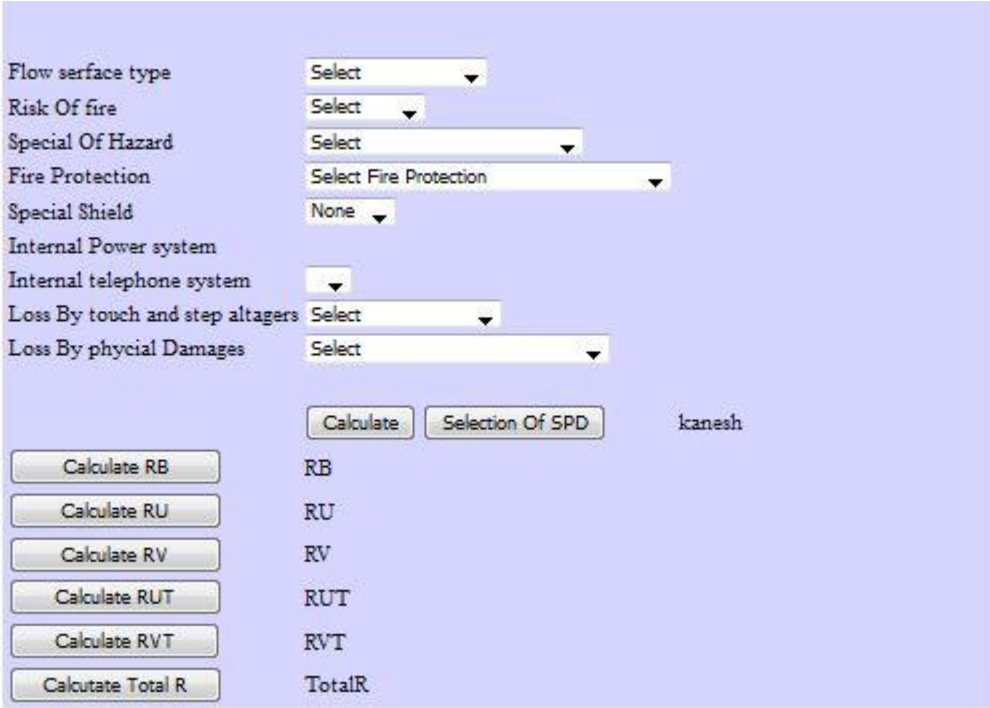




ID	Make	Model	Nominal Voltage	DistbSystem	NomDiscCurrent	Imax	MaxLightCurrent	SystmCompatability	MaxCONTOprtVoltage	TOV	IScc	STAND_OFF_VOLTAGE
11	CITEL	DS 250VG-400	400V	LL,NL,NPE	30kA	70kA	25kA	TT	440V	580V	50kA	
12	CITEL	DS250E-400	400V	LL,NL,NPE	50kA	140kA	25kA	TT	440V	580V	50kA	


Search
Complete Risk Assesment
Height
Width
Length
Number Of People
Shield At Structure
Shield Internal
Line Location Factor
Select Location Factor
LPS
Select LPS
LPS
Label
Soild Resistivity
Length Of Power Line
Cable Lacation
Select Cable Lacation
Height Of Power Line
Transformer
Select
Line Location Factor
Line Environment Factor
Select Location factor
Line Shielding
Select Shield
Internal Wiring Precotions
Withstand Of internal System
Select
Cordination Protection
Select
Length Of Telecom Line
Height Of Telecom Line
Line Location Factor
Select
Line environment Factor
Select Location factor
line Shilding
Select sheild
Internal Wiring Preportion
Widthstand of Internal Syatem
Select
Cordinator SPD Protction


Flow serface type
Select
Risk Of fire
Select
Special Of Hazard
Select
Fire Protection
Select Fire Protection
Special Shield
None
Internal Power system
Internal telephone system
Loss By touch and step altagers
Select
Loss By phycial Damages
Select
Calculate
Selection Of SPD
kanesh
Calculate RB
RB
Calculate RU
RU
Calculate RV
RV
Calculate RUT
RUT
Calculate RVT
RVT
Calcutate Total R
TotalR

APPENDIX B

DATA TABLE FOR RISK CALCULATION

Value of collection area depending on the evaluation method Table A.1

	Graphic method	Structure (Max)	Structure (Min)	Protrusion (Hp)
Structure				
Dimension m				
(L,W,H)				
m^2	Ad	Ad max	Ad min	Ad'

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

$A_d' = 9 \times \pi \times (H_p)^2$

Length	70
Width	30
Height	40
Ad	71357.14286
Protrusion	40
Ad'	45257.14286

Location factor Cd Table A.2

Location factor	Cd	Comments
Object surrounded by higher objects or tree	0.25	Higher objects
Object surrounded by objects or trees of the same height or smaller	0.5	Same/smaller
Isolated object: no other objects in the vicinity	1	Isolated
Isolated object on a hilltop or a knoll	2	On top hill

Collection area Ai and Al depending on the service characteristics Table A.3

	Aerial	Buried	Aerial
Al	(Lc - 3(Ha + Hb)) 6Hc	(Lc - 3(Ha + Hb)) $\sqrt{\rho}$	Buried
Ai	1000 Lc	25 Lc $\sqrt{\rho}$	

Lc	Length of the service section (m)		1000
Ha	Hight of the structure connected at end "a" (m)		2
Hb	Hight of the structure connected at end "b" (m)		2
Hc	Hight of the service conductors above groung (m)		6
ρ	Resistivity of soil	(mili ohm)	500
Al (Arial)	Collection area of flashes stricking the service		35568
Ai (Arial)	Collection area of flashes to ground near the service		1000000
Al(Buried)	Collection area of flashes stricking the service		494000
Ai (Buried)	Collection area of flashes to ground near the service		559016.9944

Transformer factor Ct Table A.4

Transformer		Ct	Comments
Service with two winding trans former		0.2	Transformer
Service only		1	None

Environment factor Ce Table .5

Environment				Ce
Urban with tall building *				0
Urban				0.1
Suburban				0.5
Rural				1
*	Height of the building higher than 20m			
**	Height of the building ranging between 10m to 20m			
***	Height of the building lower than 10m			

Typical mean values of Lt , Lf and Lo Table C.1

Type of structure	Lt
All type - (persons inside the building)	0.0001
All type - (persons outside the building)	0.01
Type of structure	Lf
Hospital, hotels, civil buildings	0.1
Industrial, commercial, school	0.05
Public entertaintment, churches, museum	0.02
Other	0.01
Type of structure	Lo
Risk of explosion	0.1
Hospitals	0.001

Values of reduction factors ra and ru as a function of the type of surface of soil or floor Table C.2

Type of surface	contact resistance	r_a and r_u
Agricultural, concrete	Lese than 1	0.01
Marble, ceramic	1 to 10	0.001
Graval, moquette, carpets	10 to 100	0.0001
Asphalt, linoleum, wood	Greater than 100	0.00001
Values measured between a $400cm^2$ electrode compressed with force of 500n		

Values of reduction factor rp as a function of provision taken to reuce the consequence of fire Table C.3

Provision	r_p
No provision	1
One of the following provision: extinguishers; fixed manualy operated	
extinguishing installation; manual alarm installation, hydrants, fire proof	0.5
compartments; protected escape routs	
One of the following provision; fixed aautomatically operated	0.2
extinguishing installations;automatic alarm installations	
Only if protected against overvoltage and other damages and if	
firemen can arrive in less than 10 min	

Values of reduction factor rf as function of risk of fire of structure Table C.4

Risk of fire	r_f		
Explosioin	1		
High	0.1		
Ordinary	0.01		
Low	0.001		
None	0		

KS1 = KS2 = 0.12 * w			
w = Mesh width	9		
KS1	1.08		
Soil resistivity	Assumed 500 Ohm		
KS4=1.5/Uw	Uw = rated implulse withstand voltageof system to be protected		
Uw	2.5		
KS4=	0.6		

Uw (kV)	
Sensitive	0.6
Sensitive	1
Electronic	1.5
Electrical	2.5
Machinery	4
Other	6

Values of probability PA that a flash to the structure will cause injury to living being Table B.1

Protection measures	PA	
No protection measures	1	None
Electrical insullation of expected down conductor	0.01	Down conductor
Effective soil equippotentialization	0.01	Soil equipote
Warning notice	0.1	Notice
	0	Fence

Values of probability PB depending on the protection measures to reduce physical damage Table B.2

Characteristic of structure	Class of LPS	PB
Structure not protected by LSP	None	1
Structure protected by LSP	IV	0.2
	III	0.1
	II	0.05
	I	0.02
Structure with an air terminationsystem confirming to LPS 1 and a continous metal or	Air terminal	0.01
reinforced concrete framework acting as a natural down conductor system		
Structure with a metal roof of an air termination system ,	Metal roof +Air terminal	0.001

Values of the probability PSPD as a function of LPL for which SPDs are designed Table B.3

LPL	P_{SPD}	Comments
No coordinated SPD protection	1	None
III - IV	0.03	III- IV
II	0.02	II
I	0.01	I

Probability PC that with a flash to a structure will cause failure of internal systems PC = PSPD

Value of probability PMS as a function of factor KMS Table B.4

K_{MS}	P_{MS}
0.4	1
0.15	0.9
0.07	0.5
0.035	0.1
0.021	0.01
0.016	0.005
0.015	0.003
0.014	0.001
0.013	0.0001

Value of factor KS3 depending on internal wiring Table B.5

Type of internal wiring	K_{S3}	Comments
Unshielded cable- no routing precaution in order to avoid loop	1	None
Unshielded cable- routing precaution in order to avoid large loop	0.2	Unshielded
Unshielded cable- routing precaution in order to avoid loop	0.02	Unshielded
Shielded cable with shield resistance 5<RS< = 20 ohm/Km	0.001	Shield
Shielded cable with shield resistance 1< RS < = 5 ohm/Km	0.0002	Shield
Shielded cable with shield resistance RS < = 1 ohm/Km	0.0001	Shield

Value of the probability PLD depending on the resistance RS of the cable screen and the impulse withstand voltage UW of the equipment Table B.6

U_W	S < R_S <= 20	1< R_S <= 5	R_S<= 1
kV	ohm/km	ohm/km	ohm/km
1.5	1	0.8	0.4
2.5	0.95	0.6	0.2
4	0.9	0.3	0.04
6	0.8	0.1	0.02
R_S (ohm/km) resistance of the cable shield			

PLD=1 for unshielded cable

Values of factor h increasing the relative amount of loss in presence of a special hazard Table C.5

Kind of special hazard	h
No special hazard	1
Low level of panic (e.g. a structure limited to two floors and the number of	2
persons not greater than 100	
Average level of panic (e.g. structures designed for cultural of sport events with a	5
number of participants between 100 to 1000 persons	
Difficulty of evacuation (e.g. structures with immobilized persons, hospitals)	5
High level of panic (e.g. structured designed for cultural or sport events with a	10
number of participants greater than 1000 person	
Hazard for surroundings or environment	20
Contamination of surroundings or environment	50

Typical mean values of Lf and Lo Table C.6

Type of service	L_f	L_o
Gas, water	0.1	0.01
TV, TLC, Power supply	0.01	0.001

Typical mean values of Lf , Lt and Lo Table C.7

Type of structure	L_t
All type - Inside buildings	0.0001
All type - Outside buildings	0.01
Type of structure	Lf
Hospital, Industrial, museum, agriculture	0.5
Hotel, school, office, church, public entertainment	0.2
economic buildings	
Others	0.1
Type of structure	Lo
Risk of explosion	0.1
Hospital, industrial, office, hotel, economic building	0.01
Museum, agriculture, school, church, public entertainment	0.001
Others	0.0001

APPENDIX C