Surge Protection Handbook

ISKRA ZAŠČITE

BE ON THE SAFE SIDE


UL 1449 Third Edition
R&D
Quality
SAFETEC
Surge Protection
EN 61643-11
Lightning
SPD
PV
Solar Plants
Type 2
Class I
Iscpv
Photovoltaic
UTE C 61-740-51
Technology
Data Center
Charging station
Medium Voltage
Innovative
Laboratory
No Leakage Current

CONTENT

1. Introduction

The following question is frequently asked: Why is surge protection required on installations? To answer, we need to understand the nature and different sources of overvoltages.

Nature of the overvoltage event

Figure 1a shows a common form of overvoltage, the temporary overvoltage or TOV. These events - which occur on the power distribution networks due to switch or regulation problems are characterised by a relatively long duration in time (many cycles of the AC waveform), but relatively low overvoltage - 1,2 to 1,4 p.u. (per unit of the nominal AC r.m.s. voltage).

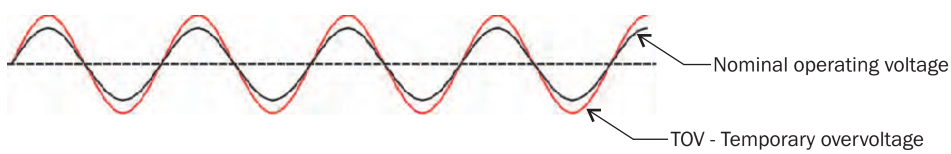
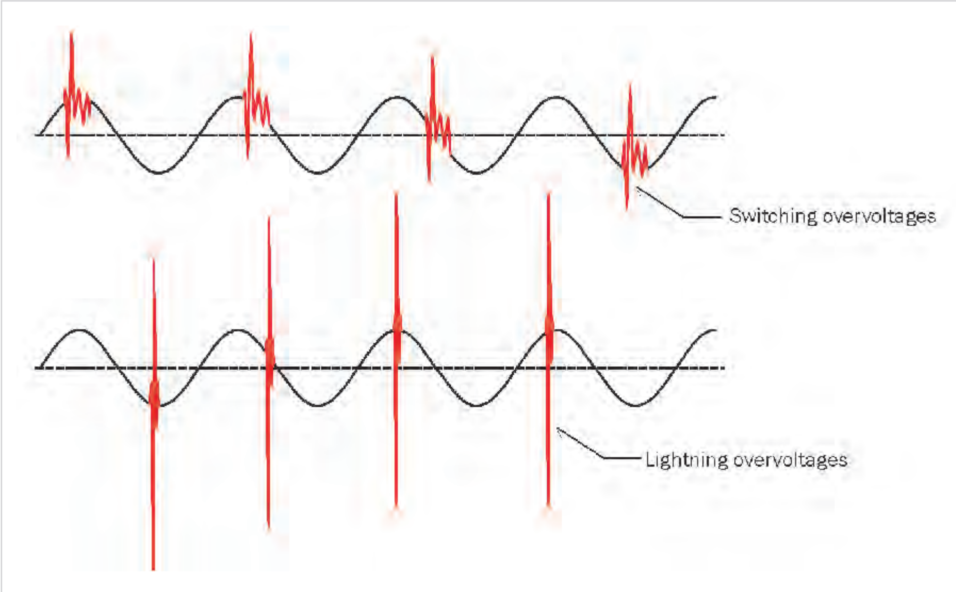


Figure 1a: Common form of overvoltage - TOV

Figures 1b and *1c* show overvoltage events characterised by a very short duration, typically a few microseconds (μs), but excessively high magnitude (kV). These events are commonly referred to as voltage surges or transients. Two of the more common sources of such events are the switching of inductive loads and lightning induced disturbances in magnetic fields with a subsequent induced overvoltage on electrical systems within the building.



Figures 1b, 1c: Various forms of overvoltage events

The role of a surge protective device (SPD) is to reduce the effects of these overvoltages on a structure's internal distribution systems to the levels which the interconnected electrical equipment can withstand.

While performing this important task or mitigating the damaging effects of overvoltages, the SPD must also ensure a safe behaviour in the event of its own failure. There are several causes for such failure, the most common being the following:

- ☐ exposure to a surge beyond its rating,
- ☐ a TOV event with durations beyond sustainability,
- ☐ natural aging and end-of-life.

Aging of an SPD results each time internal metal oxide varistor (MOV) is called upon, to divert surge current and safely protect the downstream equipment. A MOV is rated to withstand one surge of its maximum rated value (described I_{max} or I_{imp}) or many surges of a lower operating value (described I_n).

In order to ensure safe behaviour at the end of its life cycle, SPD must be designed to safely disconnect from the power system which it is protecting. This is the role of the internal disconnector which every quality designed SPD shall contain. These devices either disconnect or limit the current within the SPD during failure and help prevent hazardous conditions (e.g. fires) from occurring. The SPD should also incorporate some forms of disconnecting indication showing the user it is no longer providing protection to the downstream equipment. More information on disconnectors will be provided later on...

The need for protection

We now understand the nature of overvoltages; but why do we need protection? With the advent of microprocessor, the world has experienced a proliferation of sensitive electronic components into every walk of life from household appliances, to the sophisticated computing and communications systems which serve our competitiveness as nations. Our hunger for lifestyle such advances have brought shows no sign of abating. However, these very advances in circuit integration and miniaturization have come with a cost - lower immunity to interference and a greater susceptibility to damage from overvoltages.

The risks

To put this in perspective, the energy needed to cause failure to the typical integrated electronics is less than one millionth of what could safely be sustained by discrete technologies like the transistors and even more so in the past era of vacuum tube technology. Moreover, increasingly polluted power distribution networks where electrical disturbances, such as switching surges, lightning strikes, induced noise and poor supply regulation, are all too common and we have a recipe for equipment damage.

This damage may be all too obvious, as evident in catastrophic system failures, or may show in more subtle mechanisms, such as accelerated component degradation, reduced equipment life and lost or corruption of data. In extreme cases, such overvoltage surges and transients can cause facility fires and risk to human life.

The consequence of an unexpected power surge can be catastrophic to most businesses or facilities. To fully evaluate this cost over the designated life of the facility, it is necessary to consider not only repair and replacement costs of capital damage, but more importantly, the less tangible costs associated with operational downtime, corrupted or lost data and forgone opportunities, to name just a few. Facility managers are all too aware that as the electronic systems under their jurisdiction are becoming more complex and integrated into our everyday operations, our reliance upon their smooth and continuous operation increases and the implementation of cost-effective protection measures is turning into a critical component of their job.

Evolving industry needs

Additionally, the last ten years have seen demands being placed on power utilities like never before. Not only are customers increasingly demanding better quality in the power they receive - continuity of service, performance-based rates and penalties for inconsistent reliability - this is happening at a time of great transition within the industry as a whole. The global awareness of the limits of sustainable energy is fuelling a rapid expansion in renewable technologies concurrent with a move towards deregulation of the power industry in many western countries.

Inherent to many of these newer technologies, photovoltaic, wind, wave generation etc., is a reliance on the renewable resources provided by nature. As a result, such facilities are often particularly exposed to the forces of nature. For example, wind farms are typically situated in open or elevated locations, such as open plains, offshore and onshore, and thus rendering them particularly susceptible to lightning induced damage.

The process leading to the formation of the lightning discharge involves the development of strong electric field strengths (measured in kV/m) between cloud and ground as charge begins to separate between the upper and lower regions of the cumulonimbus cloud mass. Eventually, this field reaches a point where a stepped down-leader starts to propagate from the cloud towards the ground, causing the localized electric field in which the wind turbine is located to escalate extremely rapidly. At some point in this macro-time event, the electric field at points on the ground and surrounding structures reaches the point where localized air breakdown begins to occur. Any object which contributes to a magnification of this charge by means of its geometrical shape, such as the tips of the turbine blades, will enhance the launch of competing upward-streamers to intercept the rapidly approaching down-leader. As the two meet, many hundreds of coulombs of charge are transferred from the usually positively charged ground to the negatively charged cloud (negative lightning), resulting in the spectacular return-stroke and subsequent rapid collapse of the localized electric field.

The threat posed to exposed structures is not the only one caused due to direct lightning interceptions, but there is also the rapidly collapsing electric field (in the order of kV/ms) from nearby strikes. These changes in field serve to induce very large voltage surges within the wiring and electrical components of the turbine which can exceed the withstand level of these electrical systems and cause damage.

The cost of such damage can be extensive, particularly since wind farms are often located offshore or in remote and difficult to access terrain, such as hilltops. It is for this reason that lightning and surge protection has become a critical consideration in such installations. System integrators often work closely with manufacturers to ensure the correct selection of LPS and SPDs.

The growing interest in renewable energy generation has also lead to a proliferation of photovoltaic panels in applications ranging from small residential installations to large commercial “sun farms”. Such installations are located externally by their very nature and thus particularly subject to the effects of lightning induced damage. As a result, the use of SPDs on such panels is becoming increasingly important and new standards, such as EN50539, are being developed to address the testing and performance of SPDs intended for use in PV systems.

Making SPDs safer

By definition, an SPD contains at least one nonlinear component, which is intended to limit the surge voltage and divert the surge current. Inherent in the operation of such devices is the possibility of unexpected failure or rapid end-of-life. Under such conditions, it is important that the SPD can safely isolate itself from the prospective supply to which it is connected without presenting a potential fire hazard. It is for this reason that standards require that SPDs incorporate some form of “disconnector”, either internal or external, and manufacturers go to significant lengths to carefully design these components for safe and reliable operation if required. This often involves many complex and interrelated aspects, such as: thermal response times, optimization of i^2t with surge capacity and arc quenching.

SPD manufacturers are only just starting to address these, somewhat more onerous requirements. A number of innovative new disconnection designs have been developed and patented.

Most of these use various mechanical shutters to extend the arc length while disconnecting, thereby causing self-extinguishing even though a voltage zero-crossing point is not present.

Regulation governing installation of SPDs

With the increase in world globalization, manufacturers of surge protective devices (SPDs) are looking to enter new markets beyond their historical geographic regions of service. Many have found this decision to be more complicated than anticipated, mainly due to the myriad of local norms and standards, regulating and governing the installation of SPDs. Additionally, the variety of local market preferences such as -

required modes of protection, form factor of the enclosure, types of status indication - and the picture rapidly becomes complex.

Within the USA, it is mandatory that the National Electrical Code be followed (with a few exceptions). This in turn requires that the SPD be “listed” for its application, thereby making compliance with UL 1449 mandatory for an SPD manufacturer wishing to sell its products in the US. Contrary to popular understanding, there are many authorities which are authorized for testing in accordance with UL1449 standard. Obviously, Underwriters Laboratories Inc. is one of them, but there are also others, such as Canadian Standards Authority (CSA mark) and Intertek Services (ETI mark), etc. These are broadly called NRTL (nationally recognized test laboratories) in the USA.

The situation with IEC is different. An SPD manufacturer may still sell its product, even if it does not comply with the relevant IEC standard, and even if the country of manufacturer is an international signatory to the IEC. However, this is not the case at CENELEC levels where European norms, such as EN 61643-11, are called up by the mandatory LV Directives. This said, aspects of this “mandatory” situation are still not fully enacted and it is to remain so until a specific law is imposed to regulate it.

Other developing countries, such as China and India are actively developing their own national standards and regulations governing the installation of SPDs. Most of these draw up their requirements and carry out tests in accordance with existing IEC standards.

The 35 mm DIN standards for enclosures have found wide acceptance in panel boards for such devices as miniature circuit breakers (MCBs) and SPDs, making them ideal for power. Not only are most IEC based SPDs available in this industry standard package for easy mounting, but inherent to this packaging is the comforting fact that such an SPD must incorporate safe disconnection. In other words, it is not relying on its enclosure alone for safety.

International standards such as the IEC 62305 series on Lightning Protection and the IEC 61643 series on Surge Protection, categorize SPDs into various test classes associated with the electrical exposure of the location in which they are intended to be installed.

For example, an SPD tested to test Class I is intended to be installed where it is likely to carry direct or partial lightning current, while an SPD tested to test Class II is intended to be installed where overvoltage protection of electronic systems from the effects of induced lightning currents is required. SPDs tested to Class III are generally installed at the end-use equipment such as power outlets, or for data and signal line protection.

Conclusions

The electrical environment in which today's sensitive electronic systems are required to operate is becoming increasingly polluted by electrical disturbances, such as voltage surges and transients. At the same time, the susceptibility of these systems to failure has increased as the use of micro-controlled based electronics has proliferated into even the simplest consumer appliances.

This situation is driving the need for effective surge protection at competitive cost. Iskra Zaščite is the leading designer and OEM manufacturer of surge protective devices. It is at the forefront of many new and patented technological advances and actively participates in various international standards setting committees dealing with surge protection, including IEC, Cenelec, UL and IEEE.

2. Overvoltage sources

2.1 Atmospheric discharge - Lightning

During storms, powerful electrical currents flow between clouds and ground. The consequence of these discharge currents is the induction of overvoltages and surges in metallic elements of buildings, power supply and communication lines due to the electromagnetic coupling. Overvoltage can also be generated by a direct strike which is more dangerous than indirect strike. Direct strike may result in explosion, fire, or total destruction of the struck object. In order to minimize damage risk due to lightning surges, it is important to describe the transient characteristics of such pulses, that could cause a partial or total collapse of distribution network or electrical system (power, communication, etc.).

The first parameter of the lightning strike is maximum magnitude of the current. This value cannot be exactly predicted. It appears in the range between several tens of kA and 200 kA. The probability of amplitude discharge intensity is statistically described in *Figure 2*.

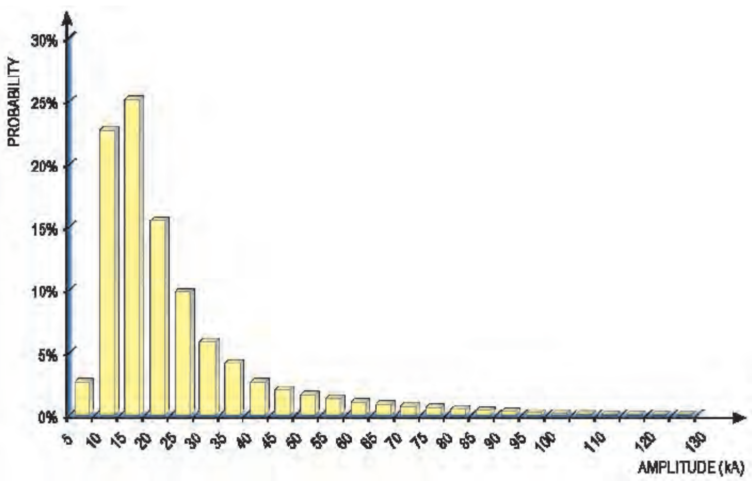
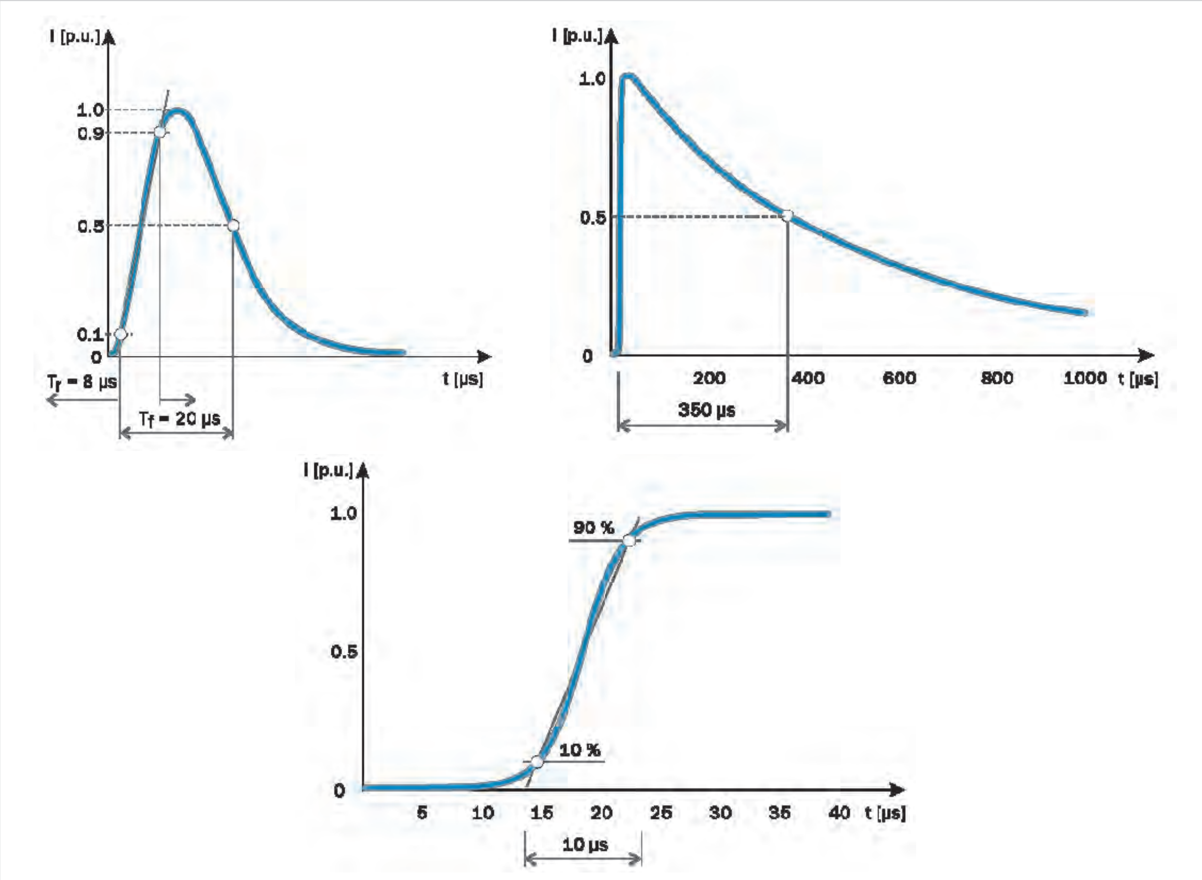


Figure 2: Statistical distribution of the amplitude discharge density

The highest probability of current magnitude is in the range between 10 and 30 kA. Waveforms used for testing surge protection devices have a long tradition of using unidirectional waves, particularly a 1.2/50 μs voltage impulse and an 8/20 μs or 10/350 μs current impulse *(Figures 3a, 3b, 3c)*.



Figures 3a, 3b, 3c: Standard current lightning surge waveforms

In *Figure 3*, the value 8/20 μs or 10/350 μs refers to the 8 or 10 μs rise time of the surge, and the 20 or 350 μs fall time. The latter value defines the time for the voltage to reach half of its peak value.

This rapid raise of current at the beginning of pulse causes strong magnetic field, creating dangerous levels of induced voltages. Therefore, an important factor is a rate of current rise. This parameter is usually expressed in kA/μs. This data is required for voltage determination on the protected device that includes inductance. The distance between protective device and object or device should be as short as possible.

If the aim of design is to provide protection for a direct and indirect stroke to the building, the correct selection of surge protection devices also requires knowledge of lightning charge:

$$Q = \int i dt \quad [As] \tag{2-1}$$

The protective device must be chosen with sufficient current-handling capability to sustain the surges resulting from the lightning.

Lightning down-conductors and surge protection devices dissipate switching surges by absorbing thermal energy. Next important parameter is therefore specific energy:

$$\frac{W}{R} = \int i^2 dt \quad \left[\frac{J}{\Omega} = A^2 s\right] \tag{2-2}$$

The amount of dissipated energy is related to the switching surge waveform, its magnitude, the system impedance, circuit topology, the characteristics of surge protection device, and the number of strikes. The selected equipment should have an energy capability greater than the energy related to the expected switching surges on the system.

2.1.1 Influence of lightning strikes on power lines

Overhead power lines are distributed on wide geographical area and are thus very likely to be affected by lightning. Different atmospheric discharges in the vicinity of lines cause the induction of overvoltage along the power line. In that case, transmission line itself acts as a widespread antenna. The power line network is primarily designed for transmission of electrical energy but it is also the media for transmission of overvoltage through the network. The power lines therefore suffer different consequences caused by atmospheric discharges. A lightning strike can generate transient overvoltage on an overhead line by:

- ☐ direct strike to a phase conductor (shielding failure),
- ☐ direct strike to the overhead shield wire or tower, which then flashes over to the phase conductor,
- ☐ strike a several hundred meters away from the power line (indirect strike), which also induces overvoltage on the power line.

The overvoltage impulses caused by direct or indirect strikes travel from the point of impact through the whole network. These impulses can be transferred also through transformers from higher to lower levels of a network where they present another source of overvoltage disturbances.

2.1.2 Electromagnetic couplings

Galvanic connection causes the most dangerous overvoltage and arises at juncture of two wires with different operating voltages or electrical arc appearance between such wires.

The example is a stick between communication and power cables *(Figure 4a)*. Overvoltage from one network to another can also be transferred if there exists capacitive coupling between two networks *(Figure 4b)*, or in the case of parasitic capacitance in the transformer, which will transfer overvoltage from high voltage side to low voltage side in the case of unbalance on the high voltage side. The most common coupling between two networks is inductive coupling. It is well known according to the Faraday's law that magnetic field varying in time will induce voltage in the loop inside that field. If magnetic field corresponds to the transient current with the high rate of change, transient overvoltage will be induced in such loop *(Figure 4c)*.

a) Galvanic *b) Capacitive* *c) Inductive*

Figure 4: Different couplings between two electrical systems

The lightning is always followed by electromagnetic field. When lightning develops, space charges in the thunder cloud and further in the stepped leader, causing electrical field in the surroundings. Electrical field brings to charge separation in metal constructions. Due to impulsive character of the lightning current, rate of change of the magnetic field is fast in the conductive loops and high voltages may be induced. The example of such induction is lightning hitting a down conductor installation of the house *(Figure 5)*.

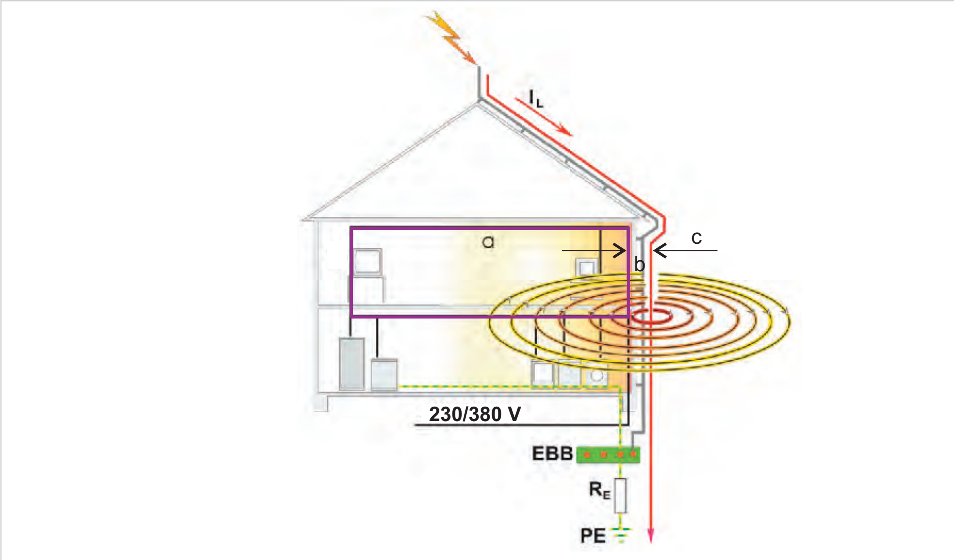


Figure 5: Induced voltage in the surroundings of the lightning down conductor

Should lightning strike into the air terminal, lightning current I_L flows through down conductor to the earth. Induced voltage in the installation loops causes different disturbances, i.e. faults that can even lead to a fire. If the loop is at the horizontal distance c from the down conductor, and loop dimensions are a and b as in *Figure 5*, the induced voltage V equals:

$$V = -\frac{\mu_0}{2\pi} b \frac{di}{dt} \ln \frac{a+c}{c} = M \frac{di}{dt}$$

For instance, for the square loop 10x10 m, 1 m away from the conductor, mutual inductance M equals 4.8 H and, under assumption di/dt = 40 kA/s, induced voltage amounts to 192 kV.

2.1.3 Switching surges

Switching overvoltage is transient disturbance caused by switching operation, fault condition or fault clearance in a power supply system. Any sudden change in the system can initiate damped oscillations with high frequencies that clear only when the system is stabilized again to its new steady state. Switching actions in a power supply may be caused intentionally (load or capacitor switching) or can happen unintentionally (power system faults).

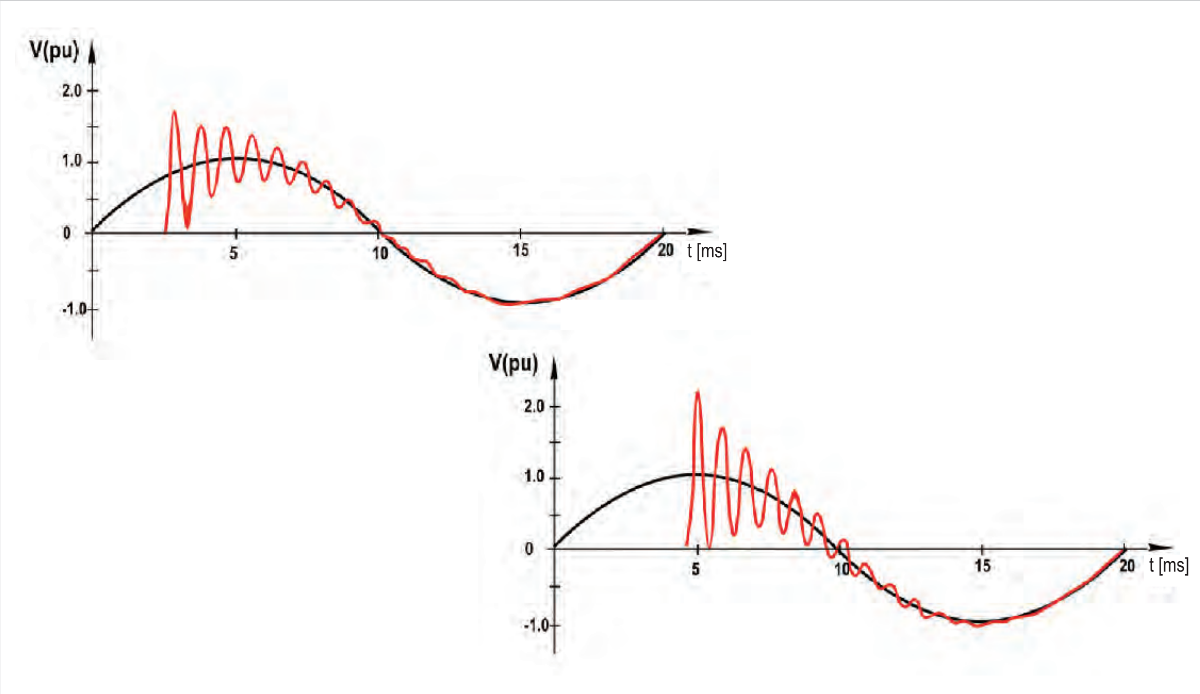


Figure 6: Switching overvoltage

When switching an RCL load on or off by a circuit breaker, peak of switching overvoltage does usually not overreach a double value of the rated system voltage *(Figure 6)*. The maximum voltage is mainly determined by closing instant of the breaker in relation to the voltage phase of supply system. The highest high-frequency overvoltage occurs when the breaker is closed at the maximum value of supply voltage.

Higher overvoltage can appear due to switching inductive loads, such as inductors, transformers, motors as well as capacitive loads. Interruption of short-circuit currents also causes high overvoltage. As with circuit breaker caused overvoltage, here also the peak is correlated with the power-frequency voltage value in the moment of switching operation.

The shape of the overvoltage wave is a ringing wave. Rate of voltage rise is usually in the order of a few kV/μs, while the transient can then last from μs to ms.

The time duration of switching surges is much longer than lightning surge duration, but voltage peak is significantly weaker. The peak is determined by response of the low-voltage installation, inductance and capacitance of a circuit, type of switching (on/off, circuit breaker or fuse) and load types.

In the case of resistive load, switching currents are in the order of rated equipment value. When inductive/capacitive load is switched on/off, high frequency oscillations appear. Oscillating voltage is superimposed with rated voltage of the system and total voltage represents the stress to the equipment connected to the power supply system. Overvoltage caused by switching on load side is higher than overvoltage on the line side.

The presence of capacitor banks for the power factor correction is also a cause of capacitor-switching surges. These capacitor banks are typically installed on a medium-voltage side. Capacitor-switching overvoltage is frequently below double value of the system normal voltage *(Figure 7)*.

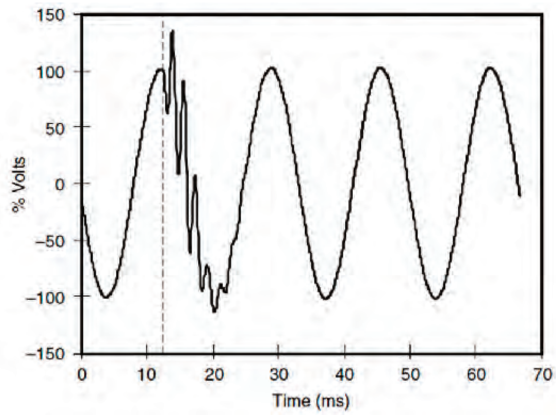


Figure 7: Overvoltage due to capacitor switching

Occurrence of short-circuits or earth faults on the medium-voltage side may cause that phase-to-earth voltage of fault-free phase increases to the phase-to-phase voltage. Such overvoltage is further transferred from the medium voltage to low-voltage side of power supply transformer.

Fuse operation in power supply network initiates overvoltage, which takes somewhat triangular wave shape. This overvoltage is less frequent than the one caused by switching operations.

2.2 Temporary overvoltages

Temporary overvoltages (TOVs) are defined as AC overvoltages with significant duration and amplitude appearing in a system following a fault condition. A wide range of phenomena, either resulting from normal system operation or from accidental conditions, can produce overvoltages, which must be distinguished from other surge overvoltages due to their longer duration time.

These overvoltages occur at the power system frequency. Short-duration overvoltages (lasting a few seconds at most) are considered “swells” and should not be confused with the generic term “temporary overvoltage”. Swells end when the power system returns to its normal state without intervention. Extended overvoltages generally require operation of some existing over-current protective equipment to clear the circuit. On the other hand, surge protective devices (SPDs) at the present state of technology - as applied for protection against lightning and switching surges do not have the energy-handling capability required for limiting extended temporary overvoltages, but might tolerate short swells of limited magnitude. Therefore, when selecting the maximum operating voltage for SPDs at a particular installation, the expected magnitude of duration, and probability occurrence of temporary overvoltages at the actual site have to be taken into consideration.

2.3 Surges caused by different electrostatic discharges

The electrical charges that surround us are commonly separated by external influence, such as motion of different materials. Such separations lead to charged objects that deform electrostatic field in the vicinity. When two charged objects are close enough, the strength of electrostatic field reaches certain value and electrostatic discharge occurs.

Measurements of electrostatic voltage and current discharge waveforms showed impulsive character with the rise time of a few nanoseconds and duration of about 0.1 μs. The peak current reaches 100 A, while overvoltage peak is up to 40 kV *(Figure 8)*.

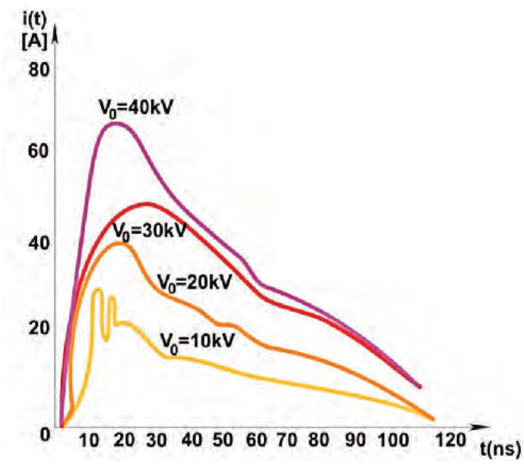


Figure 8: Electrostatic discharge pulse current

The electrostatic discharge is commonly caused by people walking across an insulating carpet or when synthetic cloths rub against the skin. In such cases, electrostatic discharge voltage between a human and earth can reach up to 35 kV in the case of running across the carpet or up to 18 kV when sitting on an insulated chair.

Electrostatic discharges cause insulation breakdowns of many electronic devices during handling and shipping.

3. Earthing and network topology

International standard IEC 60364 distinguishes three families of earthing arrangements, using the two-letter codes TN, TT and IT.

The first letter indicates the connection between earth and power supply equipment (generator or transformer)

T : direct connection of a point with earth

I : no point is connected with earth (isolation), except perhaps via a high impedance

The second letter indicates the connection between earth and the electrical device being supplied

T : direct connection of a point with earth

N : direct connection to neutral at the origin of installation, which is connected to the earth

3.1 TN system

In TN earthing system, one of the points in the generator or transformer, is connected with earth, usually the star point in a three-phase system. The body of the electrical device is connected via this earth connection to the transformer.

The conductor, that connects the exposed metallic parts of the consumer, is called protective earth (PE). The conductor that connects to the star point in a three-phase system, or carries the return current in a single-phase system, is called neutral (N). It is to be distinguished among three variants of TN system:

TN-C: a combined PEN conductor fulfils the function of both, a PE and an N conductor

TN-S: PE and N are separate conductors that are connected together only near the power source

TN-C-S: part of the system uses a combined PEN conductor; at a certain point it is split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separates the service head.

3.1.1 TN-C system

In TN-C system, combined PE and N conductors (PEN) are used from the transformer neutral point to the consuming device. An example of a typical TN-C system is presented in *Figure 9*.

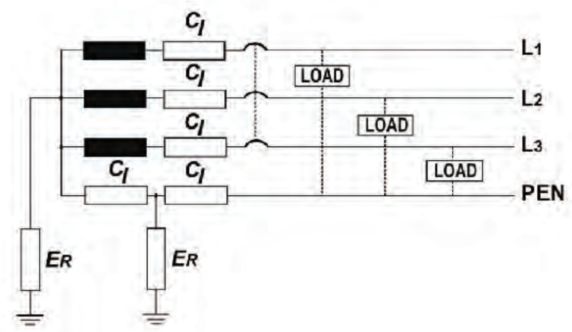


Figure 9: TN-C system (ER earthing impedance, CI conductor impedance)

The neutral current and the earth-fault current flows via the same return path to the earthed neutral point of the power transformer. Usage of a single conductor for both currents reduces the cost of an additional conductor needed for separate N and PE connections.

3.1.2 TN-S system

The separate protective earth (PE) and neutral (N) conductors from transformer to consuming device are used in TN-S system. The PE conductor is connected to the neutral conductor at the neutral point of the power transformer *(Figure 10)*. The neutral current and the earth-fault current use separate conductive paths.

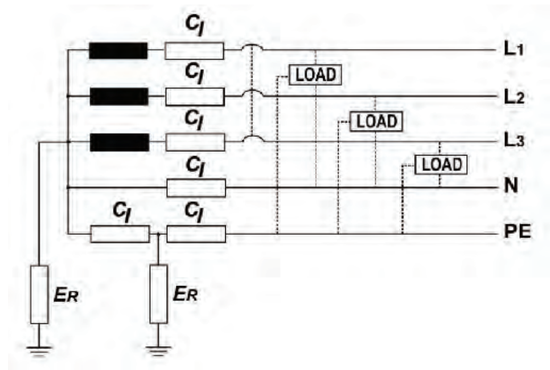


Figure 10: TN-S system

Exposed conductive parts are connected to the PE conductor for the conduction of earth-fault current. Separated PE and N conductors allow successful application of residual-current circuit breakers.

3.1.3 TN-C-S system

This system represents combination of the above defined TN-C and TN-S systems. TN-C-S system has a separate N and separate PE conductor, as well as their combination as PEN conductor *(Figure 11)*. PEN conductor is used for the connection between power supply transformer and service-entrance point of the building. After this point, separate N and PE conductors are utilized. As in the TN-S system, separate N and PE conductors inside the building allow usage of successful application of residual-current circuit breakers.

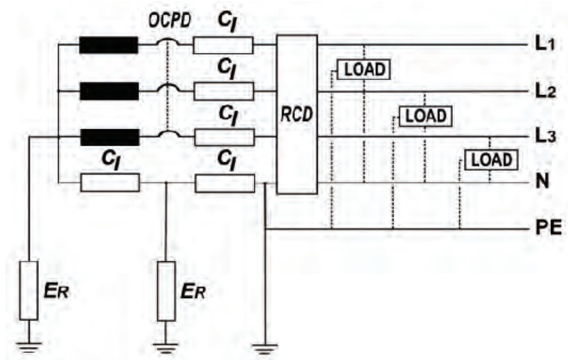


Figure 11: TN-C-S system (with overcurrent protective device - OPCD)

TN-C-S earthing system is well accepted in Europe and in most residential installations in the US and Canada.

3.2 TT system

In TT earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independently of any connection at the generator.

The greatest advantage of the TT earthing system is that it is clear of high and low frequency noises coming through neutral wire from various electrical appliances connected to it. This is why, TT has always been prefered for special applications like telecommunication sites benefiting from interference free earthing. Additionally, TT does not pose the risk of broken neutral.

In locations where power is distributed overhead and TT is used, earthing conductor installation is not at risk should any overhead conductor be fractured, e.g., due to a fallen tree or branch.

In pre-RCD era, TT earthing system was unattractive for general use because of its slim capability of accepting high currents in short circuit (in comparison with TN systems). But as residual current devices mitigate this disadvantage, the use of TT earthing systems is becoming more popular in premises where all AC power circuits are RCD protected.

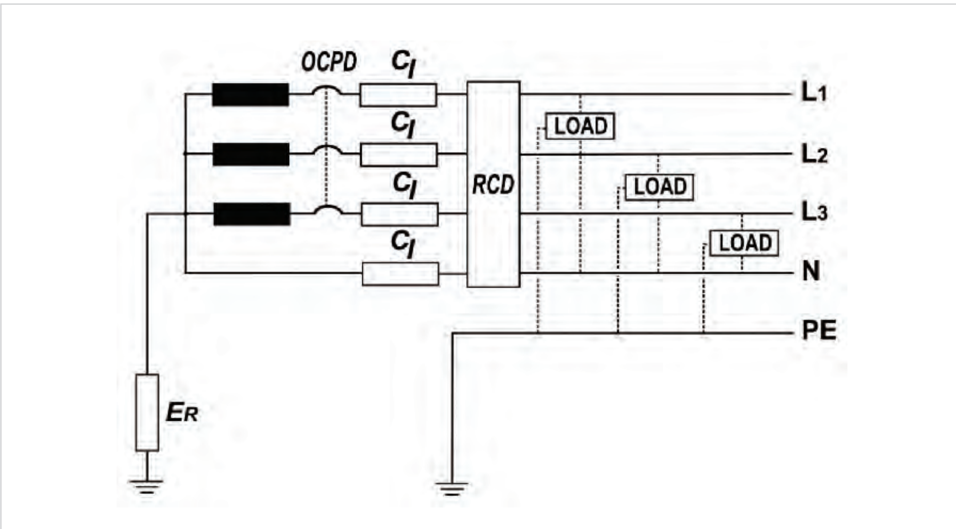


Figure 12: TT system

3.3 IT system

In an IT network, the distribution system has no connection to earth at all or it only has high impedance connection.

In such systems, an insulation monitoring device is used for monitoring the impedance.

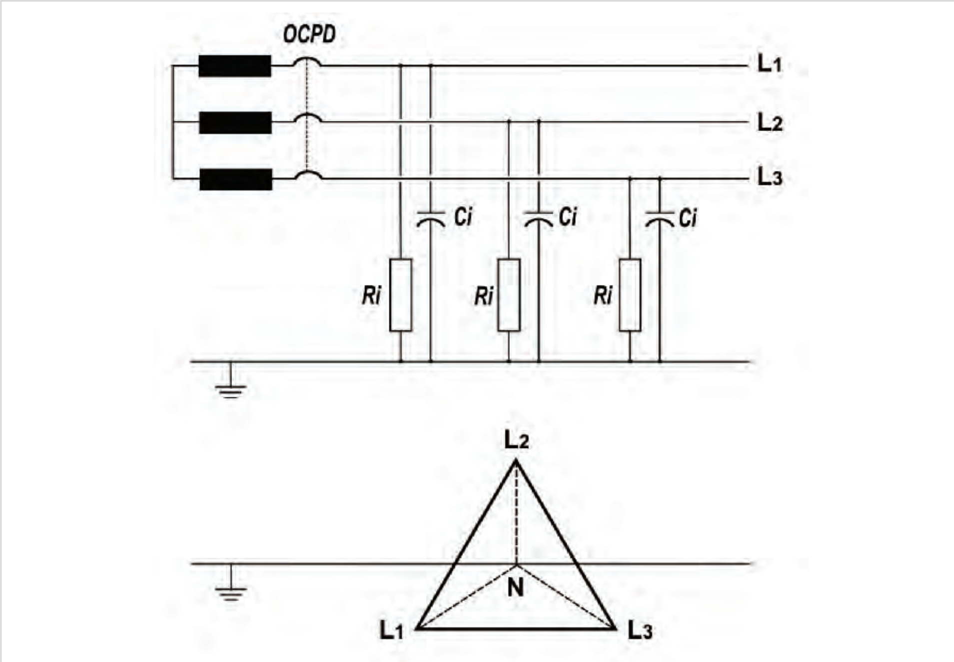


Figure 13: IT system

3.4 TOV in different neutral earthing systems

Magnitude of temporary overvoltage in the power supply system strongly depends on the neutral earthing and the type and location of a fault causing TOV. TOV magnitudes for different types of neutral earthing and scenarios are given in *Table 1*.

Occurrence of U_{TOV}	*System*	*Maximum values for U_{TOV}*
Between phase and earth *(faults in the medium-voltage network)*	TT, IT	12000 + *Uref* (duration 200ms)
Between neutral and earth *(faults in the medium-voltage network)*	TT, IT	1200 V (duration 200ms)
Between phase and neutral *(loss of the neutral conductor in LV network)*	TT, TN	1.73 x *Uref*
Between phase and earth *(accidental earthing of the phase conductor in LV system)*	IT	1.73 x *Uref*
Between phase and neutral *(short-circuit between line conductor and neutral conductor)*	TT, IT and TN	1.45 x *Uref* for duration up to 5 s

Table 1: Temporary overvoltage for different types of neutral earthing, fault type and fault location [adopted from IEC 61643-11 Ed 1]

3.5 Expected temporary overvoltage (Utov)

Some examples of TOV:

☐ fault (short circuit) distributed from high voltage side

☐ earth short circuits (fall of phase conductor on earth)

☐ short circuits (one pole, two poles)

☐ loss of neutral conductor

3.6 Risk assessment

SPD (surge protective device) should be subjected to different types of overvoltage Utov (temporary overvoltage).

3.6.1 TN network

For SPD connected between L and PE, the general rule for dealing with maximal temporary overvoltage is Utov = 335V. SPD itself can be exposed to this phenomenon for a longer period.

A solution is to increase nominal voltage of SPD to 335 V (in this case SPD is not subjected to Utov), or disconnect it from live conductor via thermal disconnector, but in such case SPD is out of order.

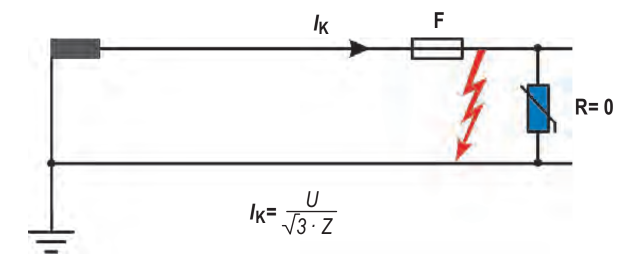


Figure 14: Fuse interruption

Proper disconnection of overcurrent protection F (fuse) is achieved due to low conductor impedance, meaning that short circuit current Ik is able to interrupt fuse.

3.6.2 TT network

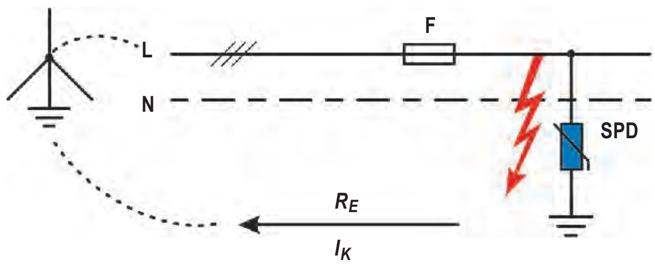


Figure 15: No overcurrent protection

When SPD is connected between L and PE conductors, proper overcurrent protection reaction (fuse cannot separate SPD from live conductor) is not possible. Besides, there is also a problem of touch voltage, which is higher than allowed 50 V (in this case 230V).

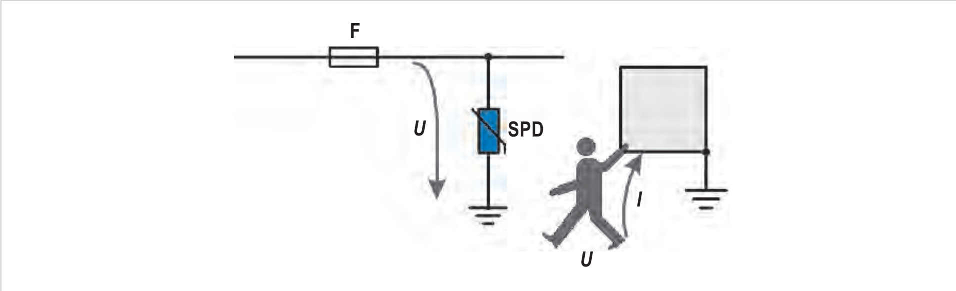


Figure 16: Touch voltage

A solution is to installing RCD (residual current device) upstream SPD.

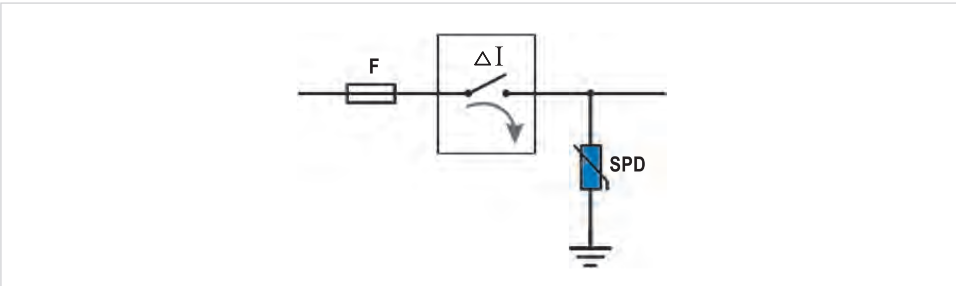


Figure 17: RCD installation

However, this is not a reasonable solution because RCD has relatively low dielectric strength and can suffer mechanical damage in case of atmospheric discharges. These damages can have serious influence on RCD operation and are not visible, making operator unable to know if it is still functioning.

In TT system, SPD should be connected in two ways: 3+1 or 4+0 connection.

Connection 3+1 can be used before or after RCD.

Connection 4+0 is allowed only in the case when SPD is connected downstream of RCD.

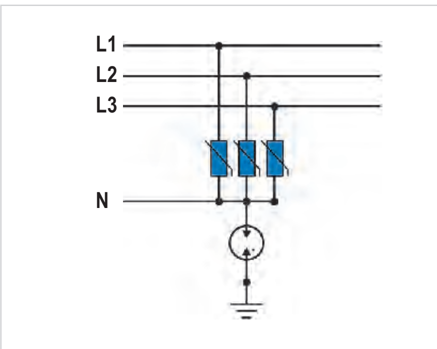


Figure 18: TT system - connection 3+1

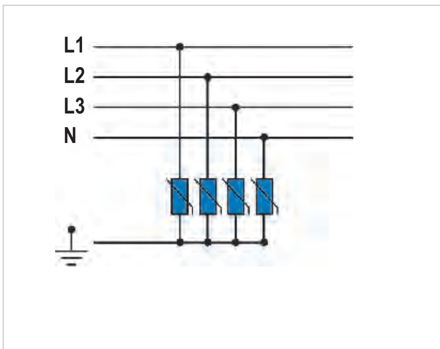


Figure 19: TT system - connection 4+0

Galvanic separation between N and PE conductor

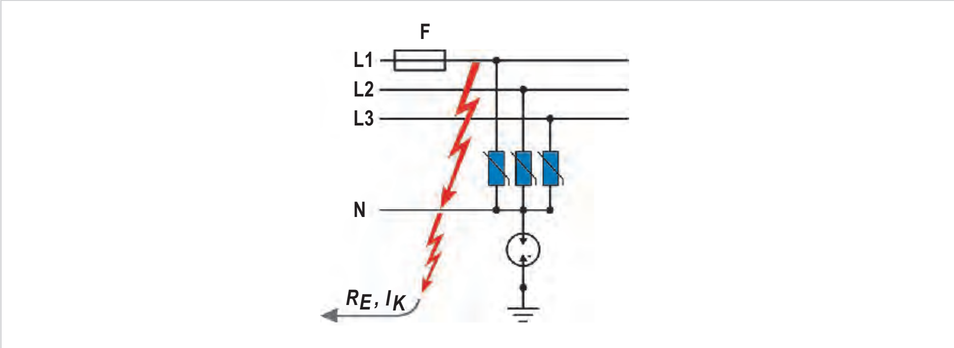


Figure 20: Galvanic separation between N and PE conductor

If short circuit and impulse overvoltage happen in the system at the same time, Ik (short circuit current) starts flowing through gas discharge tube (GDT). That is the reason why GDT should be able to extinguish the follow-up current and at the same time preventing allowing touch voltage endangering human life.

3.7 Typical connection of SPD in different networks (IEC 60364-5-53, edition 3.1, 2002.06)

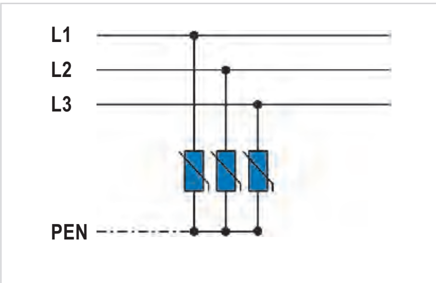


Figure 21: TN-C SPD (3+0)

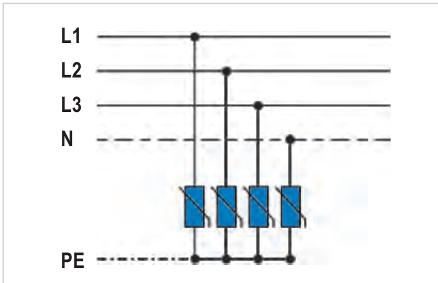


Figure 22: TN-S SPD (4+0)

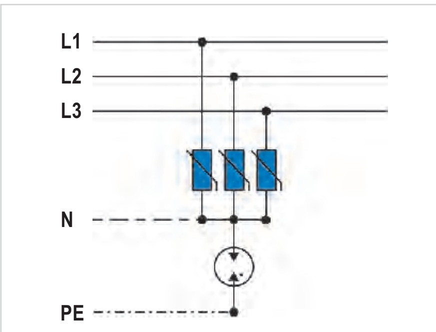


Figure 23: TT SPD (3+1)

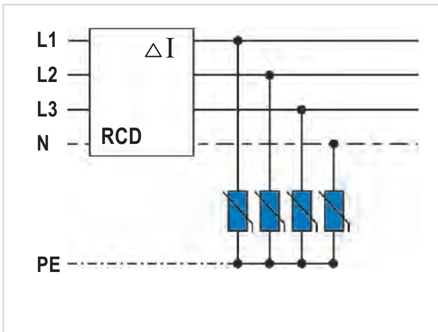


Figure 24: TT SPD (4+0)

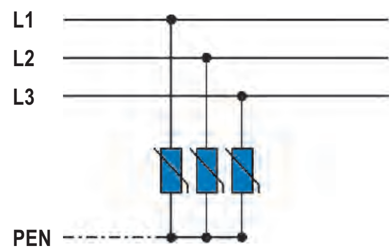


Figure 25: IT SPD (3+0); note: Uc= 3√Uref

Reference:

1. *IEC 61643-1 Surge protective devices connected to low voltage power distribution systems-requirements and test*
2. *IEC 61643-12 Surge protective devices connected to low voltage power distribution systems- selection and application principles*
3. *CEI IEC 60364-5-53 Electrical installation of buildings- Part 5-53: Selection and erection of electrical equipment isolation, switching and control*
4. *IEC PAS 60099-7 Surge arresters- Part 7: Glossary of terms and definitions from IEC publications 60099-4, 60099-4, 60099-6, 61643-1, 61643-12, 61643-21, 61643-311, 61643-321, 61643-331 and 61643-341*
5. *IEC 61000-4-5: Electromagnetic compatibility (EMC) Part 4-5: Testing and measurement techniques - Surge immunity test*
6. *IEC 62305-1 Protection against lightning- Part 1: General principles*
7. *IEC 62305-2 Protection against lightning- Part 2: Risk management*
8. *IEC 62305-3 Protection against lightning- Part 3: Physical damage to structures and life hazard*
9. *IEC 62305-4 Protection against lightning- Part 4: Electrical and electronic systems within structures*
10. *IEC 61312-1 Protection against lightning electromagnetic impulse (LEMP)- Part 1: General principle*
11. *IEC 61312-2 Protection against lightning electromagnetic impulse (LEMP)- Part 2: Shielding of structures, bonding inside structures and earthing*
12. *IEC 61312-3 Protection against lightning electromagnetic impulse (LEMP)- Part 3: Requirements of surge protection devices*
13. *IEC 61312-4 Protection against lightning electromagnetic impulse (LEMP)- Part 4: Protection of equipment in existing structures*

4. Lightning protection

4.1 Standards

Lightning protection covers the fields of interception systems, down conductors, grounding, potential equalisation or isolation. In the following standards the complete procedure of design drawings is defined, from the calculations to the use of materials.

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

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

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

IEC 62305 - 4: 2010 Protection against lightning Part 4: Electrical and electronic systems within structures

4.2 Need for lightning protection

Lightning flashes to earth may be hazardous to the structures and lines.

The hazard to a structure can result in:

- ☐ damage to the structure and to its components,
- ☐ failure of associated electrical and electronics systems,
- ☐ injury to living beings in or close to the structure.

Consequential effects of the damage and failures may be extended to the surroundings of the structure or may involve its environment.

To reduce the loss due to lightning, protection measures may be required. Whether they are needed, and to what extent, should be determined by risk assessment.

The risk - **R** - is the value of a probable average annual loss. For each type of loss which may appear in a structure or in a service, the relevant risk shall be evaluated:

R1: risk of loss of permanent injury of human life

R2: risk of loss of service to the public

R3: risk of loss of cultural heritage

R4: risk of loss of economic values, should be assessed whenever the economic justification of lightning protection is considered (IEC 62305-1; 2010)

To evaluate risks, **R**, the relevant risk components (partial risks depending on the source and type of damage) shall be defined and calculated. Risk components description is found in the standard IEC 62305-2; 2010.

Each risk, **R**, is the sum of its risk components. When calculating the risk, its components may be grouped according to the source of damage and the type of damage.

In *Table 2*, the risk components are considered for each type of loss for the structure and line.

Source of damage	*Flash to a structure* **S1**			*Flash near a structure* **S2**	*Flash to a line connected to the structure* **S3**			*Flash near a line connected to the structure* **S4**
Risk component	R_A	R_B	R_C	R_M	R_U	R_V	R_W	R_Z
Risk for each type of loss								
R_1	*	*	*1)	*1)	*	*	*1)	*1)
R_2		*	*	*		*	*	*
R_3		*				*		
R_4	*2)	*	*	*	*2)	*	*	*

1) Only for structures with risk of explosion, and for hospitals or other structure where failure of internal systems immediately endangers human life.

2) Only for properties where animals may be lost.

Table 2: Risk components (IEC 62305-2; 2010)

By calculating some of the risk components, the isokeraunic maps are used. Isokeraunic maps show areas where a similar number of thunderstorms occur each year.

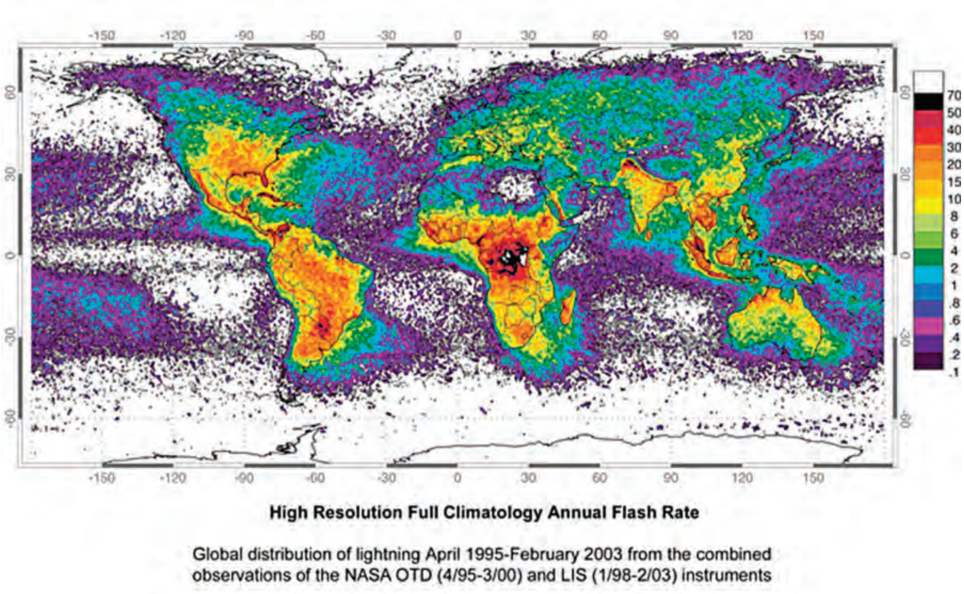


Figure 26: Isokeraunic map

The lightning current is the primary source of damage. The following sources are distinguished by the strike attachment point:

S1: flashes to a structure
S2: flashes near a structure
S3: flashes to a line
S4: flashes near a line

For practical application of this risk assessment, it is useful to distinguish between three basic types of damage, which can appear as a consequence of lightning flashes. They are as follows:

D1: injury to living beings by electric shock
D2: physical damage
D3: failure of electrical and electronic systems

The decision to protect a structure or a service against lightning, as well as the selection of protective measures, shall be performed according to IEC 62305-1; 2010. The following procedure shall be applied:

☐ identification of the structure to be protected and its characteristics;

☐ identification of all types of loss in the structure and the relevant corresponding risk R (R1 to R4);

☐ evaluation of risk R for each type of loss R1 to R4

- ☐ evaluation of the need for protection comparing the risks R1,R2 and R3 with the tolerable risk RT (IEC 62305-2;2010);
- ☐ evaluation of cost effectiveness of protection by comparing the costs of total loss with and without protective measures. In this case, the assessments of components of risk R4 shall be performed in order to evaluate such costs (IEC 62305-2; 2010)

4.3 Protection level and requirements for SPDs

Four lightning protection levels (I to IV) are introduced in the standard IEC 62305-1; 2010. For each LPL, a set of maximum and minimum lightning current parameters is fixed.

First positive impulse			**LPL**			
Current parameters	*Symbol*	*Unit*	**I**	**II**	**III**	**IV**
Peak current	I	kA	200	150	100	
Impulse charge	Q_{short}	C	100	75	50	
Specific energy	W/R	MJ/Ω	10	5.6	2.5	
Time parameters	T_1/T_2	µs/µs	10 / 350			
First negative impulse*			**LPL**			
Current parameters	*Symbol*	*Unit*	**I**	**II**	**III**	
Peak current	I	kA	100	75	50	
Average steepness	di/dt	kA/µs	100	75	50	
Time parameters	T_1/T_2	µs/µs	1 / 200			
Subsequent impulse			**LPL**			
Current parameters	*Symbol*	*Unit*	**I**	**II**	**III**	**IV**
Peak current	I	kA	50	37.5	25	
Average steepness	di/dt	kA/µs	100	150	100	
Time parameters	T_1/T_2	µs/µs	0.25 / 100			
Long stroke			**LPL**			
Current parameters	*Symbol*	*Unit*	**I**	**II**	**III**	**IV**
Long stroke charge	Q_{long}	C	200	150	100	
Time parameter	T_{long}	s	0.5			
Flash			**LPL**			
Current parameters	*Symbol*	*Unit*	**I**	**II**	**III**	**IV**
Flash charge	Q_{flash}	C	300	225	150	

*) The use of this current shape concerns only calculations and not testing.

Table 3: Maximum lightning current parameters (IEC 62305-1; 2010)

Minimum lightning current values are also defined in IEC 62305-1; 2010.

Here is the example how to choose the Iimp of the SPD according to the protection levels. The lightning current is divided in accordance with the principle 50% to ground and 50% to installation, provided that:

- ☐ calculation shows that lightning protection level I (which is the most exacting level) with the maximum lightning current is needed
- ☐ no other building is in that area

The maximum lightning current of 200 kA (from the above table) is then divided into the current of 100 kA, which flows to the ground, and into the current of 100 kA, which flows to installation (across main bus bar and SPD) and from there to the other distant buildings and a transformer. According to the type of the power supply network, there are the minimum values of the Iimp the SPD should withstand:

- ☐ three phase TT, TNS, IT (with neutral) systems: 100 kA/4 wires = 25 kA/wire
- ☐ three phase TNC, IT (without neutral) systems: 100 kA/3 wires = 35 kA/wire
- ☐ single phase TT, TNC system: 100 kA/2 wire = 50 kA/wire

According to *Table 3*, the minimum lightning strike current is 100 kA. Hence the minimum value of the lightning current the SPD conduct is 12,5 kA. This can be seen in the following *Figure 27*.

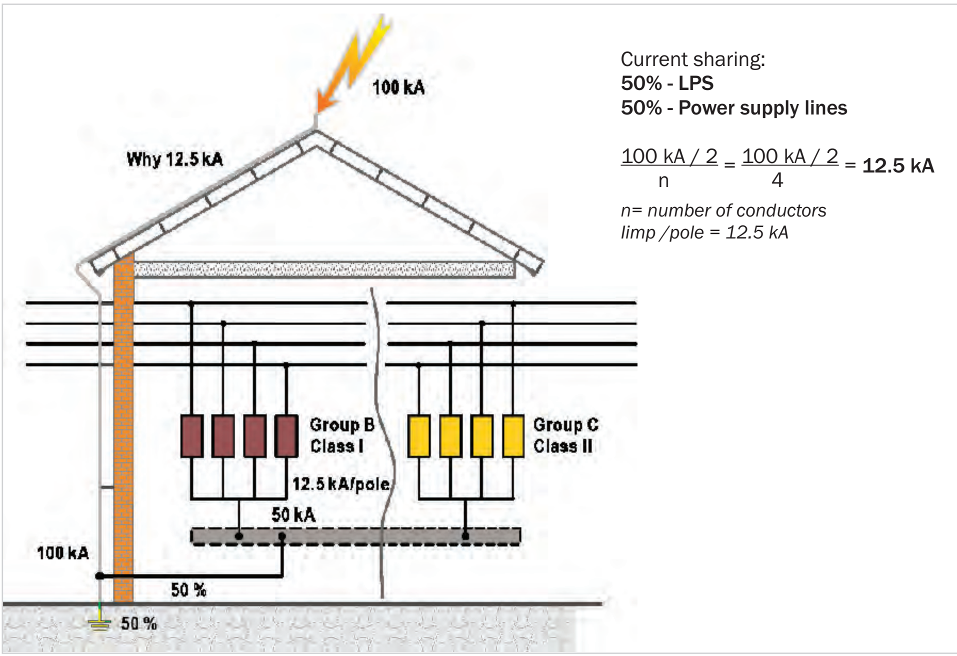


Figure 27: Distribution of lightning strike current

4.4 Lightning protection systems LPS

The characteristics of an LPS are determined by the characteristics of the structure to be protected and the considered lightning protection level.

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

Table 4: Relation between lightning protection levels (LPL) and class of LPS (IEC 62305-3; 2010)

Each class of LPS is characterized by the following (IEC 62305-3;2010):

a) Data dependent upon the class of LPS:
- lightning parameters (see tables 3 and 4 in IEC 62305-1; 2010);
- rolling sphere radius, mesh size and protection angle (see 5.2.2)
- typical preferred distances between down conductors (see 5.3.3)
- separation distance against dangerous sparking (see 6.3)
- minimum length of earth electrodes (see 5.4.2)

b) Factors not dependent upon the class of LPS:
- lightning equipotential bonding (see 6.2)
- minimum thickness of metal sheets or metal pipes in air-terminations systems (see 5.2.5)
- LPS materials and conditions of use (see 5.5.1)
- material, configuration and minimum dimensions for air-terminations, down-conductors and earth-terminations (see 5.6)
- minimum dimensions of connecting conductors (see 6.2.2)

Performance of each class of LPS is given in Annex B of IEC 62305-2; 2010.

The class of required LPS shall be selected on the basis of the risk assessment (IEC 62305-2; 2010).

Air-termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facade) in accordance with one or more of the following methods. According to the IEC 62305-3, acceptable methods to be used in determining the position of the air-termination system include:

- ☐ the protection angle method
- ☐ the rolling sphere method
- ☐ the mesh method

The rolling sphere method is suitable in all cases. *Table 5* shows maximum values of rolling sphere radius, mesh size and protection angle corresponding to the class of LPS.

Class of LPS	Protection method		
	Rolling sphere radius r (m)	**Mesh size W (m)**	**Protection angle α**
I	20	5 x 5	*See figure 29*
II	30	10 x 10	
III	45	15 x 15	
IV	60	20 x 20	

Table 5: Maximum values of rolling sphere radius, mesh size and protection angle corresponding to the class of LPS (IEC 62305 - 3, 2010)

Figure 28 shows the mesh method, where conductors are placed on the concrete insulation bricks and connected with flexible wires to enable extension of the system due to temperatures, wind, etc.

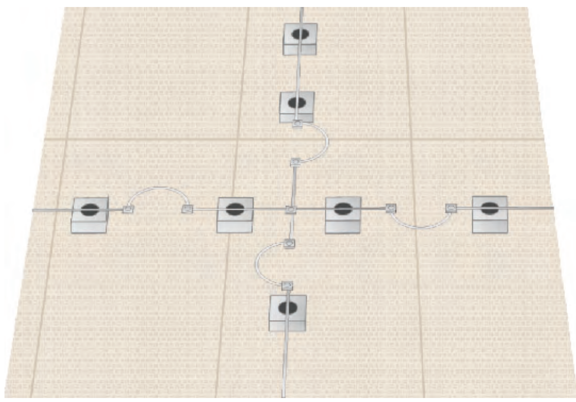
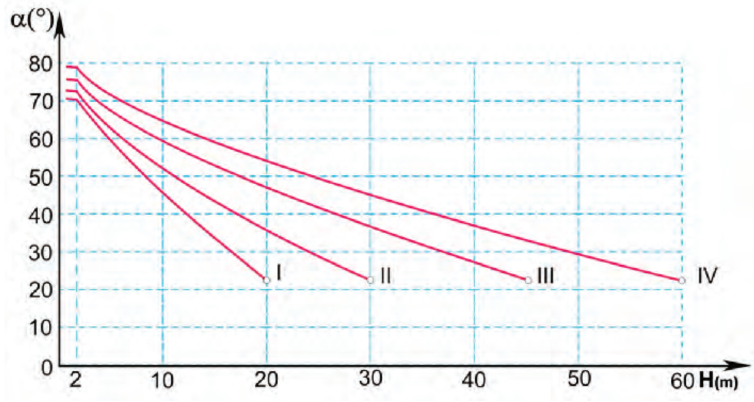


Figure 28: Mesh method

The protection angle method is suitable for simple-shaped buildings, but it is subject to limits of air-termination height (max. height is the radius of rolling sphere) indicated in *Figure 29*.



Note 1 Not apllicable beyond the values marked with ○. Only rolling sphere and mesh methods apply in these cases.
Note 2 *h* is the height of air-termination above the reference plane of the area to be protected.
Note 3 The angle will not change for values of *h* below 2m.

Figure 29: Air-termination height (IEC 62305-3, 2010)

In *Figure 30* the protection angle method of the chimney is shown.

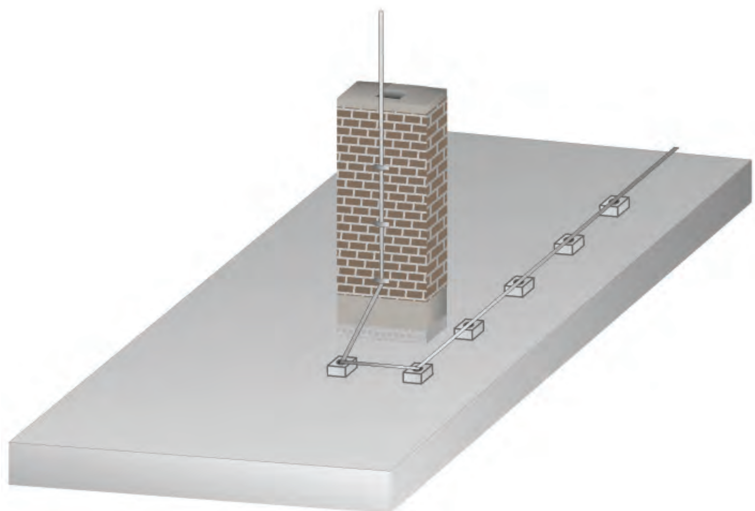
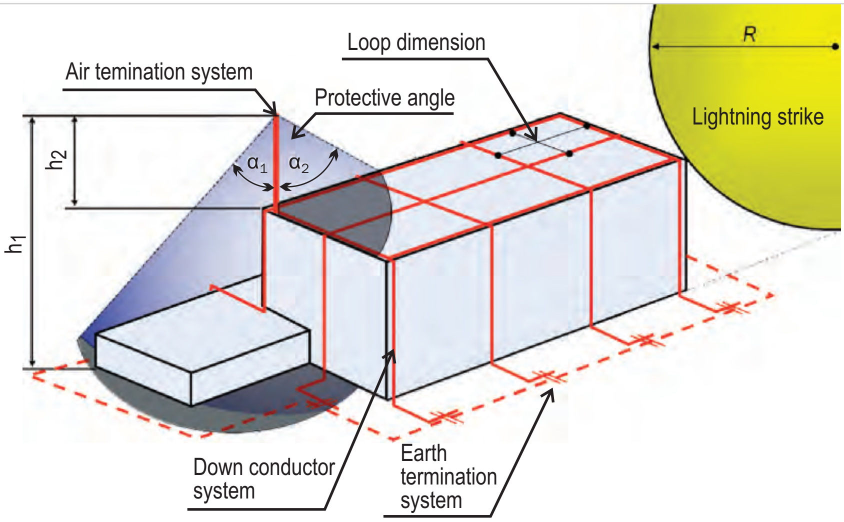


Figure 30: Chimney lightning protection with Franklin rod

The mesh method is a suitable form of protection where plain surfaces are to be protected.

The following *Figures (31 to 34)* show the principle of rolling sphere method in combination with the protection angle and mesh method. Rolling sphere method is based on the rolling the sphere around and over the building(s). Where the sphere touches the building, it is necessary to place the lightning interception system and down conductors.

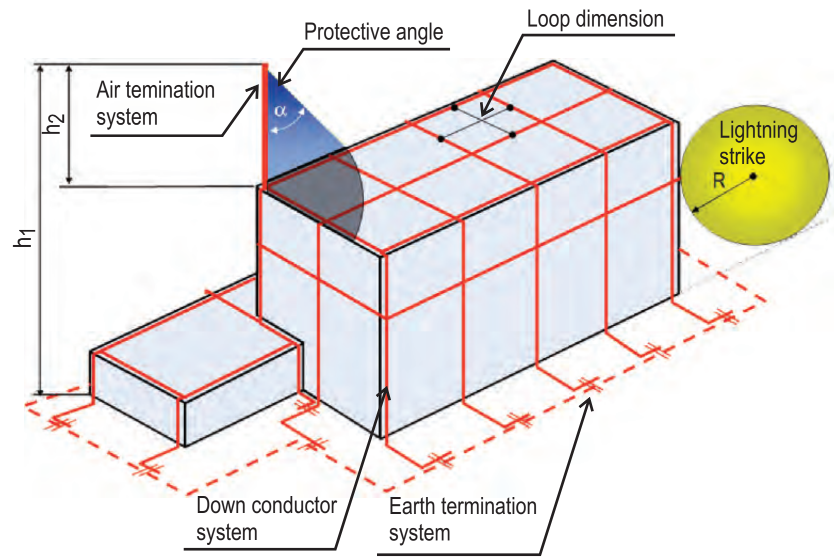
The first example shows two small buildings where higher building has the mash and Franklin rod as a lightning interception system. The rod protects the objects on the roof which are inside the angle α2 (shaded area) and the complete smaller building which is "covered under" the angle α1.



LPS type	Radius (R)	Loop dimensions
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m

Figure 31: Lightning protection I

In *Figure 32* we see that one of the buildings is much higher and the air terminal does not protect the lower building any more (rolling sphere can touch it), the lightning interception system is thus placed also on the lower structure.



LPS type	Radius (R)	Loop dimensions
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m

Figure 32: Lightning protection II

On structures taller than 60 m, flashes to the side may occur especially to points, corners and edges of surfaces. In general, the risk due to these flashes is low because only a few percent of all flashes to tall structures will hit the side and, moreover, their parameters are significantly lower than those of flashes to the top of structures. However, electrical and electronic equipment on walls outside structures may be destroyed even by lightning flashes with low peak current values.

An air termination system shall be installed to protect the upper part of tall structures - typically the topmost 20% of the height of the structure - with the equipment installed on it.

The rules for positioning air-termination system on roofs shall also apply to those upper parts of structures.

Additionally, structures taller than 120m should have protected all parts which may be endangered (above 120 meters).

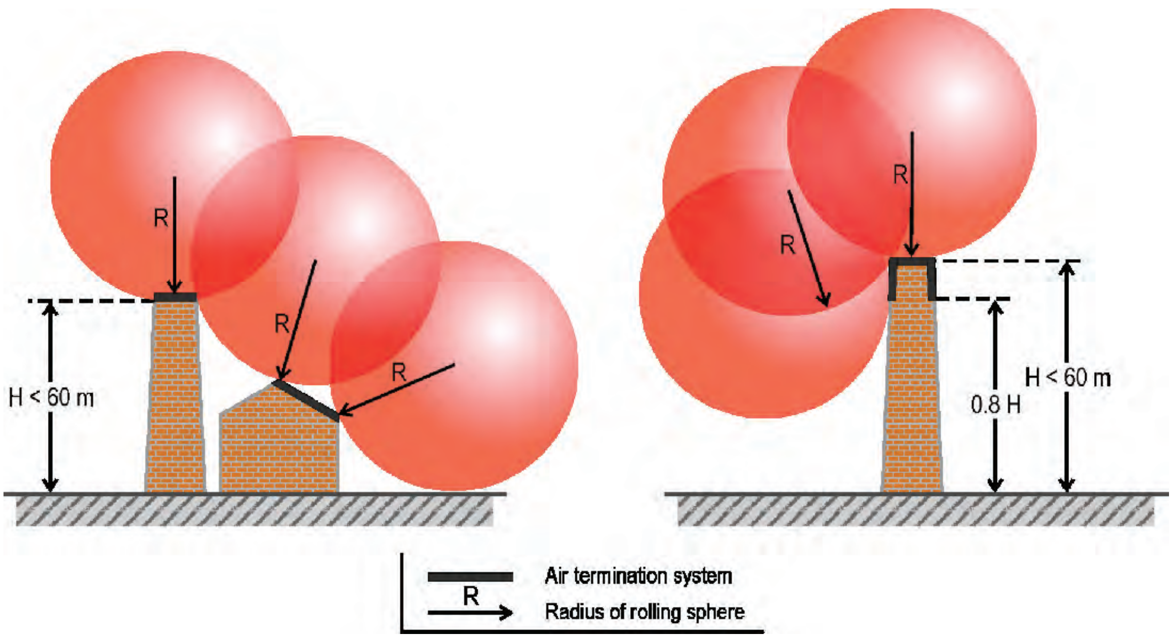


Figure 33: Rolling sphere method (IEC 62305 3; 2010)

According to the LPS and protective measures against LEMP, the protection zones are defined.

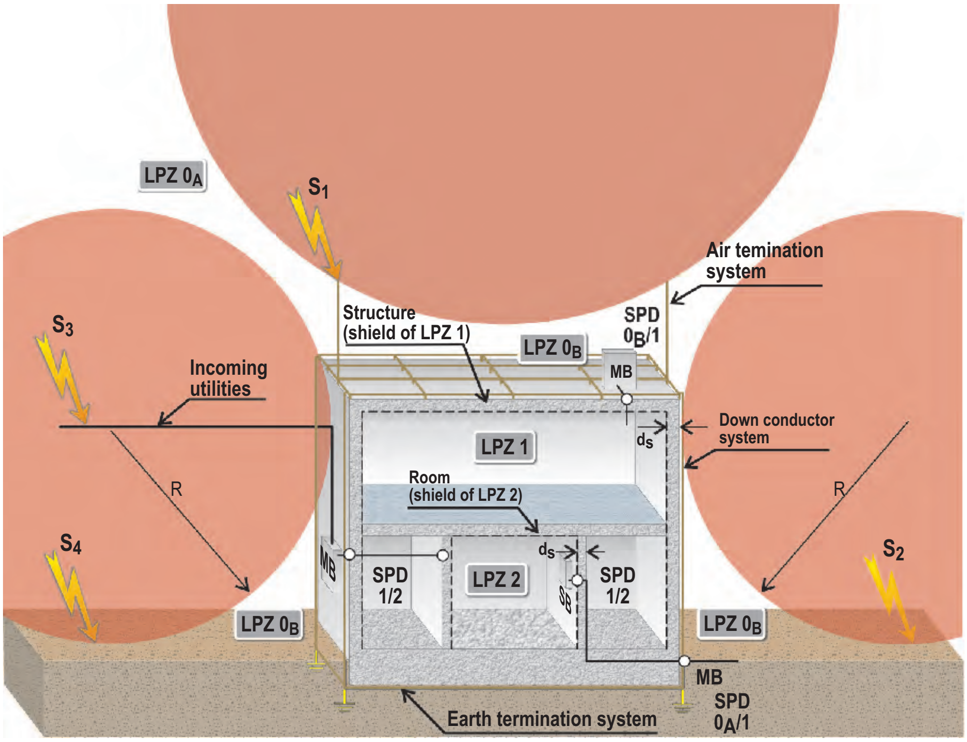


Figure 34: Lightning protection (IEC 62305-1; 2010)

In *Figure 34* we see the building with the lightning protection system on top, down conductors, grounding system, installed surge protection and Faraday cages. There are different points of lightning strikes:

S_1 - flash to the structure (air termination system)

S_2 - flash near the structure

S_3 - flash to a line connected to the structure

S_4 - flash near a line connected to the structure

Letter R in the red areas represents a radius of rolling sphere, which is rotated around and above the building. Everything it touches (building, service, objects on the building, ground, etc.) is considered to be in protection zone 0_A. This is the zone where a direct lightning flash is possible and a full lightning current and magnetic field are present. In the case of S_3, the incoming cable is protected at the entering point into the building with the SPD capable surviving a direct lightning strike (SPD $0_A/1$). Strike S_2 can influence the underground cable; that is why this cable is protected at the entrance into the building with the same type of the SPD (SPD $0_A/1$).

Where direct lightning strike is not possible, but partial lightning or induced current and full magnetic field are possible, there exists zone 0_B. Strike S_1 hits the air terminal, but it is unable to hit the area between these two rods (zone 0_B); the SPDs for indirect strike can be used there (SPD $0_B/1$). These 2 zones are also seen on the left and right side of the structure below the rolling spheres. In the case of S_2, we use SPDs for direct lightning strike even though there is a $0_B/1$ zone. The reason for this is that S_2 strike can hit the underground cable away from the building and the lightning current can flow through the cable into the building.

Inside the building we have zone 1 where no direct flash is possible, limited lightning or induced currents are present and magnetic filed is damped. Further on, we have zone 2 or even more, which have in common: no direct flash, only induced current, further damped magnetic field. Between zones 1/2, the appropriate SPDs for indirect strikes are placed.

Protective volumes inside LPZ 1 and LPZ 2 must respect safety distances d_s *(Figure 34)* against too high magnetic field (e.g. the equipment is placed in the room away from the Faraday cage at least for the distance ds) .

The function of the internal LPS is to prevent dangerous sparking within the structure and it is thus important to use either equipotential bonding or a separation distance S (and hence electrical isolation) between the LPS components and other electrically conducting elements internal to the structure.

4.5 Lightning effects

There exist different lightning effects, which can have catastrophic consequences, if not properly addressed:

☐ **thermal**:

- fire, if there is no proper lightning protection
- heating of lightning interception system and down conductors

☐ **mechanical**:

- damages on the structures, services, devices, etc. if there is no proper lightning and surge protection system
- bending of the lightning protection elements (interception system, down conductors, etc.)

☐ **electromagnetic**:

- electrodynamic force (cables out of ducts, walls, etc.), induced voltages (insulation breaks between cables, etc.)

☐ **electrical:**

o sparking between metal parts, if there is no connection or separation distance, rise of grounding potential and a danger of step and touch voltage (lacking potential equalisation between all metal parts, incorrectly designed and performed grounding systems).

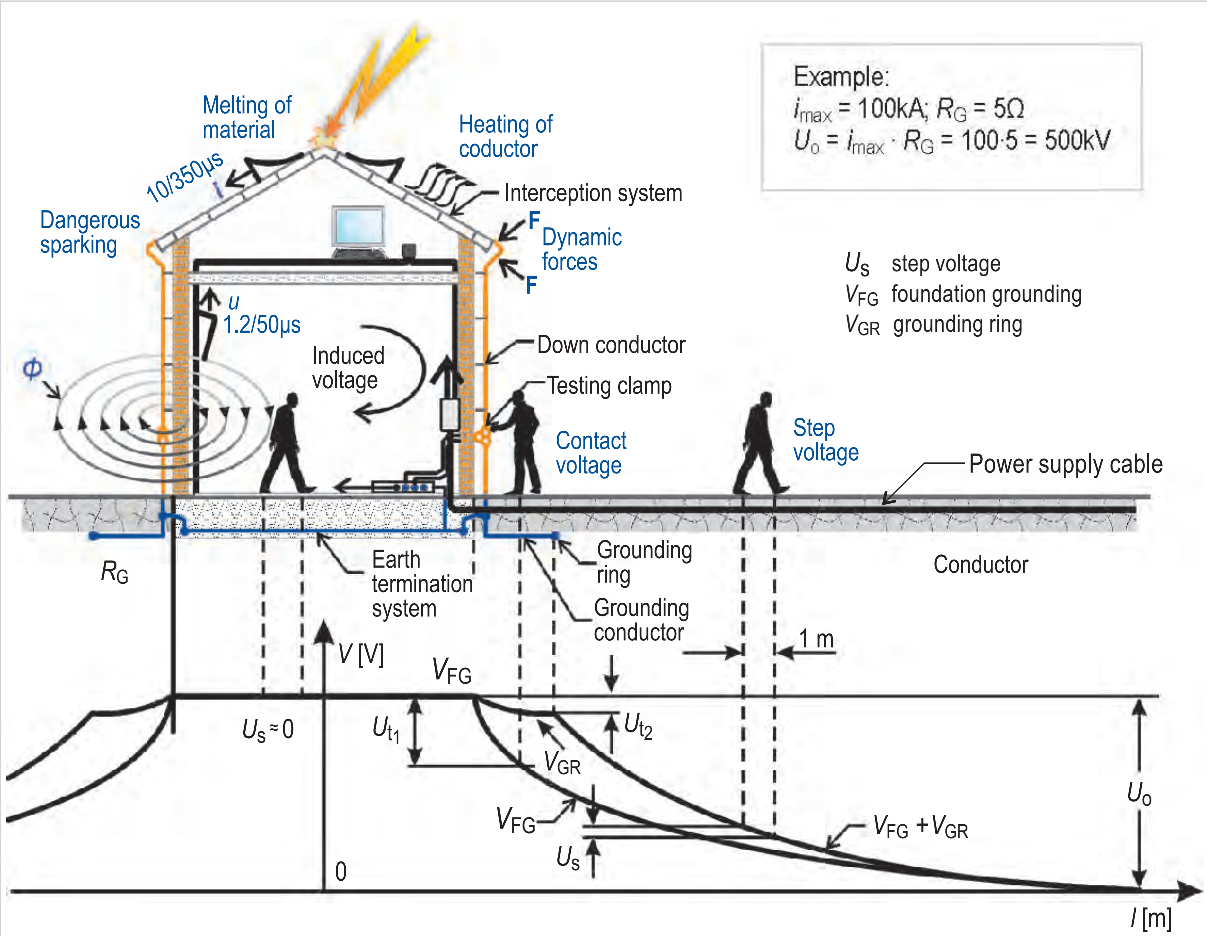


Figure 35: Lightning effects

The key solution to avoid step and touch voltage is to build a proper grounding system and to connect all metal parts together, first to local bus bars, then to the main bus bar. In some cases, the connection is not done directly but with assistance of special elements - for example, cathode protected oil pipe connected to the bus bar with gas discharge tubes or spark gaps to prevent stray current flow.

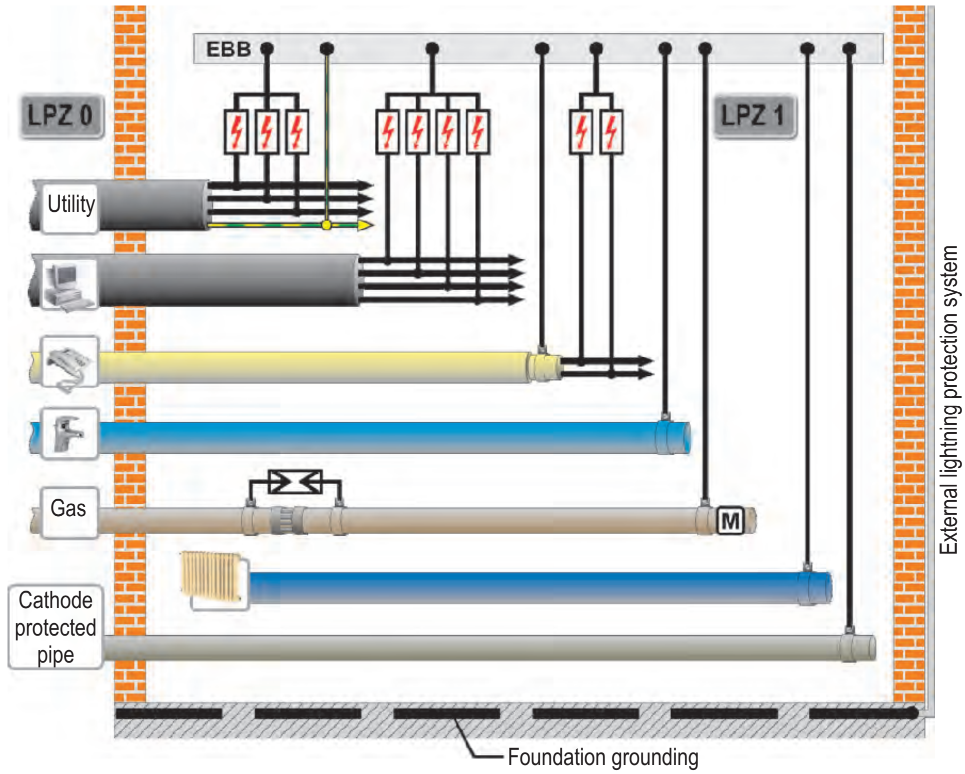


Figure 36: Principle of potential equalization (Blitzshutz, Montage-handbuch, VDB)

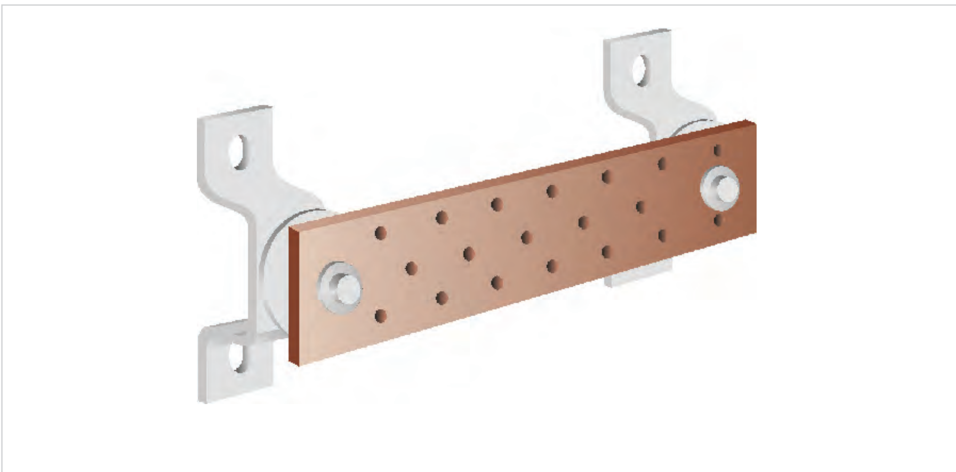


Figure 37: Grounding bus bar

4.6 Grounding

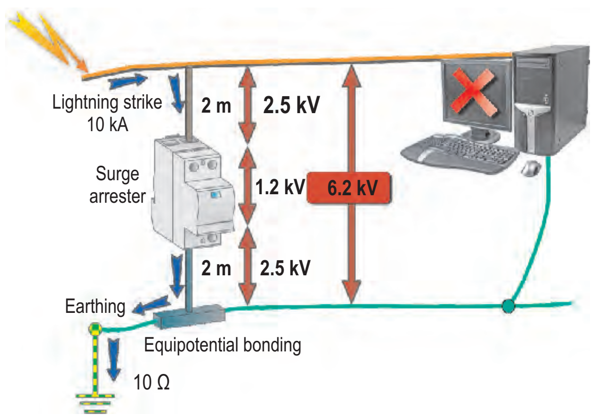
Grounding is needed to dissipate the energy of the lightning strike, to limit the noise, to reduce electrostatic charge, as well as to ensure personal safety, fuse operation in earth short circuits and device protection, etc.

The main goal of a grounding system for the needs of a lightning protection is energy dissipation of the lightning strike, as fast as possible. Consequently, the occurrence of dangerous voltages has to be prevented. When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground, whilst minimizing any potentially dangerous overvoltages, the shapes and dimensions of the earth termination system are the important criteria.

All different grounding systems should be directly connected together or through the spark gap and gas discharge tube into a common grounding system.

Naturally, the lower grounding resistance, the more favourable conditions. In general, a low earthing resistance, if possible lower than 10 Ω when measured at low frequency (IEC 62305-3; 2010), is recommended to avoid high voltage drop values on the grounding system. *Figure 38* shows the conditions at the SPD in the moment of a lightning strike.

From the viewpoint of lightning protection, a single integrated structure earth-termination system is preferable and suitable for all purposes (lightning protection, power systems and telecommunication systems).



An example of incorrect mounting of surge arrester

Figure 38: Conditions at the SPD

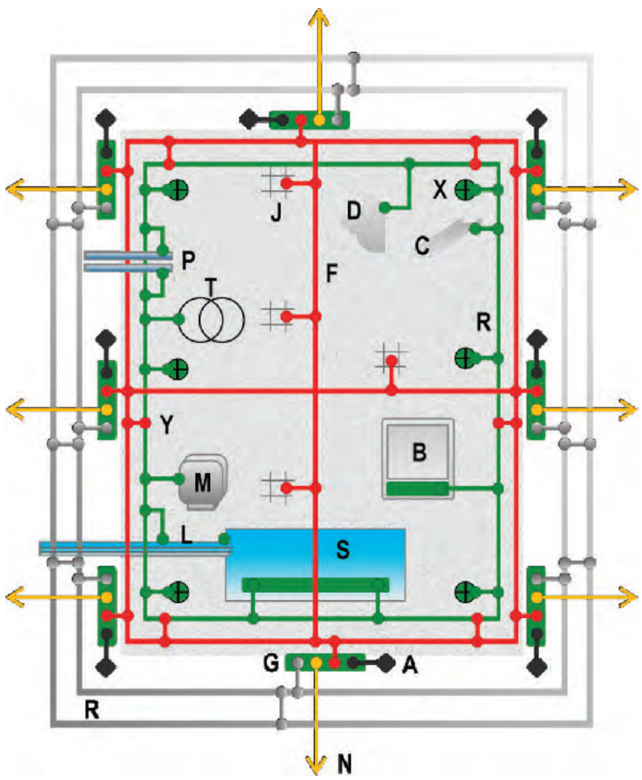
Example: an inductance of a cable is cca 1 μH/m, a lightning strike 10,000 A, a grounding resistance 10 Ω.

U device = L di/dt + Up + iRe = 4 x 10,000 A/8 us + 1,2 kV + 10,000 A x 10 Ω = 5,000 + 1,200 V + 100,000 = 6,200 + 100,000 = 106,200 V

If the grounding resistance is 1 Ω, the device feels only 10,620 V.

The requirements for the SPD grounding resistance are regulated referring to different countries. In Slovenia, the value is 5 Ω.

The example of proper grounding solution and potential equalization is seen on *Figure 39*.



F *Foundation grounding*
J *Iron frame joint*
R *Grounding bus bar conductor*
Y *Grounding fix point*
T *Transformer*
C *Cable tray*
P *Metal pipes*
M *Motor*
L *Data lines*
B *Control box*
S *Switchboard*
X *Supporting small column for double floor system*
D *Control desk*
G *Grounding bus bar*
A *Down conductor*
R *Grounding rings for potential equalization*
N *Connection to the neighbouring grounding systems*

Figure 39: Proper grounding solution and potential equalization (Blitzshutz, Montage-handbuch, VBD)

Transformer, cable trays, metal pipes, motor, data line screen, control box, switchboard, double floor system supporting column, control desk are all connected to the grounding bus bar conductor, which is fastened on the grounding fix point to the foundation grounding. Iron frame joints are attached to the foundation grounding as well. Grounding bus bars are fixed to the foundation grounding and to the grounding rings for potential equalization. Down conductors are connected to the grounding bus bars. This complete system is connected to the grounding system of neighbouring buildings.

5. Surge Protective Devices

The main task of surge protective device (SPD) in low-voltage power supply lines is suppression of the overvoltage transients travelling along lines to the sensitive electronic devices connected to the line terminals. Overvoltage impulse appears between phase conductors and the earth or between various phase conductors. In both cases, there is a risk of dielectric breakdown which can lead to the destruction of the equipment. In order to avoid damage of the equipment, surge protective devices must be utilized. Equipment vulnerability depends on the sensitivity of the used electronic components determining the level of overvoltage protection needed for installation. Surge protective devices consist of basic electrical elements, such as resistors, inductivities, capacitors and overvoltage protection elements as crucial elements of device. Characteristics of basic electrical components are well known and their descriptions can be found in any textbook about basic electrical circuits. The overvoltage protection elements are closely related to overvoltage protective devices since their characteristics directly determine the characteristic of an overvoltage protective device. A surge protective device contains at least one nonlinear element; usually, surge protective devices available on the market are mainly composed of two or more nonlinear components. Additionally, they may include other components, such as fuses, disconnections, indicators, inductors, capacitors and other components. In order to assure easier design and installation of surge protective systems, SPDs are classified into groups, in accordance with general and electrical parameters in common. After introductory explanation of surge protection principles and nonlinear elements used in LV power supply systems, the classification of SPDs and their electrical characteristics is presented.

5.1 Surge protection elements

Electric, electronic, communication and information devices are expected to operate continuously. This requirement will be fulfilled using two possible approaches. First possible solution is isolation of the protected device from the power supply line during overvoltage transient *(Figure 40)*, and second possibility is redirection of the overvoltage impulse in front of the device through small shunt impedance *(Figure 41)*.

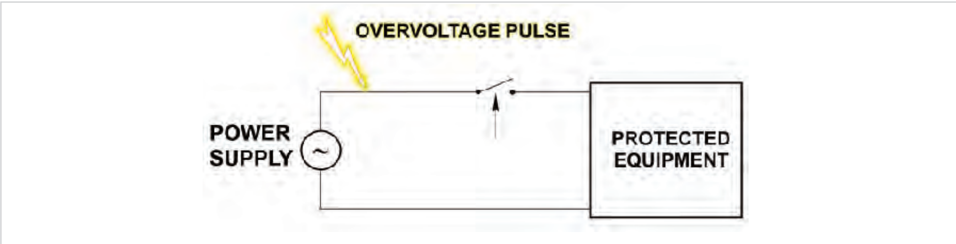


Figure 40: Installation of overvoltage protection element in series with line

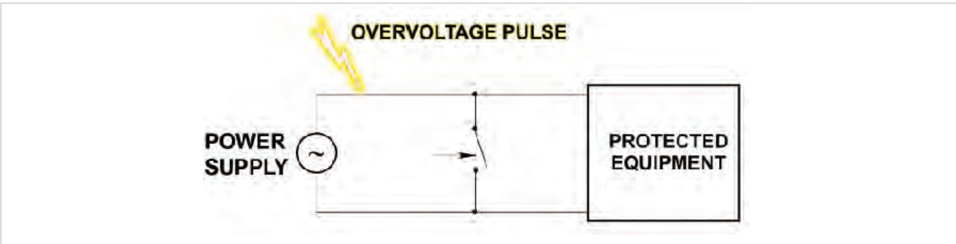


Figure 41: Installation of overvoltage protection element in parallel with line protected equipment

These two solutions require the usage of elements with different electrical characteristics under normal operation and during overvoltage impulse. In the first case, the protective component is installed in series with the power supply line and must have the as small impedance in normal operation and as large impedance during an overvoltage impulse (thermal or automatic fuses) as possible. These elements can be used for over-current protection but their response time represents main limiting factor for the overvoltage protection. This method of overvoltage protection is equivalent to equipment unplug from the all incoming lines during an expected storm or announced switch manipulations in the power grid.

In the second case, the protective component is installed in parallel with the protected equipment and must have large impedance in normal operation and small impedance during overvoltage impulse, providing that overvoltage impulse can be conducted to the earth. The second solution is primarily used in surge protection because of existence of appropriate elements assuring adequate protection.

5.1.1 Classification of overvoltage protection elements

Following general classification, overvoltage protection elements from the second group can be divided into:

- ☐ voltage switching elements, and
- ☐ voltage limiting elements.

Voltage switching elements operate by switching from high to low resistance state at a certain threshold voltage (breakdown voltage) and behave like a short circuit. Breakdown voltage must be above the maximum continuous operating voltage of the system. Spark gap, gas discharge tube (GDT) and PNPN structures (thyristors, breakover diodes, triacs) operate in accordance with this principle. Voltage-current characteristics of some ideal element and GDT are presented in *Figure 42*.

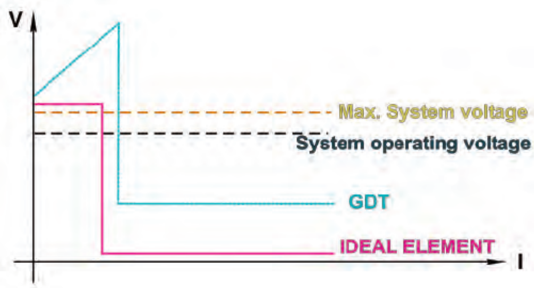


Figure 42: V-I characteristics of voltage switching elements

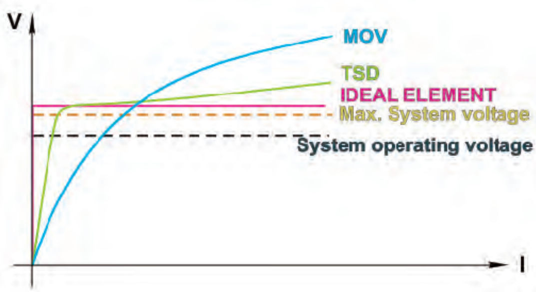


Figure 43: V-I characteristics of some voltage limiting elements

Elements in the second subgroup limit a transient overvoltage impulse to a predefined voltage level. This voltage must be chosen to be just above maximum continuous operating voltage of the LV system. Voltage-current characteristics of the ideal element, transient suppression diode and metal oxide varistor (MOV) are presented in *Figure 43*.

5.1.2 Overvoltage protection elements - Basic characteristics

The ideal characteristics of the surge protection elements described above cannot be achieved with commercially available components. The real characteristics of a particular component play very important role in the design of overvoltage protectors. Such elements are mainly described by their nonlinear terminal voltage-current characteristics. Basic overvoltage protective components are presented using classification introduced in the previous section. Surge protective devices used in LV power supply systems are mainly based on elements with high energy withstand capability. Used material of the element determines its energy withstand capability. The elements with high energy capability are spark gap, GDT, and MOV. A description of overvoltage protection elements used in LV power supply systems is limited, in this section, to the previously mentioned elements. Such elements have relatively slow response. However, slow response can be compensated by semiconductive protection elements. The low-power components based on semiconductive materials, such as diodes, transistors and thyristors, which have low energy withstand capability but very fast response. They must be capable of carrying the surge energy until the moment at which the element in first stage responds, which represents the main reason for the utilization of such components. The low-power components are principally installed in the last stage of overvoltage protective system *(Figure 44)*.

Component	*High energy High current*	*Low Let-through voltage*	*No follow-on Current*
Air Gaps & Gas arrester	✓✓	✗	✗✗
Metal Oxide Varistor	✓	✓	✓
Silicon Avalange Diodes	✗✗	✓✓	✓

Table 6: SPD elements characteristics

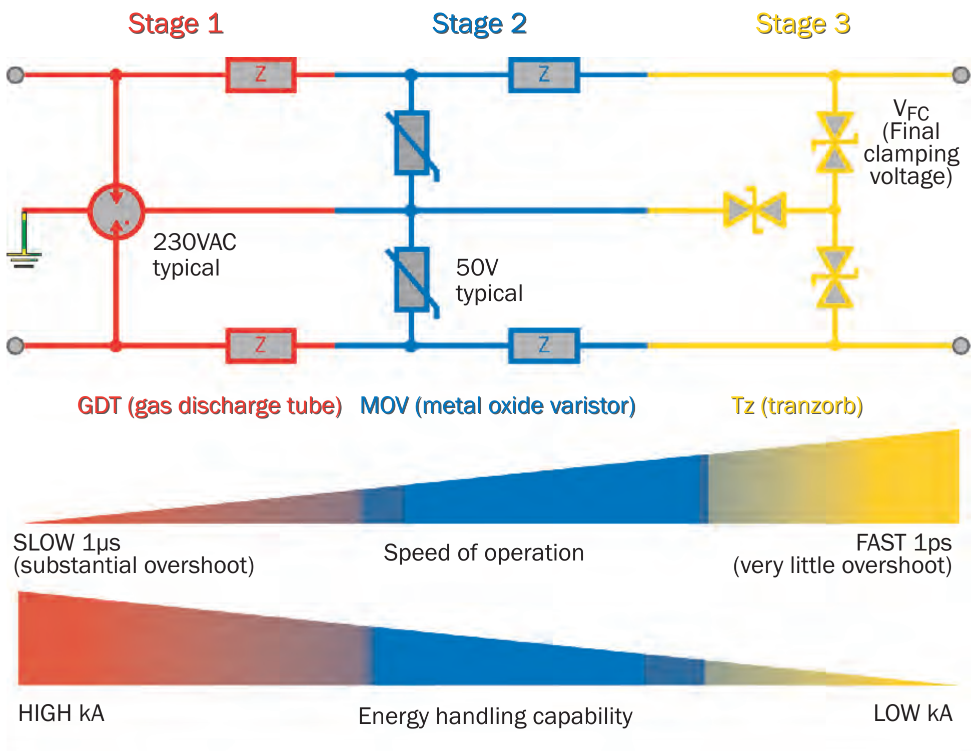


Figure 44: Energy and speed characteristics

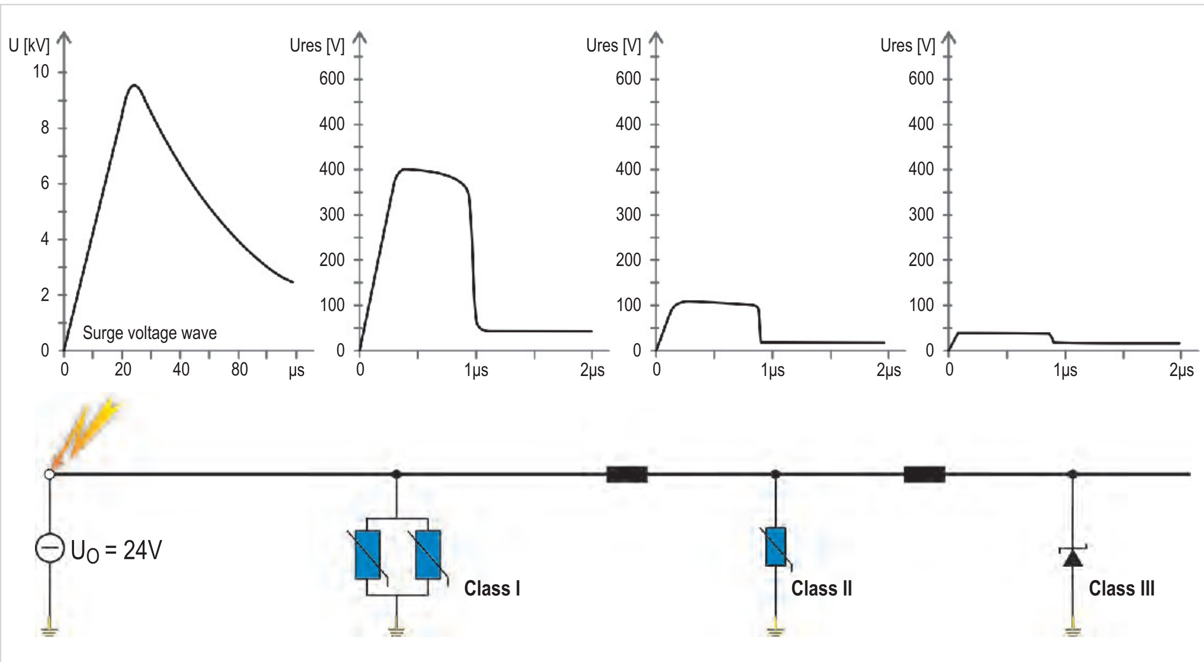


Figure 45: The sequence of the individual components results in an increasing response sensitivity towards the output

Interference voltage with a rise of 1 kV/µsV and a peak value of 10 kV at input of first stage is limited by a MOV to approx. 400 V. Second stage, decupled from the first by means of inductance, suppresses this value to approx. 100 V. This voltage pulse is then reduced to approx. 35 V (in a 24 V network voltage U_O) by the suppression diode *(Figure 45)*. Therefore, the downstream electronics need only be able to cope with a voltage pulse of approx. 1.5 x U_O.

5.1.2.1 Voltage switching components

Spark gap

A spark gap was historically the first element used in the overvoltage protective circuits. This component consists of two electrodes with air gap between them. The distance between the electrodes defines the breakdown voltage. When the voltage between the electrodes exceeds the breakdown voltage of the air, the "conduction path" (ionized air) between electrodes is established and the current flows through the space between the electrodes. The current initiates intensive thermal ionization, the spark gap resistance drops and a current increases very rapidly. The major problem recognized in the spark gap application is electrical arc extinguishing in the power supply circuits after the surge current disappears.

Gas discharge tube

GDT usually consist of two or three electrodes in a glass or ceramic, inert gas (neon or argon) filled package *(Figure 46)*. The electrodes are opposed each other across a short distance. When the three electrodes are used, the middle electrode lies between the other two electrodes located at the ends of the tube. The middle electrode has a small hole allowing conduction between the other two end electrodes. Commercially available GDTs are enclosed in ceramic tubes whose terminals are metal electrodes.

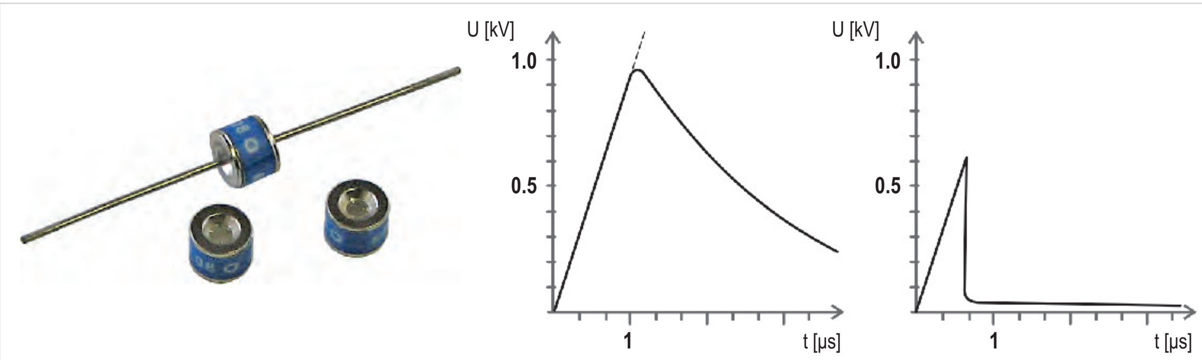


Figure 46: Voltage rise shape of 1 kV/µsV without voltage switching component and pulse response voltage switching component (a peak value of 1 kV is limited to approx. 600-700 V)

A typical V-I curve for GDT is shown in *Figure 42*. The problem connected with GDTs is the presence of the electrical arc and follow-up current in the power supply network (power-frequency current continuous to flow after surge current disappears). The advantages are found in the application of MOV in the series with GDT.

Figure 47: Example of self-extinguishing spark gap

5.1.2.2 Voltage limiting component

Metal-oxide varistor

At very low voltages, MOV has the ability to indicate that conduction is blocked. When higher voltage is applied at MOV's terminals, MOV resistance is reduces to a very small value *(Figure 50)*. MOV is thus classified as a strongly nonlinear resistor. The electrical properties described in this section are defined by physical dimensions (thickness, area and volume) of the varistor. Static symmetrical voltage-current curve *(Figure 48)* can be modelled in three regions. In the first region, known as leakage region, at low current values, V-I curve is approximately linear. A varistor behaves as an open circuit having high resistance in the order of 109 Ω. The current in this region depends on the temperature - this is especially expressed at low voltages. A leakage current becomes noticeable when temperature increases. The capacitance in this region has approximately constant value over a wide range of voltage and frequency. The capacitance decreases when the voltage approaches the nominal voltage of a varistor. The capacity of varistors available on the market is usually a few nanofarads and depends on the diameter and thickness of the discs. As the voltage increases, varistor becomes conductive. Temperature has influence on the nominal voltage of the varistor. At very high current values, the current through varistor tends towards a linear or ohmic law (upturn region). In this region, the temperature has no significant influence on the V-I curve. The main advantage of varistors is their energy/cost ratio. For that reason, the varistor has become the essential component in designing surge protective devices.

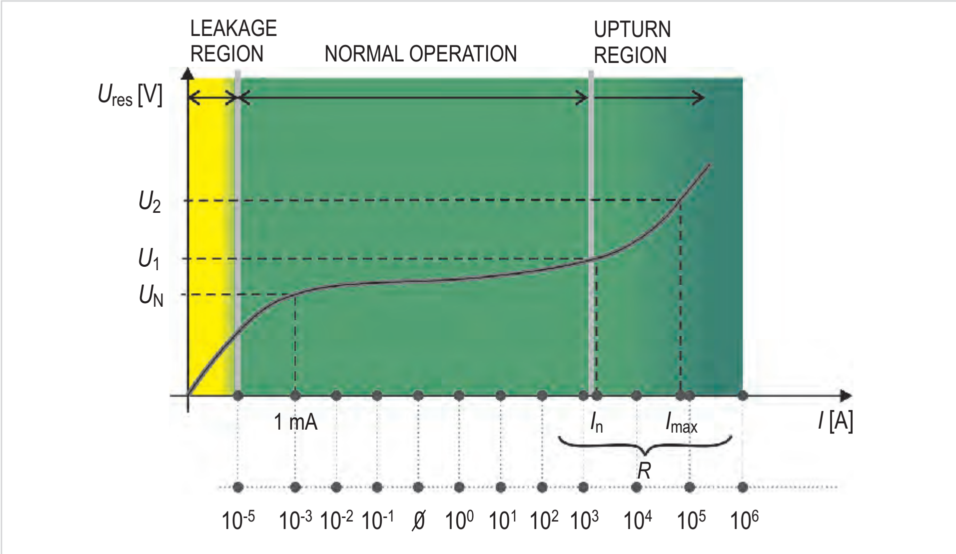


Figure 48: Typical V-I characteristics of metal-oxide varistor, and three regions of varistor operation

Figure 49: Metal-oxide varistor blocks

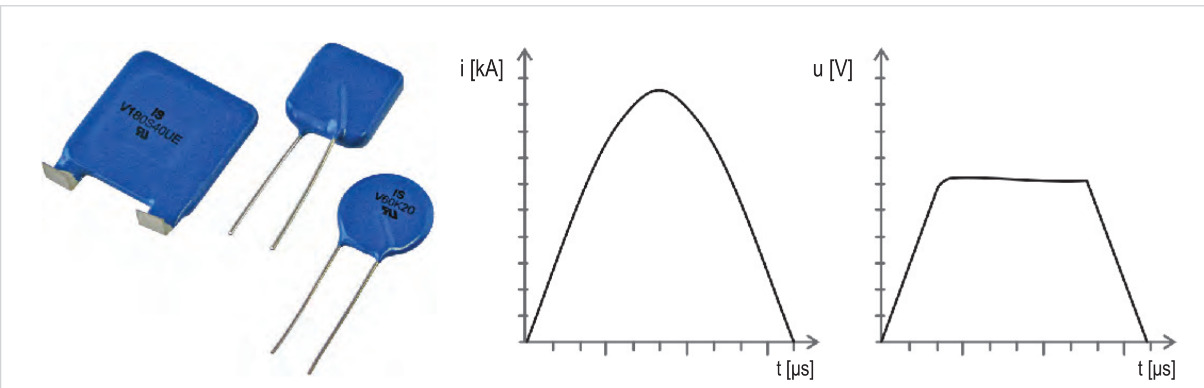


Figure 50: The response of Metal Oxide Varistor (MOV) on current shape 8/20 μs

<u>Transient-voltage-suppression (TVS) diode</u>

A transient-voltage-suppression diode *(Figure 51)* can respond to over-voltages faster than other common over-voltage protection components such as varistors or gas discharge tubes. The actual clamping occurs in roughly one picosecond, but in a practical circuit the inductance of the wires leading to the device imposes a higher limit. This makes transient-voltage-suppression diodes useful for protection against very fast and often damaging voltage transients. These fast over-voltage transients are present on all distribution networks and can be caused by either internal or external events, such as lightning or motor arcing.

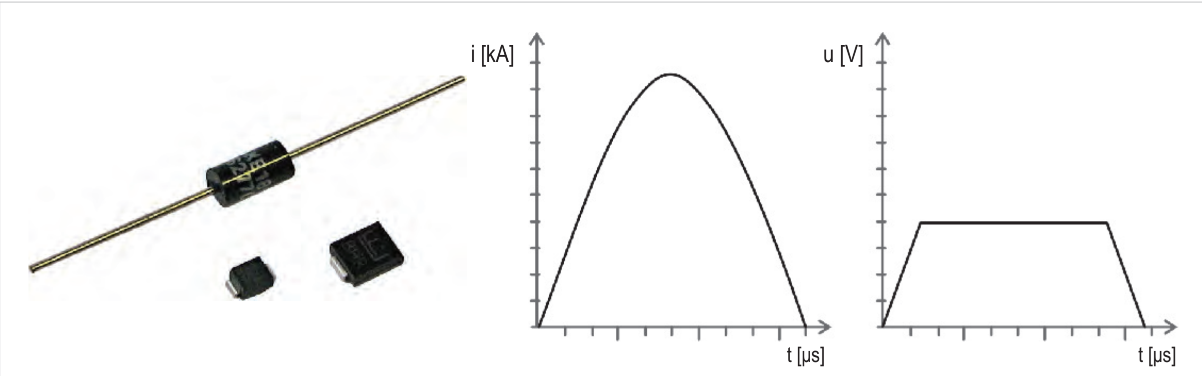


Figure 51: The response of suppressor diode on current shape 8/20 µs

5.2 Characteristics of surge protective devices

In the process of SPD selection it is important that the chosen device belongs to the required energy withstand capability class and fulfils certain electrical parameters. SPD classification is completed through the definition of general characteristics of a device and required conditions for its installation. On the other side, electrical parameters describe attributes of the SPD necessary for its installation in a given system and its response to different surges appearing in the system.

5.2.1 Classification of SPDs

Design topology:	According to this criterion SPDs are classified as: voltage-switching component, voltage-limiting component and serial or parallel combination of both.
Number of ports:	One-port SPD, two-port SPD.
Class:	Surge protection according to IEC standards is classified into three classes *(Figure 52)*:

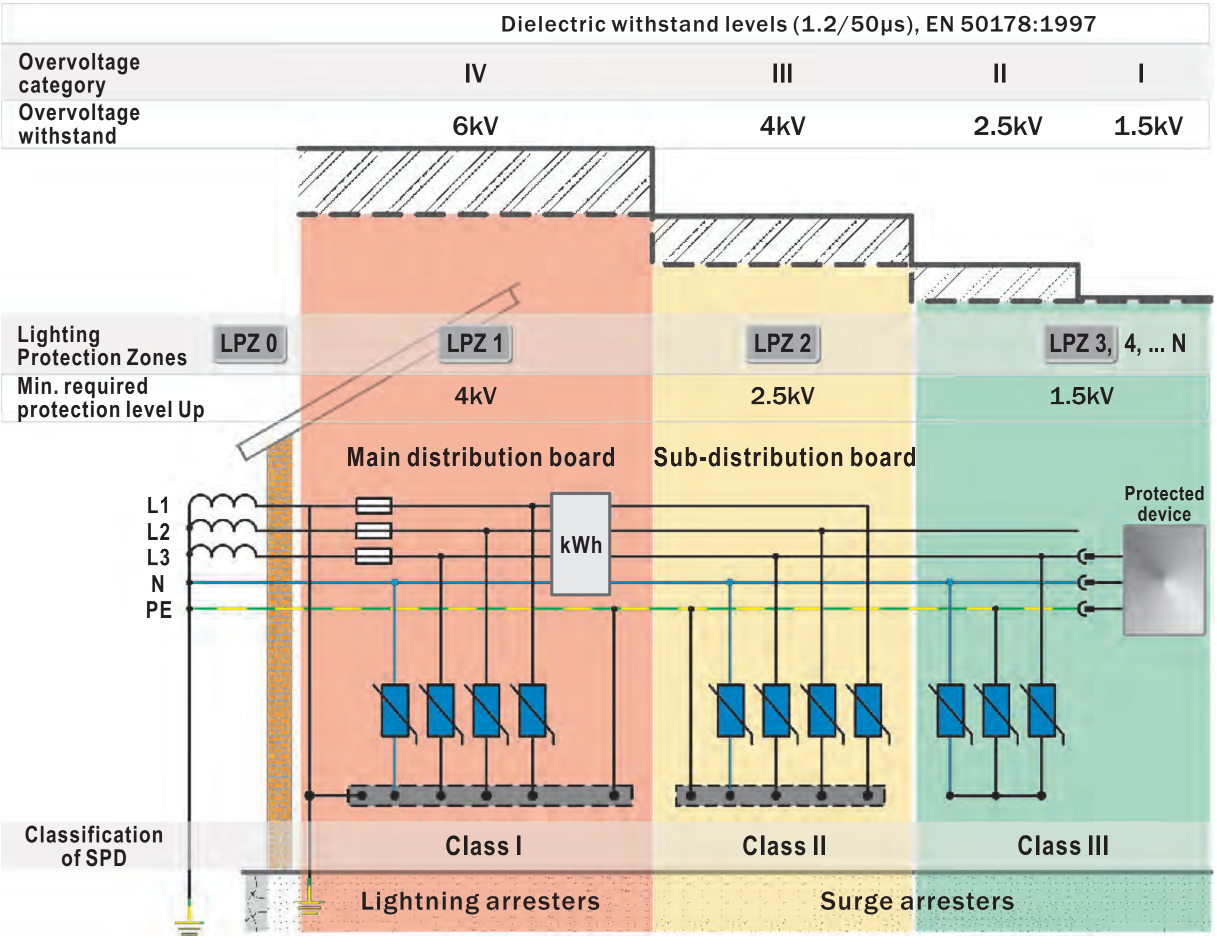


Figure 52: Surge protection according to IEC standards

Class I: The task of this stage is protection against direct and indirect lightning currents and potential compensation of the input point into a structure. The test pulse 10/350 μs *(Figure 53)* is used for tests of the protectors in this class.

Class II: SPDs in this class are intended for protection against indirect effects of lightning and reduction of remaining voltages from class I. The test pulse 8/20 μs *(Figure 54)* is used for tests of the protectors in class II.

Class III: Class III is positioned between the sub-distribution panel and the end consumer or within the power socket. Some of the more sensitive consumers have their own surge protection installed inside the device casing. The task of class III is protection against switching overvoltages and reduction of remaining voltages from class I and II. The test pulses 1.2/50 μs *(Figure 55)* and 8/20 μs are used in test procedures.

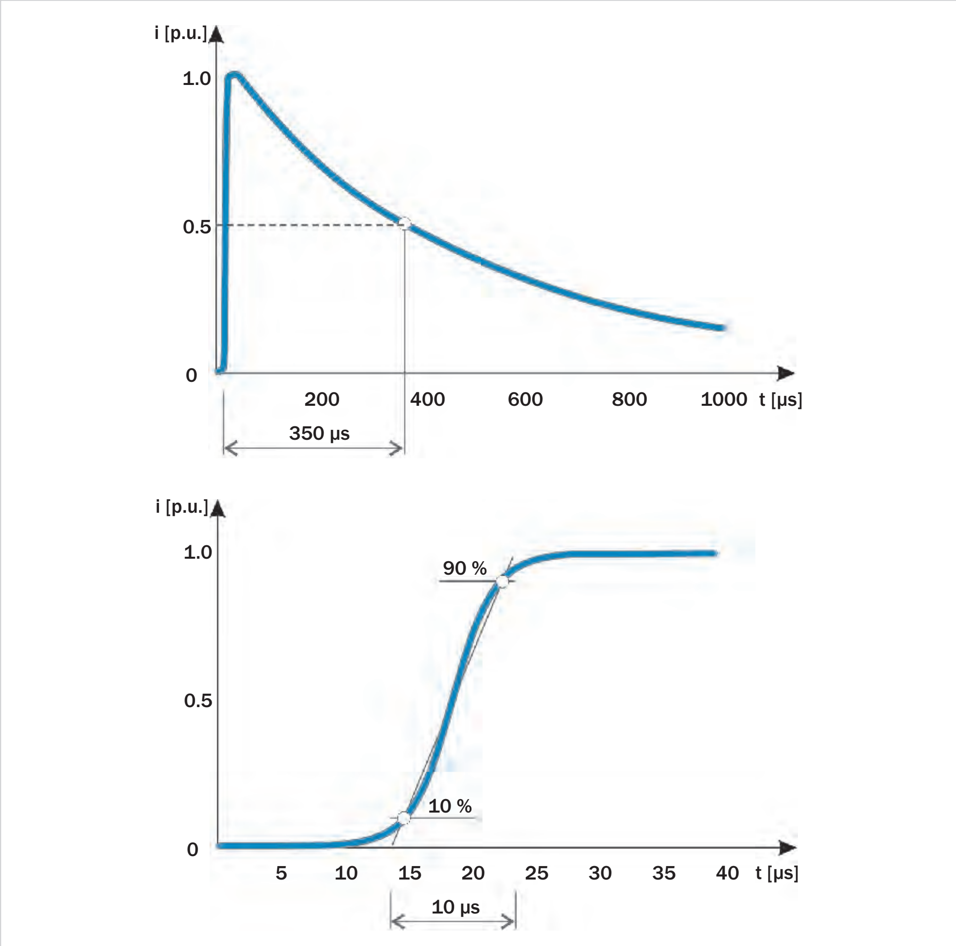


Figure 53: Standard current lighting surge waveform 10/350 µs

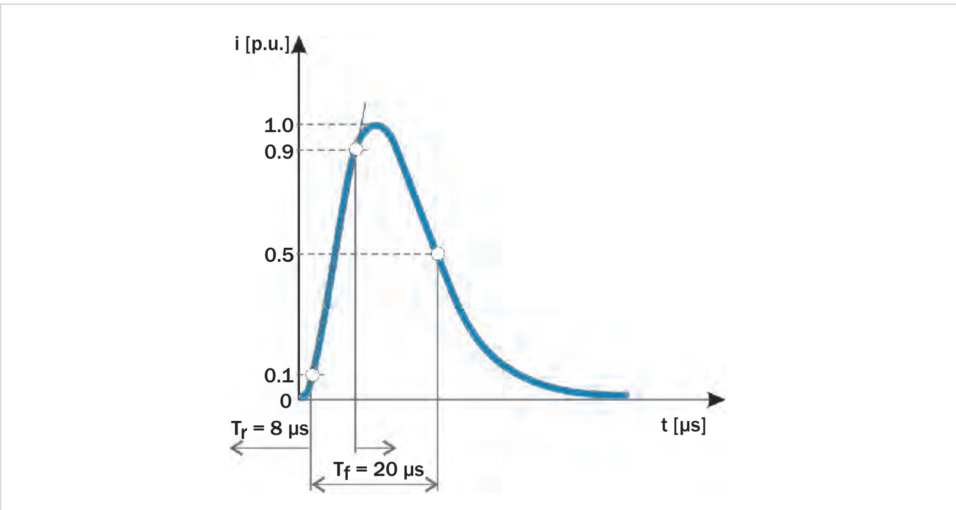


Figure 54: Standard current surge waveform 8/20 µs

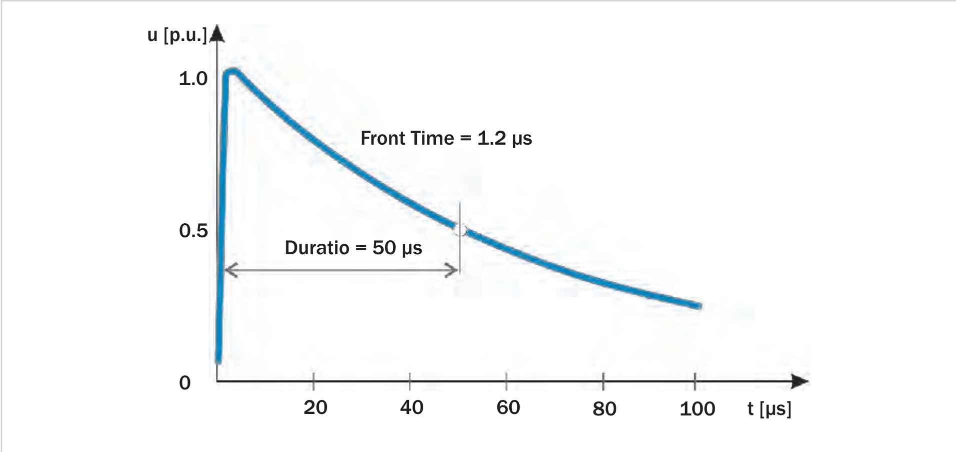


Figure 55: Standard voltage lighting surge waveform 1.2/50 µs

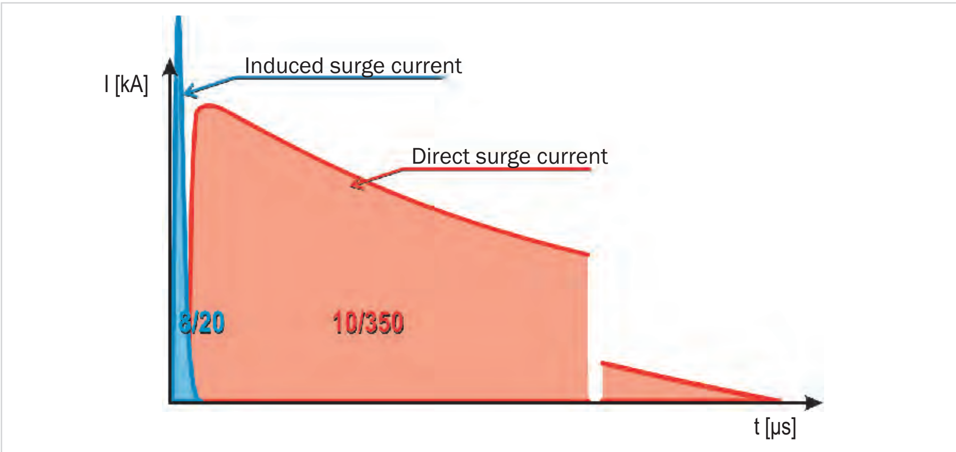


Figure 56: Correlation between current surge waveforms 8/20 and 10/350

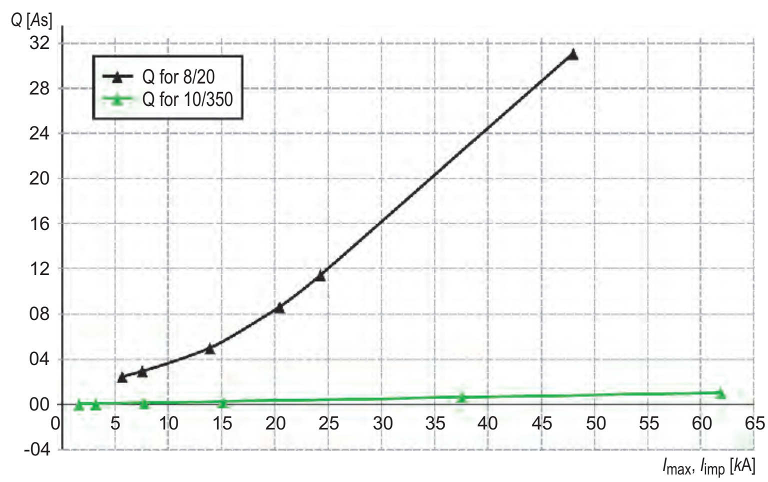


Figure 57: Correlation of charge Q between Imax (8/20) and Iimp (10/350)

Location:	indoors and outdoors;
Accessibility:	accessible, inaccessible;
Mounting method:	permanent or portable;
Disconnector:	location (external, internal, both external and internal, none), function (thermal, leakage current, overcurrent - installation of overcurrent device is realized in order to avoid overheating and destruction of SPD when SPD is unable to interrupt the power frequency short-circuit current);

5.2.2 Electrical parameters of SPD

Maximum continuous operating voltage U_C

U_C represents the value of maximum RMS or DC voltage that may be applied continuously between the terminals of SPD.

Temporary overvoltage U_{TOV}

U_{TOV} represents the value of power-frequency overvoltage of relatively long duration occurring on the network at a given location. It is usually associated with switching operations or faults, and/or nonlinearities. More detailed description of U_{TOV} is found in section 2.2.

Nominal discharge current I_n (only for classes I and II)

Maximum value the current attains through the SPD when a current waveshape of 8/20 μs is applied through the SPD. This parameter is used for the classification of the SPD for the class II test and also for preconditioning of the SPD for the class I and II tests *(Figure 54)*.

Impulse current I_{imp} for class I tests

It is used for classification of the SPD for the class I test and represents current peak value (I_{peak}) and charge (Q) tested according to the test sequence of the operating duty test. This current is associated with longer waveshapes (10/350 μs) presented in *Figure 53*. Correlation between current surge waveforms 10/350 and 8/20 is shown in *Figures 56* and *57*.

Nominal discharge current I_{max} for class II tests

This current value is used in operating duty test for the class II test. It is related to the maximum value of discharge current that can very rarely occur at the location of the SPD. Imax is associated with the class II tests.

Combination wave for class III tests

A wave characterized by defined voltage amplitude (U_{OC}) and waveshape under open-circuit condition and a defined current amplitude (I_{CW}) and waveshape under short-circuit conditions *(Figure 55)*.

***U_p* voltage protection level**

This parameter characterizes the performance of the SPD in limiting voltage across its terminals after surge occure. The voltage protection level is given by the manufacturer and may not be exceeded by:

- the neasured limiting voltage, determined for front-of-wave sparkover (if applicable and the measured limiting voltage, determined from the residual voltage measurements at amplitudes corresponding to I_n and/or I_{imp} respectively for test classes II and/or I;
- the measured limiting voltage at U_{OC} determined for the combination wave for test class III.

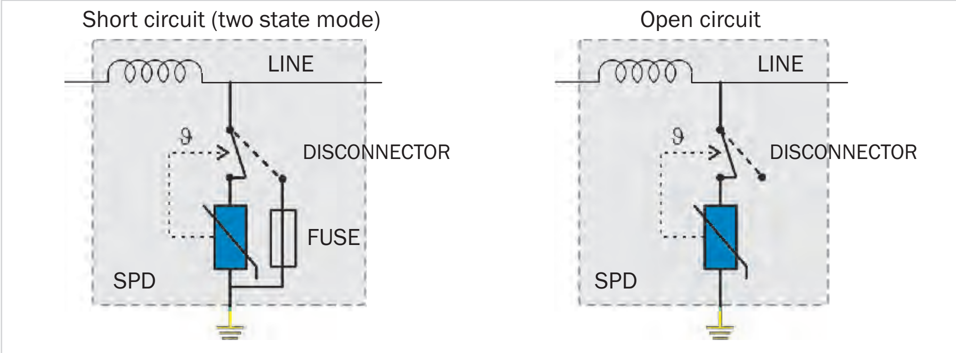
The value of this voltage is equal to or greater than the highest value of the measured limiting voltage. It is an extremely important parameter in the procedure of selecting SPDs; lower value of U_p level provides better protection.

Degradation

Degradation represents the change of original performance parameters after SPD is stressed with surge impulse.

Failure modes

These modes are used to define the compatibility of the SPD with other equipment, with its application and the devices used in conjunction with the SPD. Failure mode depends on the magnitude, number and waveshape of the surge current and voltage, short-circuit capacity of the power system and value of the voltage applied to the SPD at the time of failure. There are two failure modes of an SPD: short circuit and open circuit. The power supply of the protected device will not be interrupted after SPD operation, if disconnector is applied in the shunt branch with SPD *(Figure 58)*.



Figures 58a, b: Metal-oxide SPD failure modes

Short-circuit withstand:

1. Maximum continuous load current (for two-port SPDs or one-port SPDs with separate input and output terminals).
2. Voltage drop (for two-port SPDs or one-port SPDs with separate input and output terminals).

5.3 How to select proper value of back-up fuse

Surge Arrester			
Wave shape 8/20 µs (kA)	***Wave shape 10/350 µs (kA)***	***Back-up Fuse gL (A)***	***ISKRA ZAŠČITE Products***
13.0	3.0	50	
21.7	5.0	63	
43.3	10.0	125	PROTEC C
56.3	13.0	160	PROTEC B2S
65.0	15.0	200	
86.6	20.0	225	
108.3	25.0	250	PROTEC BS, PROBLOC BS
129.9	30.0	315	
151.6	35.0	315	PROTEC BS
173.2	40.0	400	
200	50.0	500	PROTEC BS

Table 7: Back-up fuse selection

A back-up fuse should be energy coordinated with maximum discharge current declared for certain type of SPD. A back-up fuse is a part of electric installation to avoid overheating and/or destruction in case SPD is unable to interrupt the power short circuit current. Value of a back-up fuse should be provided by the SPD manufacturer and cannot be changed by the user.

5.4 SPD selector

Procedure of SPD selection and installation in the LV power supply distribution system inside a structure (domestic building, industrial building, cellular base stations, TV broadcasting towers etc.) is conditioned by the system parameters of the LV power supply system as well as, by the characteristics of appliances in the protected object. Such characteristics determine parameters of the SPDs, their number and location inside the protected structure. IEC 61643 standard defines a general procedure of the installation of SPDs in the LV power distribution system. The procedure of the SPD selection described here is in accordance with the standard and other IEC standards in this field. General flowchart showing how to select and install SPD is illustrated in *Figure 59*.

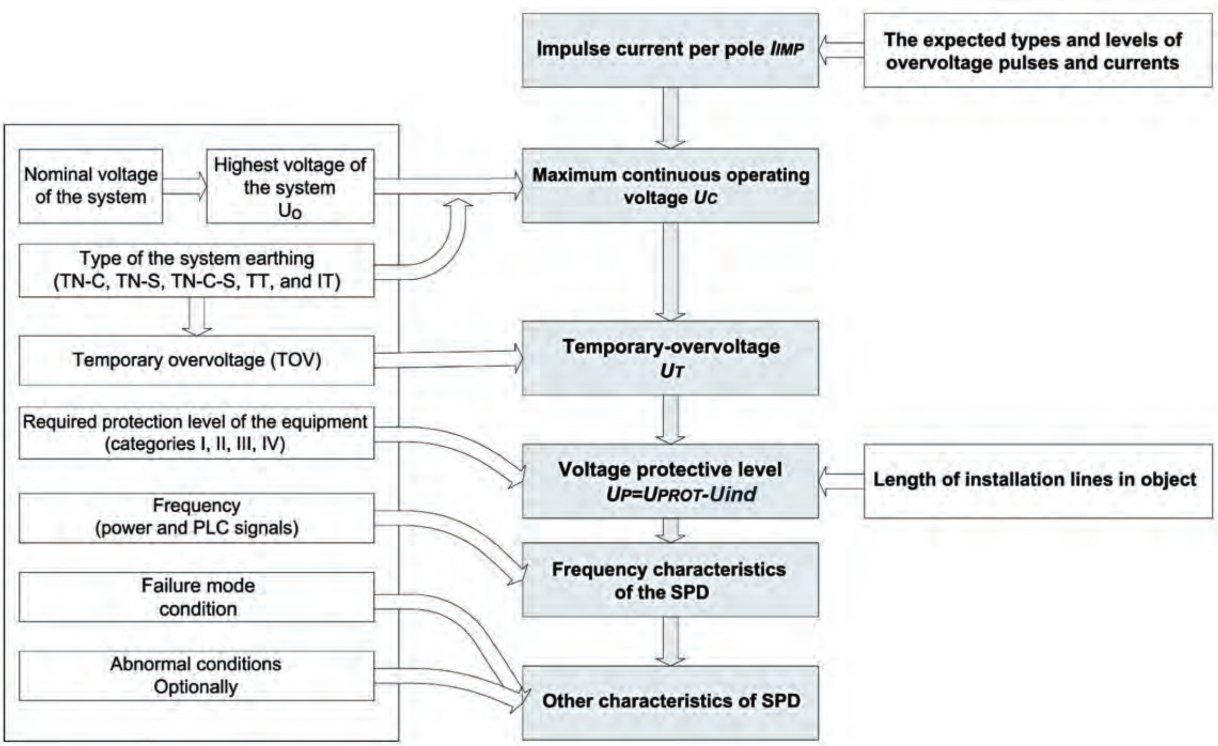


Figure 59: Flow diagram of the SPD selection

SPD selection is guided through the following steps:

5.4.1 The expected types and levels of overvoltage impulses and currents

The main risk to equipment failure connected to the power supply lines arises from direct and indirect lightning flashes. The first step in selecting SPD is thus predicting required types and levels of such overvoltage impulses and currents. The selected SPDs have to withstand the predicted values of voltages and the resulting current through them with a sufficiently high reliability.

SPDs are tested using standardized current waveforms (10/350 μs and 8/20 μs), and voltage 1.2/50 μs waveform. Magnitudes of these overvoltage impulses depend on the SPD class and typical model used for protection.

The power lines at the main distribution board are subject to partial direct lightning discharges. At this point, the class I SPD must be installed. Class I SPDs are suitable for current arrester pulses of 10/350 μs. Value of the current impulse at this point depends on the object location, installation of external lightning protection system, earthing resistance and existence of other objects in the vicinity.

There are three typical models used for determination of expected values of overcurrent impulses at the input of the protected structure:

- ☐ Model of exposed structure (exposed home with external lightning protection, cellular base stations, waterworks, RTV broadcasting transmitters, etc.) *(Figure 60)*. Model 1 has to be used for objects with installed external lightning protection systems.
- ☐ Model of two structures (earthing resistances are equal) closely together *(Figure 61)*. The first object is equipped with external lightning protective system while the second is not.
- ☐ Model of two or more structures (earthing resistances are different). In such case, current sharing depends on the earthing resistance of a particular object.

Figure 60: Current sharing in the case of exposed structure and installed external lightning protection system

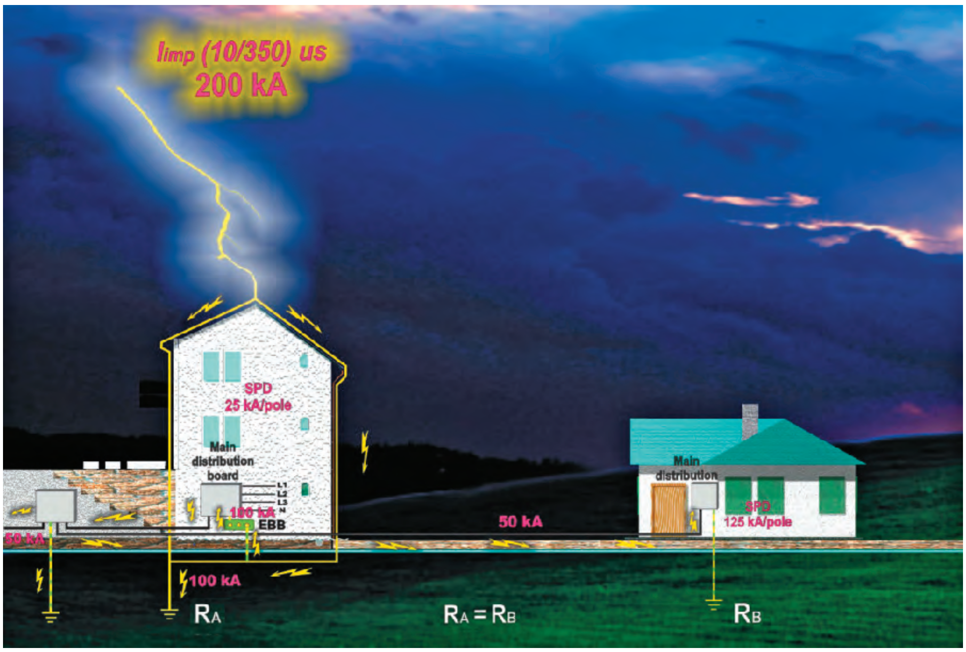


Figure 61: Current sharing in the case of objects in the vicinity (earthing resistances are equal)

It is required to choose appropriate model for own application and define current per pole I_{imp}/pole (for some systems also current between N and PE). For a three-phase TT system current $I_{N-PE} = 4\ I_{imp}$/pole, and for a single-phase TT system $I_{N-PE} = 2\ I_{imp}$/pole are required. Required values are summarized in *Table 8*.

Protection modes	***Impulse current (kA) (10/350 µs pulse)***
I_{imp}/pole (L-N or N-PE) (12,5 kA/pole is min. requirement according to IEC 60364-5-53: 2012-03	25 kA *(see Fig. 60)*
For TT system I_{imp}/pole (N-PE) (50 kA at 3 phase system or 25 kA at 1 phase system is min. Requirement according to IEC 60364-5-53: 2012-03	100 kA in case of L-N= 25 kA/pole *(see Fig. 60)*
I_{in}/pole (L-N or N-PE) (5 kA/pole is min. requirement according to IEC 60364-5-53: 2012-03	5 kA
For TT system I_{imp}/pole (N-PE) (20 kA at 3 phase system or 10 kA at 1 phase system is min. Requirement according to IEC 60364-5-53: 2012-03	20 kA in case of L-N= 5 kA/pole

Table 8: Current values

5.4.2 Characteristics of LV power supply system

Parameters of the LV power distribution system required for the definition of this stage are summarized in *Table 9*. Designer of the surge protective system should fill the parameters of the LV power supply system in the table. The values represent starting parameters in the process of the SPD selection.

System data	***Value or system parameter***
Type of the system (earthing) (TN-C, TN-S, TN-C-S, TT or IT)	TN-S in most case in Europe
The nominal voltage of the system (230/400) and highest voltage of the system	230/400 Vrms
The power frequency of the system and other high frequency signals	50 Hz
Temporary overvoltages in the LV power system	441 Vrms for all systems L - N, *see Table 1*
The required protection voltage levels of the equipment to be protected (this is defined through overvoltages categories: I, II, III, and IV), *see Fig. 52*	< 4.0 kV
Failure mode condition (definition of priority: power supply continuity or protection), *see Fig. 58*	Open circuit, power supply continuity
Abnormal conditions (ambient conditions some special conditions in the system)	Ex environment, temp. extended range: -40^{o}C to +70^{o}C

Table 9: Parameters of the LV power distribution system

5.4.3 Determining dielectric withstand category of protected devices

Protected devices in the structure have different dielectric withstand categories. The values of dielectric withstand are given by the manufacturer of a particular device. *Table 10* shows standardized values of dielectric withstand levels for different categories and their installation locations in the object.

The minimum required protection level represents the starting value in the process of designing overvoltage protection. The following calculation is based on this value. It shows the sensitivity of protected appliances to overvoltage impulses. The dielectric strength of the most sensitive device should be defined by *Table 11*.

Overvoltage category	*Dielectric withstand (kV)*	*Installation location*
IV	6.0	Utility terminal
III	4.0	Distribution panel
II	2.5	Power socket
I	1.5	Device

Table 10: Dielectric withstand levels

Dielectric withstand of device Ui (kV)*, see Fig. 52*	2.5 kV overvoltage category II

Table 11: Dielectric withstand of device Ui

5.4.4 Determining protection level at the installation point of SPD

In general, it is preferred to install the SPD at the entrance of the object in order to avoid current sharing through conductors located inside the structure. This approach will provide the protection of in-home power supply installations. If the SPD protection level of the first stage is not acceptable or equipment is not within the protective distance of the SPD installed at the entrance (main distribution board), the second class of the SPD should be installed at sub-distribution board and power socket. The voltage sensed by the device U_{prot} has to be less than dielectric strength:

$$U_{prot} \leq U\mathrm{i}$$

The voltage U_{PROT} is the sum of protection level of the SPD U_p and inductive voltage drop appearing on the conductors connecting SPD and protected device:

$$U_{prot} = U_p + U_{ind} = U_p + L\,\mathrm{d}i/\mathrm{d}t \leq U_i$$

From the last expression, protection level of the SPD (kV) is determined as:

$$U_p = U_{prot} - U_{ind} = U_{prot} - L\,di/dt$$

A distributed inductance of a typical conductor is approximately 1 μH/m, which at the current rate of rise of 1 kA/μs contributes approximately with 1 kV per meter length. Using the last expression, the required protection level of SPD at the entrance of the structure is determined.

The SPD class I installed at the main distribution board is intended to protect equipment classified for the installation in categories III and IV *(Table 12)*.

***Required protection level of SPD U_p (kV)**, see Fig. 52*	1.5 kV overvoltage category II

Table 12: Required protection level of SPD Up

Installation of additional SPD depends on the actual protection level of the selected device, protection level of the SPD class I and induced voltage U_{ind} in the installation conductor loop connection between SPD and protected appliances *(Figure 62)*. The value of protection level of the SPD at class I may be obtained from the catalogue, while the distance between the SPD and protected appliance may be obtained from the project documentation of the protected structure. If the condition

$$U_{PROT}=U_p+U_{ind} \leq U_i/2$$

is not achieved, installation of an additional SPD is necessary.

At the sub-distribution board SPD of class II should be installed. Such devices are intended to protect against the effect of induced voltages. Installations of the class III SPDs are based on the same procedure and the condition:

$$U_{PROT}(\text{after class II})=U_p(\text{class II})+U_{ind} \leq U_i/2$$

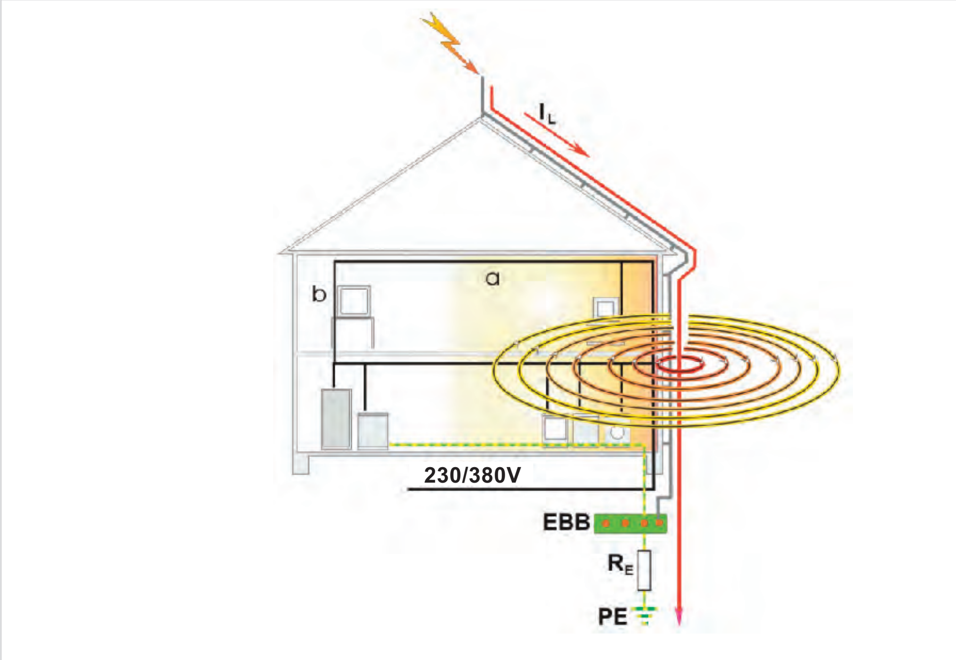


Figure 62: Voltage induction in the electrical installation due to lightning current in the down conductor

5.4.5 SPD selection

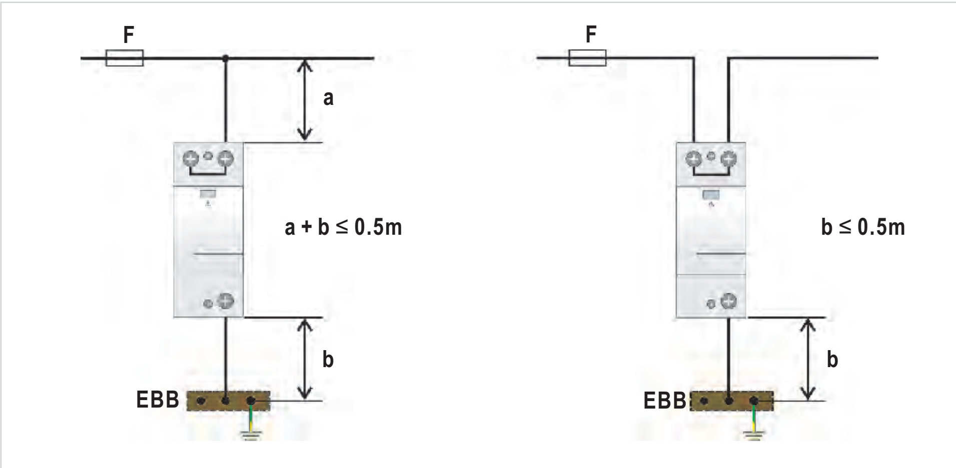
The previously described four steps define the necessary parameters for the SPD selection. In this phase, obtained parameters are used for proper selection of SPDs. The process of the SPD selection should be completed using the parameters in the same order as applied through the four steps. Therefore, the first parameter for SPD selection is impulse current per pole and optionally current between N and PE for the TT system.

Other obtained parameters from *Tables 9* and *10* determine other characteristics of the SPD located at the main distribution board. The selection of the class II SPD is based on the condition that nominal discharge current per pole I_n is greater than 5 kA 8/20 μs, while the current between N and PE in the TT case is greater than 10 kA 8/20 μs in the mono-phase system, and 20 kA 8/20 μs in the three-phase system. I_n is used in the classification of SPDs to test class II.

5.4.6 Installation of SPDs and analysis of its effect on the protection provided by SPDs

Installations of SPDs in different neutral-earthing systems are presented in Chapter 3.7. The class I SPDs should be installed in the main distribution board or other entrance points into the structure. The class II SPDs are mainly installed in the sub-distribution boards located at particular flats of the building. If necessary, the class III may be added in the power socket.

In order to achieve optimal overvoltage protection, connecting conductors of SPD should be as short as possible. Long lead length will reduce the protection efficiency of SPD. *Figure 63* shows preferred schemes of the SPD connection and maximum lengths of conductors.



Figures 63a, b: Example of correct connection and maximum length of connected conductors.

It is better to use the scheme b, where the effect of inductance is considerably reduced. The cross sectional area of the earthing conductor used to connect SPD should not be less than 16 mm^2 for the class I SPD and 6 mm^2 for classes II and III.

6. Applications

6.1 Households

SINGLE HOUSE

Based on the isokeraunic levels chart and lightning protection calculations, it was found that an isolated object (without the surrounding buildings) sized 11 x 11 m is located in the environment with a large annual flash density per km^2 required degree is Lightning Protection Level I. This suggests that it must be designed in accordance with all the parameters applied to this level.

The entire lightning system is tested by rolling sphere method. Imaginary sphere rolls up and over (and is supported by) lightning masts, shield wires, substation fences and other grounded metallic objects that can provide lightning shielding. An object/equipment is said to be protected from a direct stroke if it remains below the curved surface of the sphere. For Lightning Protection Level I, sphere radius is 20 meters *(Figure 31)*.

How to design appropriate lightning protection?

Safety network (5 x 5 meters) is established on the roof *(Figure 31)*, with additional air terminal mast for satellite antenna protection. Air terminal mast is protecting satellite antenna under certain fixed angle method (isolated solution).

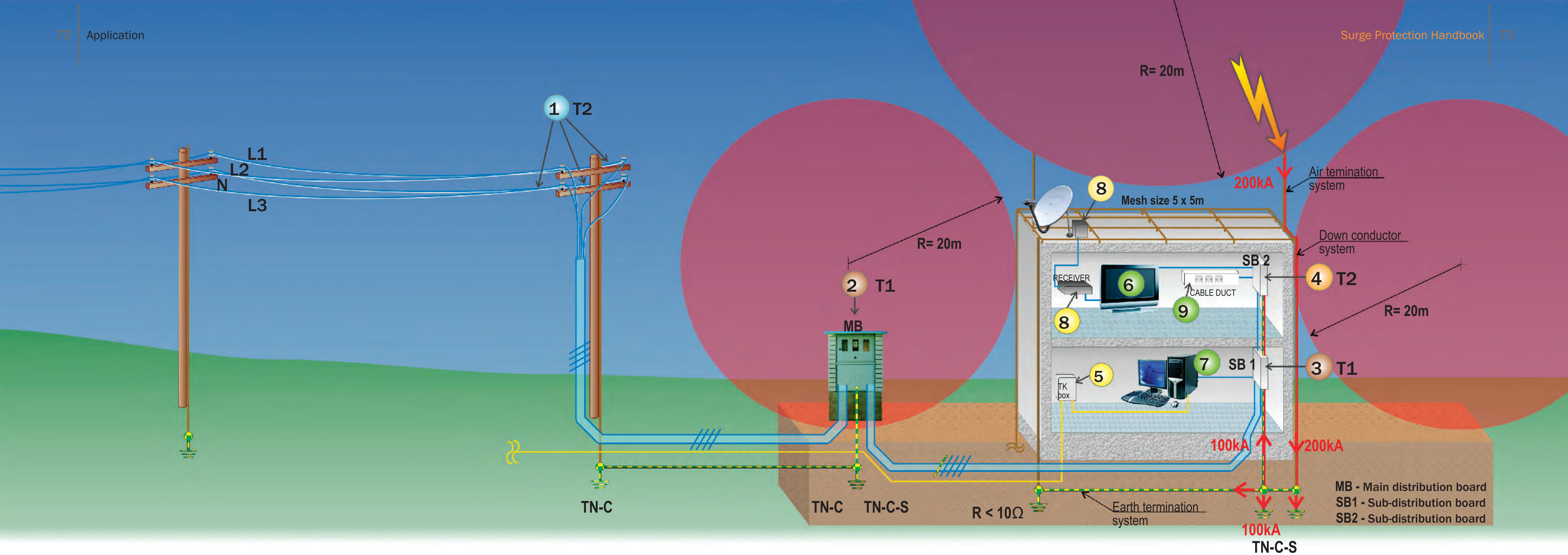
The antenna is thus located in Zone 0_B and the rest of the roof in zone 0_A. From the side of the building, deployment of the zones 0_A and 0_B is also visible. Given the dimensions of the building, four discharge paths exist.

All metal parts of the building are connected to the grounding bus bar, which is associated with the basic grounding and earthing ring, preventing the danger of step and touch voltages resulting from ground potential rise in the event of lightning. The earth resistance of the building is less than 10 ohms, which corresponds to the recommendations of IEC 62305 - 4. As the lightning current reaches up to 200 kA, it spreads in accordance with the principle of 50-50% *(Figure 60)*; 100 kA runs into the ground and 100 kA over the grounding bus bar into the installation, according to the recommended surge class I (3), strength I_{imp} = 25 kA (100 kA/4 wires in the TNS system) and is installed in the distribution box of the house. In the sub-distribution box (of the house) surge arrester of class II (4) is located. The area after sub-distribution box LPZ 2 is defined.

Underground telecommunications cable is at the entrance of the building, protected by a separator bar and relevant telecommunication protection (5) for each pair. From there, telecommunications cable continues to the computer, which is secured by a combined class III (7) protection for power and data xDSL transmission (LPZ 3). On the mounted channel, where different users are connected, the built-in socket of class III (9) protection is used. Coaxial cable, which enters the building from satellite antenna through the satellite receiver, is protected at the entrance into the building (8) and at the receiver (8) as well. TV is protected both as part of the antenna and power supply with a combined class III (6) protection. Antenna part protection is designed I_n=5kA, class C2 in accordance with EN 61643-21.

AERIAL LINES AND DISTRIBUTION BOARDS

The main distribution box is located in front of the building, i.e. in the 0_A zone and thus requiring arresters of the class I (2), the same as in the segment (3). As well low aerial lines voltage are protected with a special silicone surge arresters resistant to weathering (1), nearby the transition to an underground cable system. Mounting frequency depends on the electrical distribution company´s policy, calculations, law, finance, etc.



1 T2, Class II

PROTEC AQS 40
Uc = 275V
In = 20kA
Imax = 40kA
Up < 1.4 kV
IP ≥ 67

2 **3** T1, Class I

SAFETEC B(R) 25 (PROTEC B2S(R) 12.5)
Uc = 275V
In = 25kA
Imax = 100kA (60kA)
Iimp = 25kA (min. 12.5kA)
Up < 1.3 kV (1.5kA)
TOV resistant

4 T2, Class II

SAFETEC C(R) 40
Uc = 275V
In = 20kA
Imax = 40kA
Up < 1.6 kV
TOV resistant

5 C2

LPA 08 K1 xDSL protection modules
Uc = 180V
In = 5kA
Imax = 10kA
Up < 0.3V
LL/K strip + **K1** earthing contact
NMI-22-1 earthing mounting frame

6 T3, Class III/ C2

ZES 1M+5S
Power: Uc = 250V; Uoc = 3.0kV; Up < 1.0 kV
Data: Uc = 50V; In = 5kA; Up < 0.7kV

7 T3, Class III/ C2

ZE 200 xDSL
Power: Uc = 275V; In = 16A; Uoc/Isc= 6kV/3kA; Up < 1.5kV
Data: Uc = 175VDC; In = 2.5kA; Up < 0.3kV

8 C2

CCP-F Series
Uc = 180V
In = 10kA
Imax = 20kA
Up < 0.7kV

9 T3, Class III

MPE - Mini
Uc = 275V
Uoc/Isc = 6kV/3kA
Up < 0.8kV

Figure 64: Sample of surge protective device designed on single house

CONTENT - FIGURES

CONTENT - TABLES

Why ISKRA ZAŠČITE?

COMPLETE SURGE PROTECTION SOLUTIONS

- Lightning
- Surge
- Consulting
- Risk assessment

PROMPT TECHNICAL AND SALES SUPPORT

- Technical trainings and consulting
- Fast response for technical questions
- Favourable delivery times
- After sales support

WIDE RANGE OF OWN DEVELOPED PRODUCTS

- Low voltage
- Medium voltage
- Computer networks
- Data lines
- Telecommunications

FLEXIBLE PRODUCTION

- Small and large quantities
- Prompt launch of production new products
- High skilled staff
- Fast response time for changes
- Short preparation times

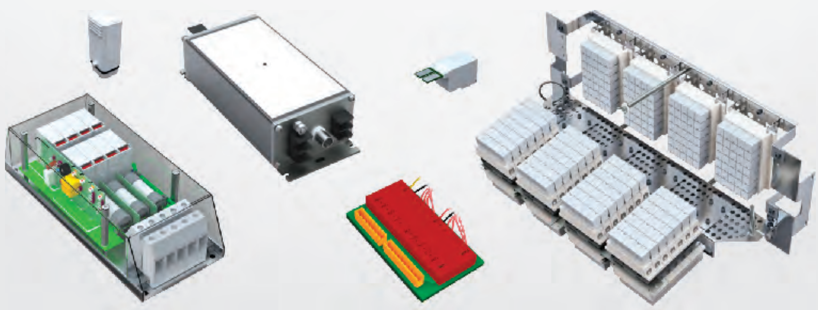
CUSTOM DESIGNED SOLUTIONS

- Domestic (EU) producer of MOVs and own development of GDTs
- Own testing laboratory
- 20% of staff working in R&D

TRUSTWORTHY COMPANY

- Present 20 years with production located in Europe
- 100% functional control and traceability
- ISO 9001 and in the process for ISO 14000

UL IEC OVE VDE PCT CCE CCC SIQ Baseefa Ex



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