

Definition and terminology according to the standard EN 61 643-11

The international standard EN 61 643-11 compiles lightning arresters and surge arresters under the integrated term SPD (Surge Protection Device).

Definition:

Surge protection device (SPD)

- a device that is intended to limit transient overvoltages and divert surge currents; it contains at least one nonlinear component.

One - port SPD

- an SPD connected in shunt with the circuit to be protected; a one-port device may have separate input and output terminals without a specific series impedance between these terminals.

Two - port SPD

- an SPD with two sets of terminals, input and output; a specific series impedance is inserted between these terminals.

Voltage switching type

- an SPD that has a high impedance when no surge is present, but can have a sudden change in impedance to a low value in response to a voltage surge; common examples of components used as voltage switching devices are spark gaps, gas tubes, thyristors (silicon-controlled rectifiers) and triacs; these SPDs are sometimes called "crowbar types".

Voltage limiting type SPD

- an SPD that has a high impedance when no surge is present, but will reduce it continuously with increased surge current and voltage; common examples of components used as nonlinear devices are varistors and suppressor diodes; these SPDs are sometimes called "clamping type".

Combination type SPD

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

Modes of protection

- an SPDs protective component may be connected line-to-line or line-to-earth or line-to-neutral or neutral-to-earth and combination there of; these paths are referred to as modes of protection.

Sparkover voltage of a voltage switching SPD

- maximum voltage value before disruptive discharge between the electrodes of the gap of a SPD; it is used for classification of the SPD class I and II by testing impulse with waveshape 1,2/50µs.

Nominal discharge current I_n (8/20)

- the crest value of the current through the SPD having a current waveshape of 8/20; this is used for the classification of the SPD for class II test and also for preconditioning of the SPD for class I and II tests; arrester must discharge this current at least 15 times without any essential changes in its qualities.

Maximum discharge current I_{max} for class II test

- crest value of a current through the SPD having an 8/20 waveshape and magnitude according to the test sequence of the class II operating duty test; I_{max} is greater than I_n ; arrester must safely discharge this current without an obvious damage or aberration from the temperature stability; records of the voltage and current development mustn't show any marks of disruptive discharge or sparkover.

Impulse current I_{imp}

- it is defined by a current peak value I_{peak} and the charge Q ; tested according to the test sequence of the operating duty test; this is used for the classification of

the SPD for class I test; arrester must safely discharge this current without any obvious damage or aberration from the temperature stability; records of the voltage and current development mustn't show any marks of disruptive discharge or sparkover.

1,2/50µs voltage impulse

- a voltage impulse with a virtual front time (time to rise from 10% to 90% of the peak value) of 1,2µs and a time to half-value of 50µs; it is used for classification of the SPD class I and II.

Combination wave

- the combination wave is delivered by a generator that applies a 1,2/50µs voltage impulse across an open circuit, and an 8/20 current impulse into a short circuit; the voltage, current amplitude and waveforms that are delivered to the SPD are determined by the generator and the impedance of the SPD to which the surge is applied. The ratio of peak open-circuit voltage to peak short-circuit current is 2Ω; this is defined as the fictive impedance Z_f ; the short-circuit current is symbolized by I_{sc} ; the open-circuit voltage is symbolized by U_{oc} .

Note: In practice when it comes to the arresters (class III) there are data I_{max} (8/20) and I_n (8/20) often mentioned in place of U_{oc} because of the commercial reasons. They are always mentioned in relation to the stated voltage protection level U_p (the data concerned are always derived from the tests by the standardized combined impulse with the amplitude U_{oc} ; the test is carried out by use of a hybrid generator with inside resistance 2Ω).

Specific energy W/R for class I test

- the energy dissipated by the impulse current I_{imp} in a unit resistance of 1Ω; it is equal to the time integral of the square of the current; expressed in kJ/Ω or in kA²s.

$$W / R = \int i^2 \cdot dt$$

Charge Q

- it equals the time integral of the current according to the time; expressed in As.

$$Q = \int i \cdot dt$$

Thermal stability

- an SPD is thermally stable if after the operating duty test causing temperature rise, the temperature of the SPD decreases with time when the SPD is energized at specified maximum continuous operating voltage and at specified ambient temperature conditions (it is monitored for 30 minutes, active power dissipation must show constant decline for the last 15 minutes).

Short-circuit withstand capability I_p

- the SPD shall be able to carry the power short-circuit current until it is interrupted either by the SPD itself, by an internal or external overcurrent disconnecter or by the backup overcurrent protection; expressed in kA_{rms} (tested according to short-circuit withstand capability test in conjunction with backup overcurrent protection).

Nominal voltage U_N

- an effective value of the alternating voltage or value of the direct voltage, which is set for the SPD by manufacturer

Maximum continuous operating voltage U_c

- the maximum r.m.s. or d.c. voltage which may continuously applied to the SPDs mode of protection; this is equal to the rated voltage.

Nominal current I_N of load

- the maximal effective value of the alternating current or value of the direct current, which can be constantly taken away by the load connected to the SPD output.

Continuous operating current I_c

- the current flowing through each mode of protection of the SPD when energized at the maximum continuous operating voltage U_c for each mode.

Note: I_c corresponds to the sum of currents flowing in the protective component of the SPD and in all internal circuits connected in parallel with the protective components of the SPD.

Follow current I_f

- current supplied by the electrical power system and flowing through the SPD after a discharge current impulse; the follow current is significantly different from the continuous operating current I_c ; expressed in kA_{rms}.

Follow current interrupting rating I_{fi}

- the prospective short-circuit follow current that is SPD able to self-extinguish after its previous activation (without a back-up fuse); this current is indicated in some company's materials as "Follow current extinguishing capability at U_c " or "Eliminates short circuit current without back-up fuse at U_c ", alternatively "Quenching short circuit current without back-up fuse".

Voltage protection level U_p

- a parameter that characterizes the performance of the SPD in limiting the voltage across the terminals, which is selected from a list of preferred values; this value shall be greater than the highest value of the measured limiting voltages.

Operating temperature ϑ

- an extent of the allowed surrounding temperatures, where manufacturer guarantees the right operating SPD.

Response time t_A

- the response time defines the reaction speed of protective elements built-in the SPD; the response time can vary in different limits, which are dependent on the rate of rise du/dt of the impulse voltage or on the di/dt of the impulse current.

Insertion loss

- at a given frequency, the insertion loss of an SPD connected into a given power system is defined as the ratio of voltages appearing across the mains immediately beyond the point of insertion before and after the insertion of the SPD under test; this result is expressed in decibels (dB).

SPD disconnecter

- a device for disconnecting an SPD from the system in the event of SPD failure; it is to prevent a persistent fault on the system and to give visible indication of the SPD failure; some kinds of the SPD are extra fitted with so-called non-potential signal contact for needs of remote failure signalling.

Backup overcurrent protection

- an overcurrent device (e.g. fuse or circuit breaker), which is a part of the electrical installation located externally upstream of the SPD, to avoid overheating and destruction in case the SPD is unable to interrupt the power frequency short-circuit current.

Residual current device (RCD)

- an electromechanical switching device or association of devices intended to cause the opening of the contacts when the residual or unbalanced current attains a given value under specified conditions.

Degrees of protection provided by enclosure (IP code)

- the extent of protection provided by an enclosure against access to hazardous parts, against ingress of solid foreign objects and/or against ingress of water (see IEC 60 529).

Impulse Test Classification

Class I tests

- tests carried out with the nominal discharge current $I_n(8/20)$, the 1,2/50 μ s voltage impulse and the maximum impulse current $I_{imp}(10/350)$ for class I test.

Class II tests

- tests carried out with the 1,2/50 μ s voltage impulse, with the nominal discharge current $I_n(8/20)$ and the maximum discharge current $I_{max}(8/20)$ for the class II test.

Class III tests

- tests carried out with the combination wave (1,2/50 μ s; 8/20 μ s).

Nominal voltage

- it is an effective value of the voltage between operating conductors of LV power system; in 3-phased LV power system, it is an effective value of the delta voltage.

Overvoltage

- any voltage, which exceeds the appropriate peak value of the highest steady voltage of LV power system under the normal operating conditions; it is expressed either absolutely or as a relative magnitude by means of overvoltage factors.

Transverse overvoltage

- a voltage between two line conductors of LV power system at the moment of its load (typically between busbars L/N).

Lengthwise overvoltage

- a voltage between particular line conductors of LV power system on earthing (typically between busbars L/PE event. N/PE).

Switching overvoltage

- an overvoltage between a phase and earth or between phases at a given place of the LV power system, caused by switching operation, short-circuit or by other cause.

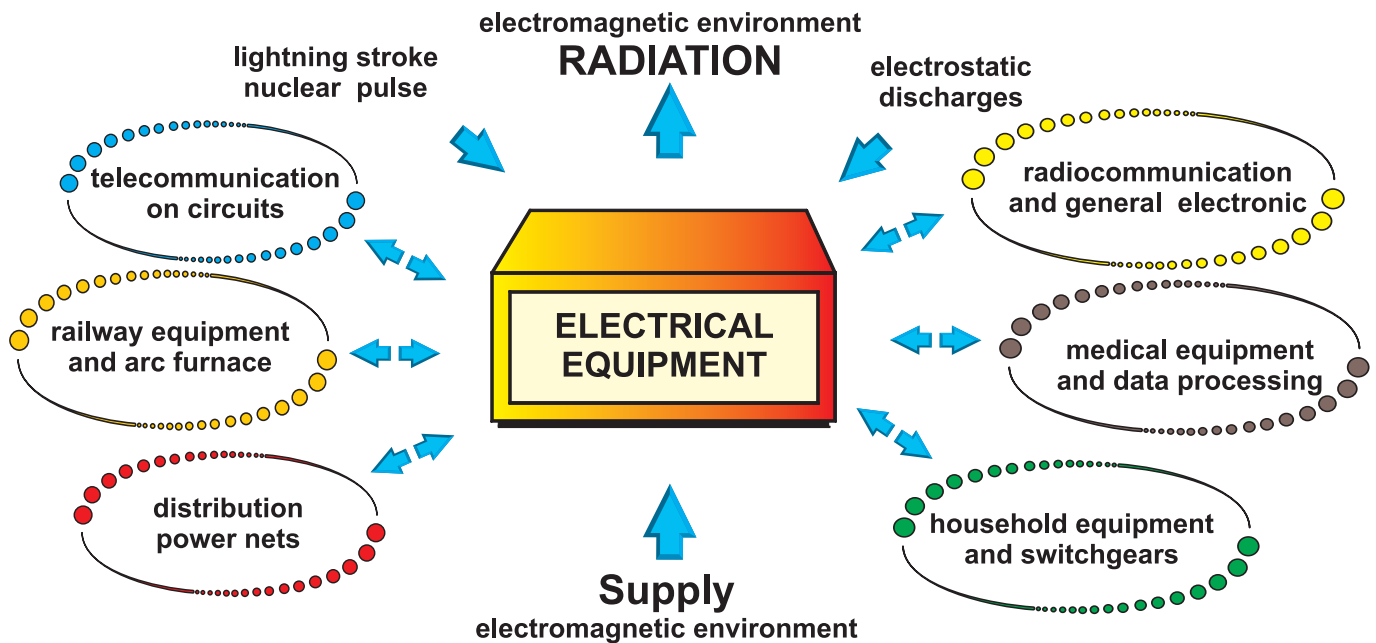
Atmospheric overvoltage

- an overvoltage between a phase and earth or between phases at a given place of the LV power system, caused by discharge of atmospheric electricity (lightning).

Electromagnetic compatibility

Electromagnetic compatibility is a discipline, which is involved in securing maximum reliability of each electrical and electronic equipment and devices. In nature, there are relations between elements or system components, which must be predicted in advance in order to prevent interference. Electromagnetic compatibility seems to be a relatively new discipline, which arose in the sixties in the USA. It started on basis of the necessity to secure flawless and reliable activity of electrotechnical equipment and devices working especially in military or aerospace systems. Electromagnetic compatibility begins to affect all of us by the development of electronics, especially microprocessor technique, which effect our day to day lives. That is why EU issued the directive No. 89/336/EEC, whose aim is to enforce electromagnetic compatibility conditions on all states involved including the states that have signed associate agreement.

The Czech Republic has also signed this agreement so all the conditions of the directive apply. Of course it is necessary that the Czech Republic would gradually have made appropriate legislative steps, which would turn this directive to live. The decree of the Czech government No. 17/2003 and the law No. 22/97 Coll. means non-replaceable move in this sphere.



Other very important decrees concerning this sphere are obligatory norms as for example CSN 332000-1, paragraph 131.6.2 saying:

„People, livestock and also property must be protected against harm caused by surge, which can arise from other reasons, for example atmospheric events, switching overvoltages and static electric.“

At the figure there are particular links among electrical equipment and environment shown. They can be expressed as two relations:

- **electromagnetic susceptibility (resistance)**
- **electromagnetic interference (disturbance)**

Surge is just one of the main problems arising from the solving of electromagnetic compatibility problems.

If we deal with parameters of electric energy, we must remember four qualitative aspects:

- the level of voltage- the level of frequency- nonlinear distortion- the level of surge (frequency of surge peaks)

On basis of these aspects the electric energy can be taken as merchandise and these qualitative parameters can be required. The main aim is to create such conditions that would be able to ensure maximum reliability and functioning of all the electronic equipment connected to LV power systems.

Terms and definitions of surge

Overvoltage is any voltage, whose peak value exceeds the appropriate peak value of the highest operating voltage in the LV power system. Overvoltage is usually an accidental phenomenon, which differs in time history and the place of its occurrence. Its parameters are defined by its cause (lightning stroke, switching in heavy-current network and so on) and also by electrical character of the circuit (wave resistance, ending impedance, discharge ability and so on). In the past few years the range of current and voltage courses for different uses has been standardized. These courses enable implementation of testing on equipment and constructive elements under the same conditions. In the following text the most important parameters of the most used standardized courses will be defined (according to EN 61 643-11, IEC 60-1 and CSN 34 5640).

Peak value (amplitude) U_{max} , I_{max}

- peak value is the maximal value of voltage or current, which is achieved by monitored impulse course

Front of impulse

- a part of voltage or current impulse before the peak value

Front time of current impulse T_1

- 1,25multiple of the time interval between moments, when actual current value rise from 10% to 90% of the peak value

Front time of voltage impulse T_1

- 1,67multiple of the time interval between moments, when actual voltage value rise from 30% to 90% of the peak value

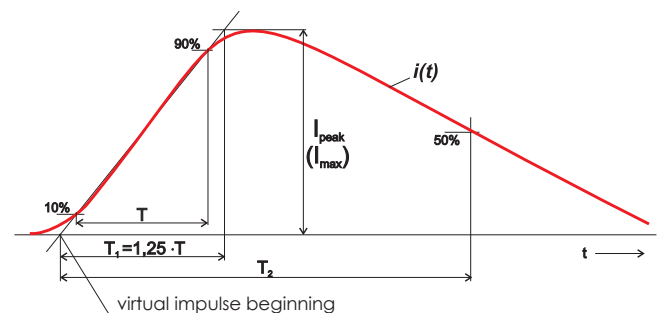
Tail of impulse

- a part of voltage or current impulse after the peak value

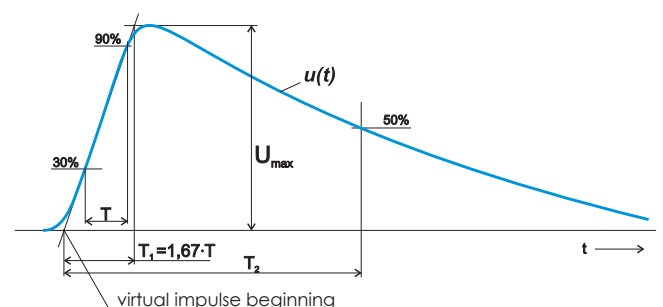
Time to half-value T_2

- the time interval between virtual beginning of impulse and the moment, when observed course reduces to 50% of its peak value

Note: The virtual beginning is an intersection of time axis and bisector, which goes through points, where actual value of the front of impulse at first time reaches partly given lower value and partly given higher value ...in detail see the following two figures.



Current impulse, definition of front time and time to half-value



Voltage impulse, definition of front time and time to half-value

Standardized testing current impulse

- two basic types of testing current impulses are used during SPD tests:

a) testing impulse of lightning current $I_{imp}(10/350)$ – it is used for simulation of lightning current (so-called test by lightning current)

b) testing current impulse $I_{max}(8/20)$ – it is used for simulation of indirect effect of lightning and switching overvoltages

Arrester must discharge cca 17,5x higher charge during test by the testing impulse of lightning current $I_{imp}(10/350)$, than during testing by the current impulse $I_{max}(8/20)$ with the same amplitude. Also resulting in a different construction of the lightning current arresters tested by the lightning current impulse $I_{imp}(10/350)$ and surge arresters tested by the current impulse $I_{max}(8/20)$.

Course and parameters of lightning voltages and currents

In the chart shown below there are typical courses and parameters of lightning impulse voltages and currents, which occur in conductive parts of landscape, building constructions and metal lines in consequence of lightning stroke (taking in account influences caused by galvanic, inductive or capacitive coupling).

The typical values of lightning impulse voltages and currents, which occur in conductive parts of landscape, building constructions and metal lines

	Surge (peak values)	Currents (peak values)	Halftail time
Direct lightning stroke	- up to few hundreds of kV	> 30kA (50% of all the strokes) > 100kA (5% of all the strokes) > 150kA (1% of all the strokes)	c. 200 μ s ... 1000 μ s
Galvanic coupling	- up to few tens of kV	distant strokes: up to 1kA near strokes: up to few kA straight strokes: up to few tens of kA	typical: c. 700 μ s
Inductive coupling	- transverse surge up to few kV - lengthwise surge up to few tens of kV	up to few kA up to few tens of kA	typical: c. 20 μ s
Capacitive coupling	- transverse surge up to few kV - lengthwise surge up to few kV	up to few kA	typical: 50 to 100 μ s

Testing current impulse in the waveform of $10/350\mu$ s is most often used for simulation of currents infiltrating into power lines and electric equipment in consequence of galvanic coupling. In case of inductive and capacitive coupling the voltage and current impulses are considerably shorter. The examination of interfering lightning effects in relation to inductive surges (currents) in consequence of inductive coupling is most often carried out by the testing current impulses in the waveform of $8/20\mu$ s. The examination of lightning effects in relation to interfering surges (currents) in consequence of capacitive coupling is similarly carried out by the testing voltage impulses in the waveform of $1,2/50\mu$ s.

Kinds of surge couplings

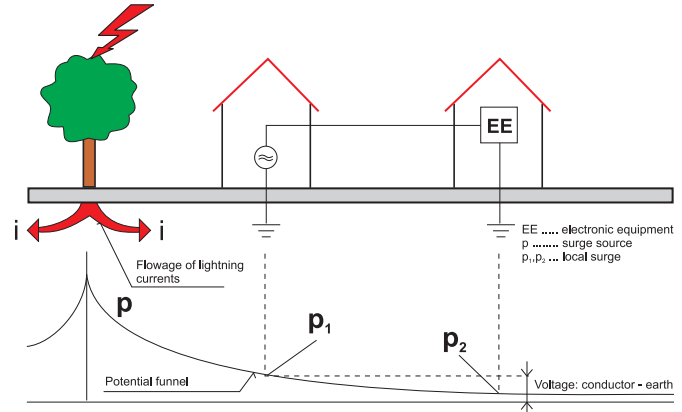
Generally

Disturbing energies (e.g. voltages, currents, fields) can infiltrate into the building by ways of different couplings whereas cabling and its layout represent an important part here. Following, there are three most important mechanisms of coupling described.

Galvanic coupling

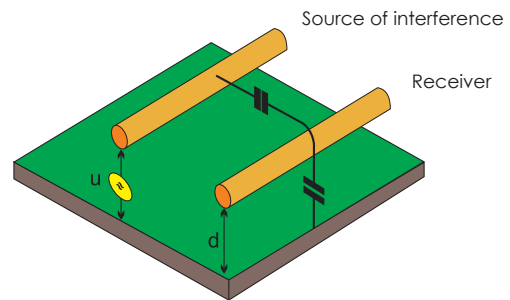
During near and direct lightning strokes into the lightning conductors of buildings, the overvoltage shows in consequences of a galvanic coupling. The galvanic coupling is given by a different size of ground potentials along the building. By arrangements for equipotential bonding (earth electrodes, protective connection etc.) it is possible to achieve certain flattening of potential funnel. This flattening results in reducing the difference of potentials in regard of its center - place of stroke. However, the difference of potentials can never be fully eliminated in conse-

quence of impedances of conductive lines of LV power system and indispensable impedance of earth.



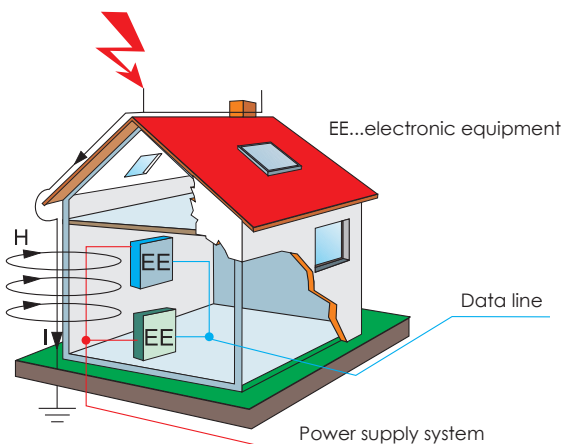
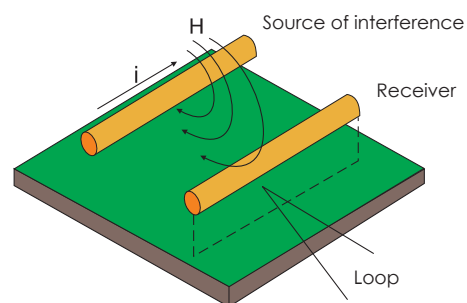
Capacitive coupling

There is always a capacitive coupling (parasitic capacity) between the source of interference and the receiver. The higher the front rate of rise of the disturbing voltage impulse (du/dt) is, the stronger its interference effect is.



Inductive coupling

There is always an inductive coupling (magnetic field) between the source of interference and the receiver. The higher the front rate of rise of the disturbing current impulse (di/dt) activating the magnetic field is, the higher the interference effect is.



Direct Lightning Stroke

A lightning stroke is an electric discharge between an electrically charged cloud and earth surface (earth lightning), between two or more clouds and each other or between parts of one cloud (cloud lightning). Just a small percentage of strokes happens between the surface and the clouds. The lightning strokes originate in the „storm cells“, which stretch average out up to few kilometers. Every storm cell is active for up to 30 minutes and generates from two to three lightning strokes per minute. The storm cell often reaches the height of over 10 kilometres, whereas the bottom visible part of the clouds is usually at the height of one to two kilometres. In the centre of the storm cell there exists a strong rising air flow, which causes separation of positive and negative charges. The positive charge is usually binded on the frazils at the top of the storm cell, while negative charge is usually binded on water drops at the bottom of the cell. Nearby the earth the cell is charged with positive charge which is usually caused by discharge especially from forest. Beyond the storm cells originating from the summer heat there are storm cells originating from the frontal cloudiness as a result of big air masses movement. The storm frequency depends on the season. In summer months (July–August) there are on average 5 times more storms than in winter months (December–February). The environmental heating up supports the storm creation. In autumn warm water near the seacoast gives the necessary energy for the storm creation. According to IEC 1312-1:1995 and IEC 62305 it is possible to describe lightning charges by five basic parameters:

	Unit	Range
Total impulse lightning charge Q_f	C	max 300C
The first stroke charge Q_s	C	max 100 C
The first stroke peak current I_{imp}	kA	max 200kA
Specific energy the first stroke current W/R	MJ/Ω	max 10 MJ/Ω
Rate of rise of the current dI/dt	kA/μs	max. 200 kA/μs



Another important parameter, which is presented during the classification of storm activity is so-called intensity of storm activity or the frequency of the lightning strokes per km^2/year . The frequency in our geographical latitudes varies from 2 to 8 strokes/ km^2/year , but in subtropical and tropical climate it varies from 30 to 70 strokes/ km^2/year .

General distribution of lightning current when an object is thunderstruck, principle of LV power system protection thanks to cascaded 3-stage protection

Protection system of LV power system composited of lightning current arresters and surge arresters SPD must be able to discharge lightning currents or their substantial parts without their damage. It is generally recommended to come out from the ohmic resistance of the building earthing, pipeline, power distribution system and so on for the purposes of establishing current distribution going through SPD in case of direct lightning stroke into a building protected by the outside lightning system. The following figure shows a typical example of lightning current distribution in an object hit by direct lightning stroke.

Where an individual evaluation is not possible, it can be assumed that:

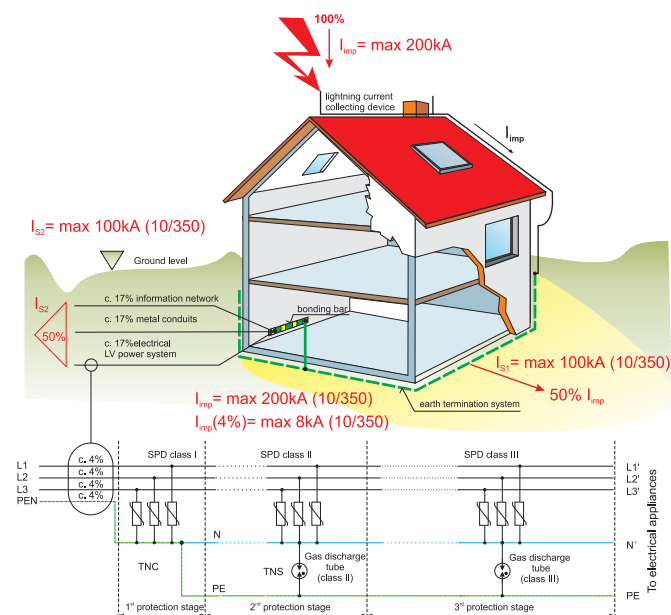
- 50% of the total lightning current $I_{imp}=200\text{kA}$ (10/350).... $I_{s1}=100\text{kA}$ (10/350) enters the earth termination system of the LPS (lightning protection system) of the structure considered

- 50% of $I_{imp}=200\text{kA}$ (10/350).... $I_{s2}=100\text{kA}$ (10/350) is distributed among the services entering the structure (external conductive parts, el.power, communication lines, etc.) The value of the current flowing in each service I_i is given by I_s/n , where n is the number of the above mentioned services (see the above figure).

For evaluating the current I_v in individual conductors in unscreened cables, the cable current I_i is divided by m , the number of conductors, i.e. $I_v = I_i/m$.

For shielded cables, the current will flow along the shield. Requirement on dimensioning of protective system SPD in the most usual connection of the building and LV power system (TNC - system 230/400V/50Hz) results from this reasoning:

For maximum lightning current size $I_{imp} = 200\text{kA}$ (10/350) it is enough to dimension the protective cascade of each phase conductor entering the object on cca 4% I_{imp} , that is on cca 8kA (10/350) in most cases.



Distribution of protected area into the lightning protection zones

The standard IEC 13 12-1 and IEC 62 305 defines the lightning protection zones LPZ from the respect of the direct even indirect lightning effect. These zones are characteristic thanks to fundamental breaks of the electromagnetic conditions in their limited zones.

LPZ 0_A:

Zone where items are subject to direct lightning strokes, and therefore may have to carry up to the full lightning current; the unattenuated electromagnetic field occurs here.

LPZ 0_B:

Zone where items are not subject to direct lightning strokes, but the unattenuated electromagnetic field occurs.

LPZ 1:

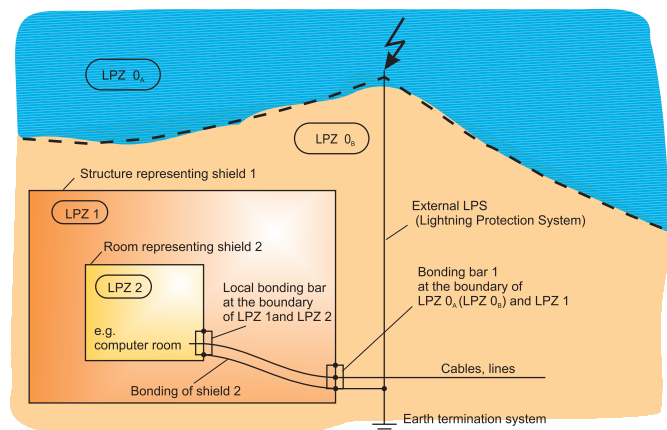
Zone where items are not subject to direct lightning strokes and where currents on all conductive parts within this zone are further reduced compared with zones 0_B. In this zone the electromagnetic field may also be attenuated depending on the screening measures.

The subsequent zones (LPZ 2 and so on):

If a further reduction of conducted currents and/or electromagnetic field is required, subsequent zones shall be introduced. The requirement for those zones shall be selected according to the required environmental zones of the system to be protected. In general, the higher the number of the zones, the lower the electromagnetic environment parameters. At the boundary of the individual zones, bonding of all metal penetrations shall be provided and screening measures might be installed.

Note: Bonding at the boundary between LPZ 0_A, LPZ 0_B and LPZ 1 is defined in IEC 13 12-1 and IEC 62 305. The electromagnetic fields inside a structure are influenced by opening windows, by currents on metal conductors (e.g. bonding bars, cable shields and tubes), and by cable routing.

The following figure shows an example for dividing a structure into several zones. There all electric power and signal lines enter the protected volume (LPZ 1) at one point, and are bonded to bonding bar 1 at the boundary of LPZ 0_A, LPZ 0_B and LPZ 1. In addition, the lines are bonded to the internal bonding bar 2 at the boundary of LPZ 1 and LPZ 2. Furthermore, the outer shield 1 of the structure is bonded to bonding bar 1 and the inner shield 2 to bonding bar 2. Where cables pass from one LPZ to another, the bonding must be executed at each boundary. LPZ 2 is constructed in such a way that partial lightning currents are not transferred into this volume and cannot pass through it.



The above described segmentation of the protected object into protection zones gives possibilities of active protection of the LV power system thanks to insertion of the protective SPDs (usually at the zone boundary LPZ 0→1 and LPZ 1→2) and other protective SPDs at the zone boundary LPZ 2→3. Standardly it is recommended to insert so-called 1st stage protection – surge arrester class I tested by lightning current $I_{imp}(10/350)$ at the zone boundary LPZ 0→1. It is recommended to insert 2nd stage protection – surge arrester class II tested by testing impulse $I_{max}(8/20)$ at the boundary zone LPZ 1→2. At the boundary of LPZ 2→3 and subsequently along the consequential circuit there is also recommended to shoulder after every cca 10m by so-called 3rd stage protection class III also tested by testing impulse $I_{max}(8/20)$ or U_{OC} . For extra important protected equipment it is recommended to secure it by a quality continuous surge protection class III with high-frequency filter at the boundary of LPZ 2→3. If there are adjacent structures between which power and communication cables pass, the earthing system shall be interconnected, and it is beneficial to have many parallel paths to reduce current in the cables. A meshed earthing system fulfills this requirement. The lightning currents are further reduced, e.g. by enclosing all the cables in metal conduits or grid-like reinforced concrete ducts, which must be integrated into the meshed earthing system.

Components used in surge protections

Generally

Components and equipment for protection against surge are always based on a fundamental principle - to keep the isolation state up to acceptable voltage level. Short-circuit happens after exceeding this level and thereby very high difference of potentials between conducting parts of one equipment or appliance is restricted to an acceptable value. Electronic switches used for this purpose are called surge arresters or devices for protection against surge. Nowadays open spark gaps, closed spark gaps, gas discharge tubes, varistors, limiting diodes or their combinations are used for protection against lightning and overvoltage.

Spark gap

The arresters class I are the applications of the SPD most oftenly used on principle of a spark gap. They are designed for 1st stage of surge protection. It is possible to divide them on so-called „open“ or „closed“ spark gaps according to constructional implementation. The shape of electrodes, their material and the distance between electrodes determine the protection level, discharge ability and features, which characterize behaviour of the spark gap when follow current extinguish. Open spark gaps excel in very high discharge abilities (up to $I_{imp} = 50 \text{ kA}$ (10/350) during high levels of self-extinguishing follow current (up to $I_{fi} = 50 \text{ kA}_{rms}$). Their fundamental inadequacy is burning plasma bursting from SPD housing during their activation by lightning current. This fact significantly complicates projective preparation (switchboard construction) regarding fire safety. The construction of the closed spark gaps has this inadequacy solved, although at the expense of parameters of self-extinguishing follow current ($I_{fi} = \text{max } 25 \text{ kA}_{rms}$) being decreased. Some constructions of the closed spark gaps have very high discharge abilities ($I_{imp} > 100 \text{ kA}$ (10/350), on the other hand the level of self-extinguishing follow current is low ($I_{fi} = \text{cca } 100 \text{ A}_{rms}$), so their application possibilities are comparable with gas discharge tubes.

Gas discharge tubes

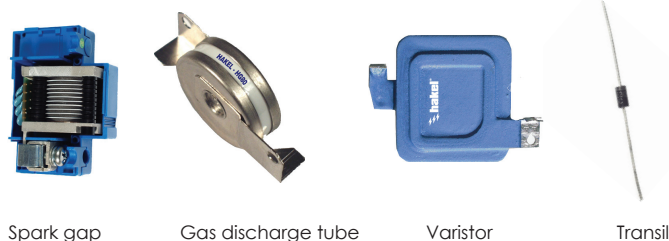
In the quiescent condition gas filled arresters and spark gaps (gas discharge tubes) behave as high resistance isolators thanks to application of corundum ceramic. They are usually constructed in the shape of cylindric ceramic housing, closed by metal electrodes on both sides. They are filled by inert gas mixture under low pressure generally. They excel in their short response time and high-level discharge ability up to $I_{imp} = 100 \text{ kA}$ (10/350). They have small self-capacity (few of pF units) and high isolation resistance ($> 1000 \text{ M}\Omega$). Gas discharge tube's application possibilities are restricted by their generally low values of self-extinguishing follow current ($I_{fi} = c. 100 \text{ A}_{rms}$). Quality guarantee for a particular application is carried out with by specific choice of used material, gas filling and electrode geometry. The special dilatation composition is used for a production of modern gas discharge tubes, because they ensure their high resistance against high temperatures up to 2000°C and extreme pressure during discharge in gas, during currents up to 100kA in the waveform of $10/350\mu\text{s}$. The electrical parameters can be predicted in a large range. E.g. direct switching voltage can be set up from 100V to 2000V with typical tolerance $\pm 20\%$. Gas discharge tubes have long lifetime and parameter stability. So they fulfil basic presumptions for their usage at the constructions of maintenance-free arresters with long lifetime.

Varistors

Varistors are voltage dependent resistances with symmetrical voltampere characteristic. They consist of 90% ZnO as a ceramic basis and 10% additives. High possible load of this type of arresters during their loading by impulse discharge currents is achieved by application of its great mass varistor capacity for energy absorption. Almost universal possibilities of varistors are limited only in the field of high frequency, where relatively high capacity (few of nF units) has a negative effect.

Limiting diodes

Limiting diodes are basically Zenner diodes dimensioned for high peak current values and extremely short access time (a few ps units). These diodes are highly suitable for protection of sensitive electronic circuits thanks to their small size, short access time and low protection levels in data and telecommunication systems.



Spark gap

Gas discharge tube

Varistor

Transil

Grounding and protective conductors

The CSN standard 33 2000-5-54 deals with this problem. The standard determines implementation of earth termination system, the resistance value of ground electrodes, voltage level of the ground electrodes, contact voltage and current-carrying capacity of particular ground electrodes. We will mention the grounding conductors in the following part.

Grounding conductors must suit by their cross-sections,

which must not be smaller then cross-section designed for the following formula:

$$S = \sqrt{\frac{I^2 \cdot t}{k}}$$

(This formula is only possible to be used during time of flowing I , which doesn't overrun 5 seconds)

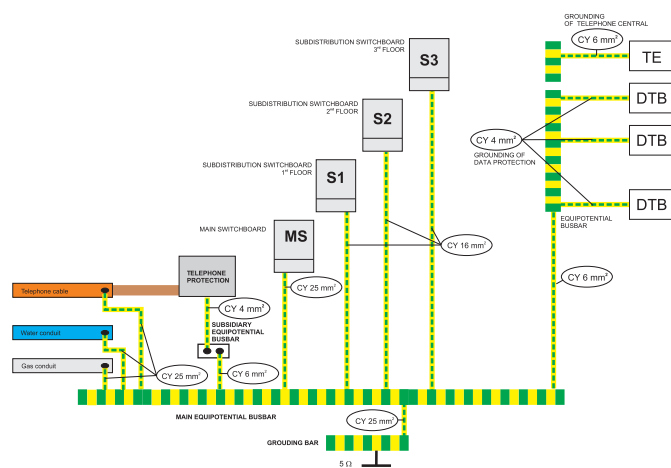
S – cross-section of grounding conductor in $[\text{mm}^2]$

I – an effective value of alternating current in $[\text{A}]$, traversing because of failure with irrelevant impedance by protection element

t – disconnection time of protection equipment in seconds $[\text{s}]$

k – coefficient depending on material of protection conductor, on isolation and on other parts, on temperature before and after short-circuit (values k for differently designed protection conductors are given in CSN standard 33 2000-5-54)

Minimal cross-section of grounding conductors must be minimally $16\text{mm}^2 \text{ Cu}$. They are placed in earth and protected against corrosion but not protected against mechanical damage. If these are not protected against corrosion (doesn't mater if they are protected against mechanical damage or not), minimal cross-section of grounding conductor must be $25\text{mm}^2 \text{ Cu}$ (exceptionally Al, which is however not recommended for use in earth).



The grounding conductor must be laid in such a way to resist all external influences, which can be expected during operating. At the same time it must not cause fire danger, eventually it should not influence operating of other equipment. It is laid to be as short as possible, without sharp curves, unnecessary arcs and loops. Over-ground parts of grounding conductors must be placed so they can be controllable. Outside part of grounding conductor must be suitably protected by panelling or by placing into tubes in places where danger of damage can occur (for example while going through a wall, going into earth). Conductive construction elements of metal constructions can be used as random grounding conductors. They create continually connected complex, as for example cable trays, cable frames, pillars, rails of crane, steel poles, reinforcement of columns made of flow spinning concrete and metal conduits. Connections of grounding conductors and ground electrodes must be correctly carried out and must be desirably dimensioned. While using clamps principle governs that the used clamp must not mechanically damage neither ground electrode (for example conduit) nor grounding conductor.

Power and communication equipment – interrelation

The smallest distance between the part of grounding communication device, which is not connected into its own transformer station should be at least 20m from the grounding power equipment part up to 1000V and 40m far from the grounding power equipment part over 1000V. If there is no way how to abide at least half of the mentioned distances, there is urgency to make one of the following arrangements:

a) It is necessary to make sure by calculating or measuring, that voltage on a communication equipment induced by the highest currents in grounding of power equipment doesn't exceed permissible limit.

b) Both groundings are connected through, if it doesn't evoke undesirable consequences of direct coupling (for example importation of dangerous or disturbing voltage into communication system, creation of route for stray currents or creation of macrocell with electrodes created by particular groundings).

The grounding of conductors and power equipment doesn't have to be connected together, if the distance between two groundings in foundation soil is bigger than 5m. The grounding of the communication equipment should be as far from grounding of conductors as possible. If the distance between grounding of conductors and any other part of grounding of communication equipment is smaller than 5m, the both groundings must be connected through. Then joint earth termination system must agree with the standard EN 62 305 and with the rule set for communication equipment. Operating grounding of the overvoltage conductors is connected to protective grounding equipment, which are protected by surge arrester. In the chapter Grounding and protective conductors there is mentioned that generally protective conductor PE can be bare and must be laid together with outlying conductors. Grounding conductor, which goes to subsidiary grounding conductor, must be isolated so as it's prevented from contact with protective conductor or any part connected to it or with dead parts, which are connected to the protective conductor. It is necessary to fulfill this condition so as by-pass of detectors is avoided. Protective conductor can be connected only to dead parts of those electrical subjects and equipment, whose power supply is disconnected in case of voltage protector equipage failing. The dead parts must be connected to a protective conductor during compliance of given conditions for every recommended kind of power system grounding. The dead parts, which are touch-accessible at the same time, must be connected to the same earth termination system separately, in groups or together. These conductible parts must be connected together into so-called main protection connection in every building: protection conductor, grounding bonding bar or main protection clamp, conduit distribution in a building, for example water and gas, metal constructions and central heating and air-conditioning (if they are in the building). The conductible parts, which come into the building from outside must be connected as close to their entrance into the building as possible. Of course the conductors of main connection must comply with their cross-sections. The main connection must be done at every metal coating of communication cables. However it is necessary to obtain an approval of these cables owner or operator.

Grounding

The grounding of overvoltage protection to a quality ground is a requirement for their correct functioning. The ground is presented by protection conductor PE. The conductor PE is

separately laid down in 5-conductor TNS system, which is enacted by standard. It is enacted for households, offices and industry. Energetics should secure this system type at the secondary side of a transformer already. All the installed overvoltage protection devices are connected to the equipotential busbar PAS by means of PE conductors. This PAS busbar has the closest potential to the ground potential. In TNC systems overvoltage protection devices are grounded onto PEN conductor, where differential balancing currents are flowing. That is why it doesn't ensure as quality conditions for overvoltage protection functioning as the PE conductor. The values of the whole grounding resistance and the resistance of grounding conductors PE, PEN in the conductor routing at the ends, are stipulate by standard CSN 33 2000-4-41. It is necessary to avoid loop connection of switchboards during the realization of the building grounding which make conditions for flow of faulty currents and a potential difference between conductors PE and PEN in their route towards ground potential. Star configuration drawing of the grounding conductors acc. to EN 62 305 is the optimal way how to eliminate these unfavourable effects.

Dimensioning of SPD type 1 EN 62305		
Location of SPD type 1 : On the boundaries of LPZ 0 and LPZ 1		
LPL	Lightning	Arresters total
I.	up to 200 kA	100 kA
II.	up to 150 kA	75 kA
III.	up to 100 kA	50 kA
IV.	up to 100 kA	50 kA

Application of HAKEL SPD type 1 EN 62305		
Location of SPD type 1 : On the boundaries of LPZ 0 and LPZ 1		
LPL	Lightning	Arresters total
I.	up to 200 kA	100 kA
Conditions fulfil :		
HZ110, HS50-50		
- big industrial buildings		
- buildings with particular importance		
SPC25		
- technological lines		
- administrative buildings		
- small technological lines		
- administrative properties		
(If SPD type 1 and 2 are placed into one switchboard)		

Application of HAKEL SPD type 1 EN 62305		
Location of SPD type 1 : On the boundaries of LPZ 0 and LPZ 1		
LPL	Lightning	Arresters total
II.	up to 150 kA	up to 75 kA
Conditions fulfil :		
SPC25, SPC12,5 a PIV12,5		
- smaller administrative buildings		
- houses with standard equipments		
- family houses		

Application of HAKEL SPD type 2 EN 62305		
Location of SPD type 2 : On the boundaries of LPZ 1 and LPZ 2		
Conditions fulfil :		
SPU, SPUM, PIII, PIIIM		
- all types of electrical sets		
- system type (TN, IT, TT)		
- mode of connection		
- nominal voltage		

Application of HAKEL SPD type 3 EN 62305		
Location of SPD type 3 : On the boundaries of LPZ 2 and LPZ 3		
Conditions fulfil :		
PI-k, PI-3k, P-3k, Pk2, ZS-1DSM,		
- all types of electrical sets		
(located in switchboard)		
Sockets ZS		
- all types of electrical sets		
(sockets with inbuilt surge protection		
the closest to the protected equipment)		
Protector MS FUL, PDU-F		
- all types of electrical sets		
(adaptors with inbuilt surge protection		
- flexible solution)		

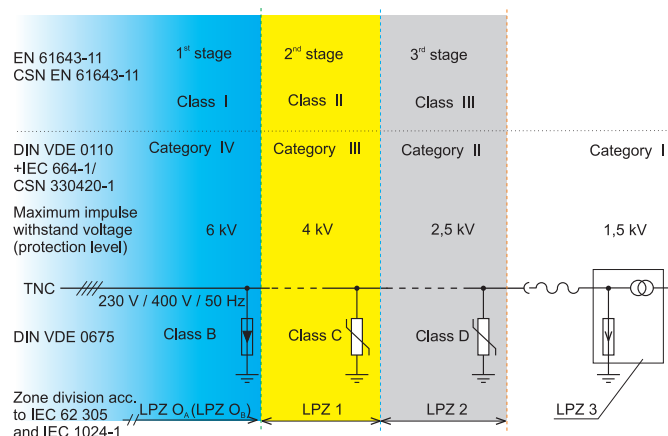
Technical standards relating to the installation of surge protection devices

All the EN standards apply to the Czech Republic, because the Czech Republic has signed the association agreement with the European Union. The directive No.89/336 EEC, the law No. 22/97 Coll. and the regulations NV 17

and 18/ 2003 Coll. enact abidance of electromagnetic compability (EMC) conditions for electrical equipment. In the other countries are these questions usually determined by relevant national directions. Mounting of the overvoltage protection devices solves most related problems and sufficiently protects electronics against influence of overvoltage spreading through galvanic routes.

Nowadays it is necessary to abide internationally recognized standard EN 61 643-11 which characterizes stages of overvoltage protections and their tests. Other standards relating to this are being prepared (for example the revisions of overvoltage protection devices).

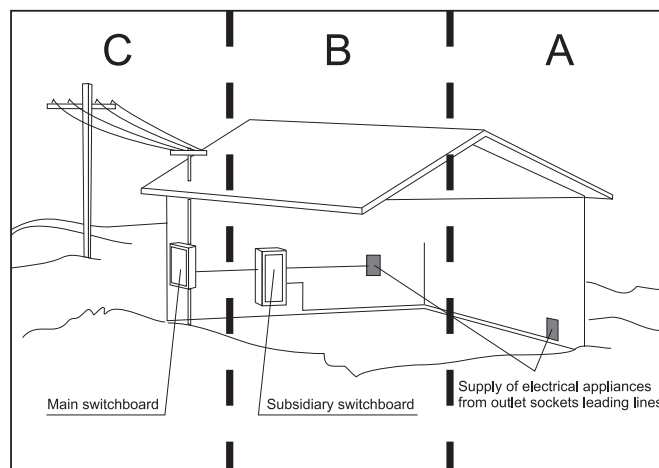
Because nowadays there is considerable assortment of SPDs with accompanying documentation according to DIN VDE 0675 or DIN VDE 0110 in the Czech Republic, it is advisable here to make a comparison of basic segmentation of SPDs according to these standards and standards obligatory in the Czech Republic, in particular IEC 664-1/CSN 33 0420-1. The standard EN 61 643-11 obligatory in the Czech Republic divides SPDs into stages (1st, 2nd and 3rd) and classes (I, II and III), whereas the standard DIN VDE 0675 divides SPDs into classes (A, B, C and D). The class A arresters are designed for protection of overground LV power system outside of the protected objects. The class B, C and D arresters are designed for usage at the boundaries LPZ 0→1, 1→2 and 2→3. On the other hand the standard DIN VDE 0110 states the definition of overvoltage category, which had been taken up by the standards IEC 664-1/CSN 33 0420-1. These standards define classification of LV power system into four categories (IV, III, II, I) and define so-called maximal impulse withstand voltages (protection levels), permitted for connected appliances. (For example overvoltage at input of distribution TNC 230/400V/50Hz must not exceed 6kV level, it must not exceed 4kV behind the main switchboard, it must not exceed 2,5kV at outputs from subdistribution switchboards and 1,5kV in the part designed for connection of protected appliances to fixed installation.)



Classification comparison of particular LV power system (acc.to EN 61 643-11, CSN EN 61 643-11, DIN VDE 0110, IEC 664-1/CSN33 0420 and DIN VDE 0675) relating to protection levels of surge protection cascade and to zone division acc. to CSN EN 62 305 and IEC 1024-1.

Interesting is a similar comparison of these classifications of low voltage network system (LV) sections owing to the overvoltage cascades protection stages in the building electric installations based on the oversea C62.41.2 - 2002 standard ANSI/IEEE (American National Standard Institute/Institute of Electrical and Electronics Engineers). This standard divides 1st, 2nd and 3rd SPD class-

es into C, B, A categories (Location Categories). Nevertheless, C category is classified into 2 levels (low, high) according to so-called „exposure degrees“ resulting from isokeraunic maps of “storms activity“ levels.



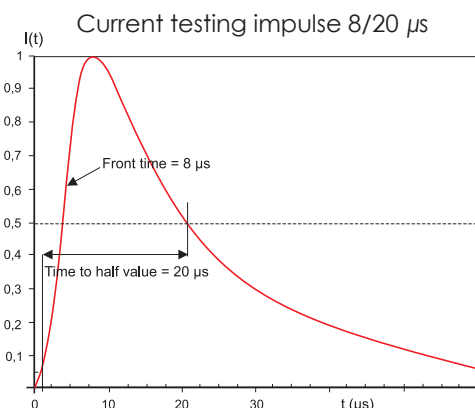
Summary of Surge Location Categories Guidelines Per IEEE C62.41.2-2002

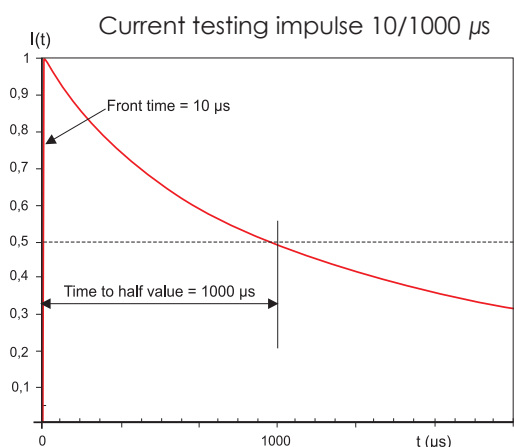
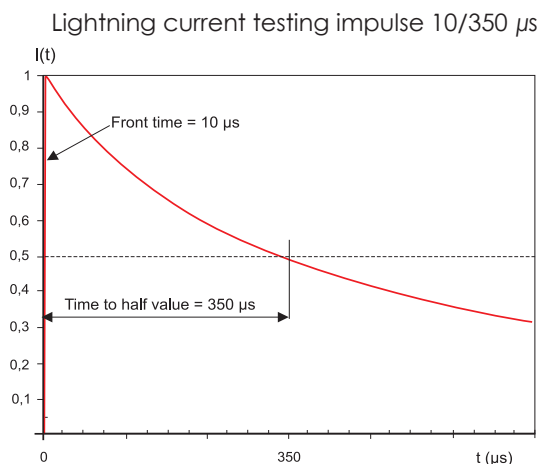
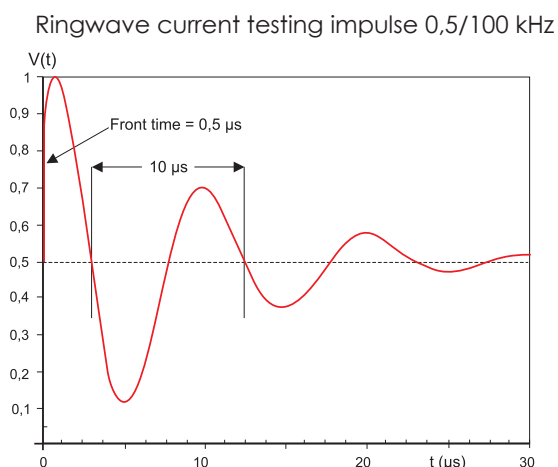
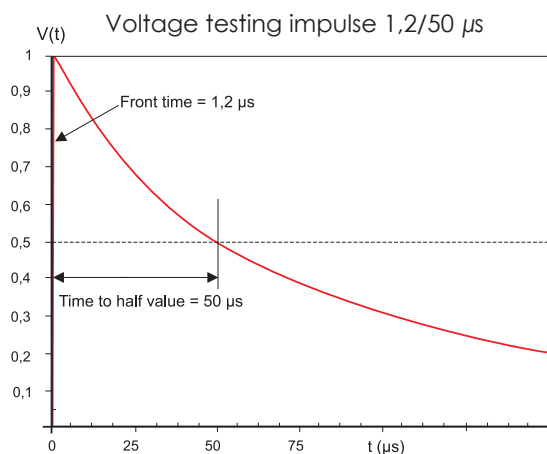
Location A	A	
Within a building		6kV 0.2kA 0.5us - 100kHz Ring Wave (30Ω)
Outlets and long branch circuits		6kV 0.5kA 1.2/50us 8/20us (12Ω)
All outlets more than 10m (30ft) from Category B		
All outlets more than 20m (60ft) from Category C		
Location B	B	
Near the service entrance		6kV 0.5kA 0.5us - 100kHz Ring Wave (12Ω)
Feeders and short branch circuits		6kV 3kA 1.2/50us 8/20us (2Ω)
Distribution Panel devices		
Bus and feeder industrial plants		
Heavy appliance outlets near service entrance		
Lighting systems in large buildings		
Location C	C Low	
External building		6kV 3kA 1.2/50us 8/20us (2Ω)
Outside and service entrance		6kV 100kHz Ring Wave
Service drop from pole to building		2.0 x V _{Peak} 10/1000 Combo. Wave
C High		
Run between meter and panel		10kV 10kA 1.2/50us 8/20us (1Ω)
Overhead line to detached building		6kV 100kHz Ring Wave
Underground line to well pump		2.3 x V _{Peak} 10/1000 Combo. Wave

It is worth mentioning that actually a complete SPD range of category C, B and A according to ANSI/IEEE is based on the tests by a combined impulse (1,2/50; 8/20μs) with a generator's internal resistance of 1 or 2 or 12Ω and partly by a test impulse at wave shape 0,5μs/100kHz (with the generator's internal resistance of 12Ω for B and C categories, alternatively 30Ω for A category).

The standard ANSI/IEEE also defines a test current impulse at wave shape 10/1000μs. It is however recommended to use it only as so-called „additional test“ performance. The test impulse at 10/350μs wave shape had been for the first time defined in VDE 0675 standard in 1986 and later on subsequently taken over by EN 61 643-11.

The following five pictures give you a well arranged information about the most used test impulse wave shapes according to IEC, EN, CSN standards, alternatively acc. to ANSI standard for the SPD testing intended for a use in a low voltage distribution networks.



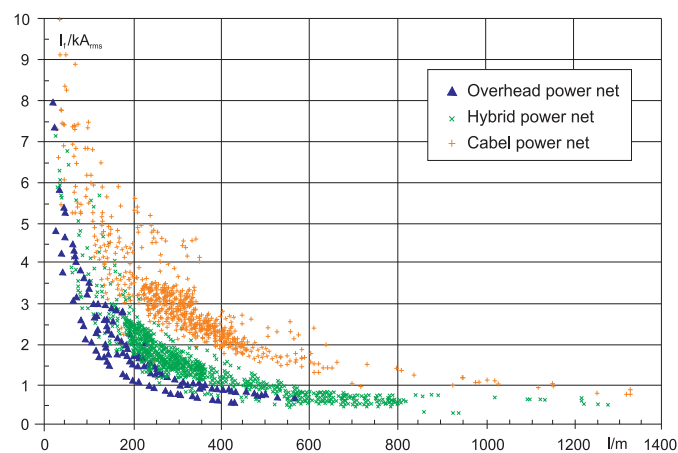


Possible usage of 1st stage surge protection

Varistor arresters of lightning current offer quality protection for their application in 1st stage of surge protection cascade with amplitude up to $I_{imp} = 20 \text{ kA} (10/350)$. In most applications it suits as well in case of so-called low voltage overground input into a building. If endurance against all higher amplitudes of lightning current is demanded, it is recommended to use arresters of spark gap type. It is necessary to pay attention to the parameter level of self-extinguishing follow current I_{fi} at U_C while a spark gap is chosen, because during the activation of a spark gap there is short-circuit in the place of its installation. Varistor arresters don't have this property.

The follow currents at the spark gaps application in a protective overvoltage cascades

The follow short circuit currents occur in the spark gap-based surge arresters (HS 45, HS 55, HS 60-20, HS 50-50, HS 50-16, HS 50-3) after their activation by an impulse discharge current, whereas their magnitude is restricted by an arisen short circuit overall impedance of the energetic power network. These follow currents are spontaneously extinguished by an overpressure acting in an individual operative spark-gap chambers during the first net's half-period transit through a zero. The amplitude of a prospective short circuit current, in place of a defined application, partly depends on the type of power system and partly on a lead distance of given application from a distribution transformer. The following diagram describes the results of measurement evaluation of these prospective follow currents performed in 2325 three-phase network of 29 distribution plants, from that 315 were made on an overhead lines, 1215 on a combine lines and 715 on a cable network. This graph shows that the value of prospective short circuit current never exceeds the value of $3kA_{rms}$ applicable for any power net type (overhead, combine or cable network) for example while using an application distance of 600 m from a distribution transformer. The above mentioned diagram is a favourably applicable in a project practice for a qualified estimation of a suitable spark-gap selection for a defined application and first of all for I_{fi} parameter determination (self-extinguish follow current at U_C). The eventual doubts, caused by a defined application specification, depends totally on a designer to cover them by a reasonable safety coefficient (the exact measurement is from the financial and technical point of view rather demanding). For example, if the value of a prospective follow current according to the qualified estimation is $3kA_{rms}$ then it is suitable to choose the surge arrester with an approximately twice higher parameter of I_{fi} .



Usage of surge separating inductors between particular stages of surge protection

Surge separating inductors with impedance $2 \div 15 \mu\text{H}$ ensure energetic coordination of particular stages of overvoltage protection cascade in few cases. They are inserted in conduct in case that the distance between 1st and 2nd stage or between 2nd and 3rd stage is smaller than 10m. Short distance or missing surge separating inductor creates a certain possibility of damage of some arrester in overvoltage protection cascade by progressing lightning current impulse. It is important to pay a special attention to the coordination between 1st and 2nd stage of surge protection cascade in all cases where the 1st stage is fitted by spark-gap based lightning arresters. The most economical way is to secure that the 1st protection cascade is placed in other switchboard than the 2nd stage (with the min. distance of 10m between them). If this min. distance is impossible to fulfil either from the constructive or structural reasons, it is recommended to use separating inductors of $15 \mu\text{H}$.

Surge protection backup

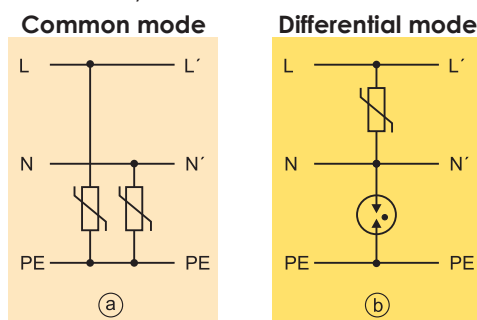
It is necessary to use additional protection of particular SPDs for protection against short-circuit in 1st and 2nd stages of overvoltage protection cascades. The protection is secured by backup safety fuses. Generally, every manufacturer of overvoltage protection devices declares dimensioning of these backup fuses in the accompanying documentation.

Recommendation for the installation of 3rd stage surge protection with the high frequency filter

3rd protection stage is an essential part of 3-stage overvoltage protection cascade. The typical representatives of this protection type are for example transient overvoltage protections-range PI-k* and PI-3k*. The products reduce overvoltage (thanks to their inside connection-high protection, filter, low protection) to the level $U_p < 0,8$ up to 1kV, which is safe for the final appliances. They are usually constructively fitted on DIN rail 35mm. It is important to place these products as near to the protected appliance (for example flat switchboards) as possible. The distance between switchboard and appliance must not overreach 15m. When there is a longer distance it is necessary to use other class III overvoltage protection devices (for example protection sockets or overvoltage protection on DIN rail) cca 10m far away from each other along the protected socket line. On the other hand protected sockets are in no way equivalent substitution for 3rd stage protection with high-frequency filter.

Standardized implementation of the particular surge cascade stages

It is possible to connect the particular stages of overvoltage cascades in two ways:



Connection **a** prefers protection against lengthwise overvoltage. Connection **b** prefers protection against trans-

verse overvoltage. Because statistical results of long-term made measurements affirm generally higher danger of transverse overvoltage (on clamps of appliances L/N) than lengthwise overvoltage (on clamps of appliances L/PE, L/PE), are all the connections and applications of SPD manufacturing range of the Hakel company oriented on preferential protection of appliances against transverse overvoltage.

Test rooms

Surge protection device examination and their testing is the only way for ensuring and verification of their supposed endurance and serviceability under the hardest operation conditions. A new product final finish and all of its important components are examined within the scope of the type tests and the certification procedure. Self-tests are performed with help of the surge generators, which in a way „substitute“ the current pulses of a natural character under a defined conditions. Testing wave shapes are set by even further connecting standards, particularly EN 616 43-11, IEC 62 305, IEC 60-1 and CSN 34 5640. Only a few working places, equipped with the wave shape generators $8/20 \mu\text{s}$, are situated in the Czech Republic. Mostly only with max. operational capacity up to $I_{\text{max}} = 10\text{kA}(8/20)$ or $20\text{kA}(8/20)$. The only one working place in the Czech Republic is equipped with the currents generators with wave shape $10/350 \mu\text{sec}$. Namely, it is Hakel's test room in Hradec Kralove, which has at its disposal such generator with operational capacity $I_{\text{imp}} = \text{up to } 210\text{kA}(10/350)$. This test room has even at its disposal two testing current pulse generators with operational capacity $I_{\text{max}} = 60\text{kA}(8/20)$ and $I_{\text{max}} = 240\text{kA}(8/20)$. Above mentioned testing devices are showed on the following two pictures.

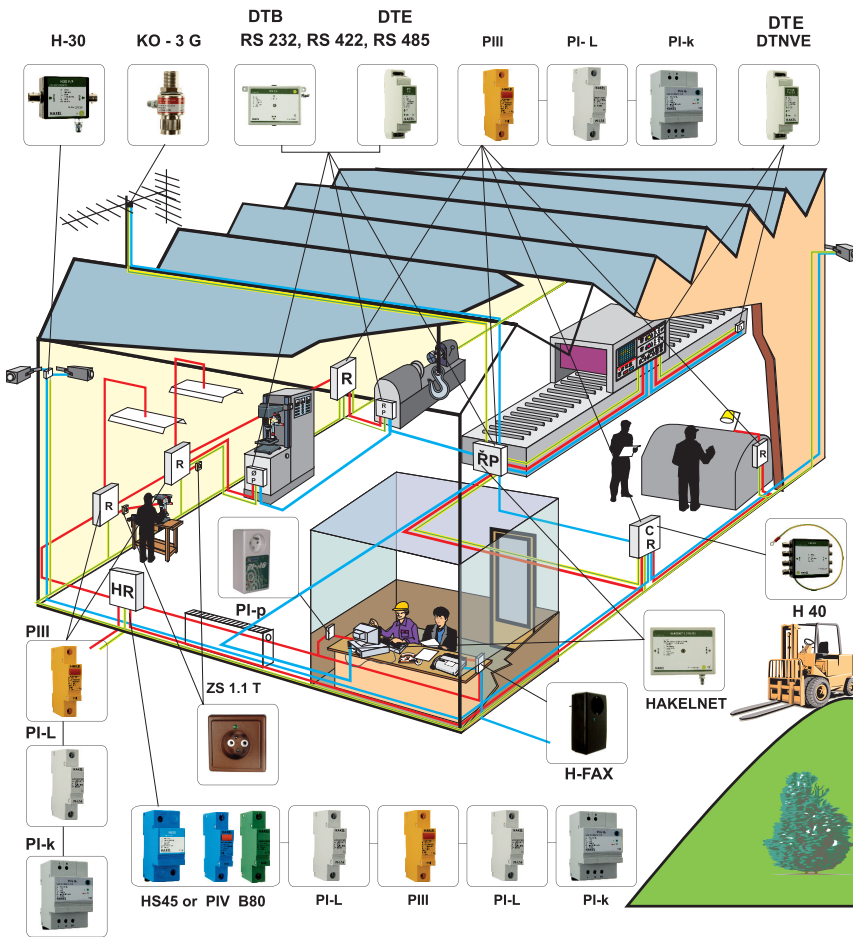


HAKELGUN 240: Testing current pulse generator with the operational capacity up to $I_{\text{max}} = 240\text{kA}(8/20)$



HAKELGUN 200BB: Lightning current generator with the operational capacity $I_{\text{imp}} = \text{up to } 210\text{kA}(10/350)$.

Industry application



- HR** – Main switchboard
- R** – Subdistribution switchboard
- TU** – Telephone central
- RP** – Control computer
- C** – Security system
- D** – Sensor
- S** – Server computer
- UPS** – Uninterrupted power supply

Application:

HS45 - main switchboard, in front of the electrometer and between L/N system TNS, L/PEN system TNC or **PIV** - main switchboard, behind the electrometer and between L/N system TNS, L/PEN system TNC

B80 - main switchboard, between N/PE only

SPC3 - main switchboard

PIII - subdistribution switchboard on each floor, between L/N system TNS, L/PEN system TNS

B20/C - subdistribution switchboard on each floor, between N/PE only

ZS-1.1 - socket circuits (every fourth socket)

PI-L - separating impedance between 2nd and 3rd stage of surge protection, in case of the spacing up to 10m

PI-k16, PI-k8 - subdistribution switchboard

H-FAX - fax, modem, telephone central supply circuit for electronic-controlled home appliances

HAKELNET1-2RJ - PC network card input

DTB, DTE, DTNVE - data and communication lines in measuring and control

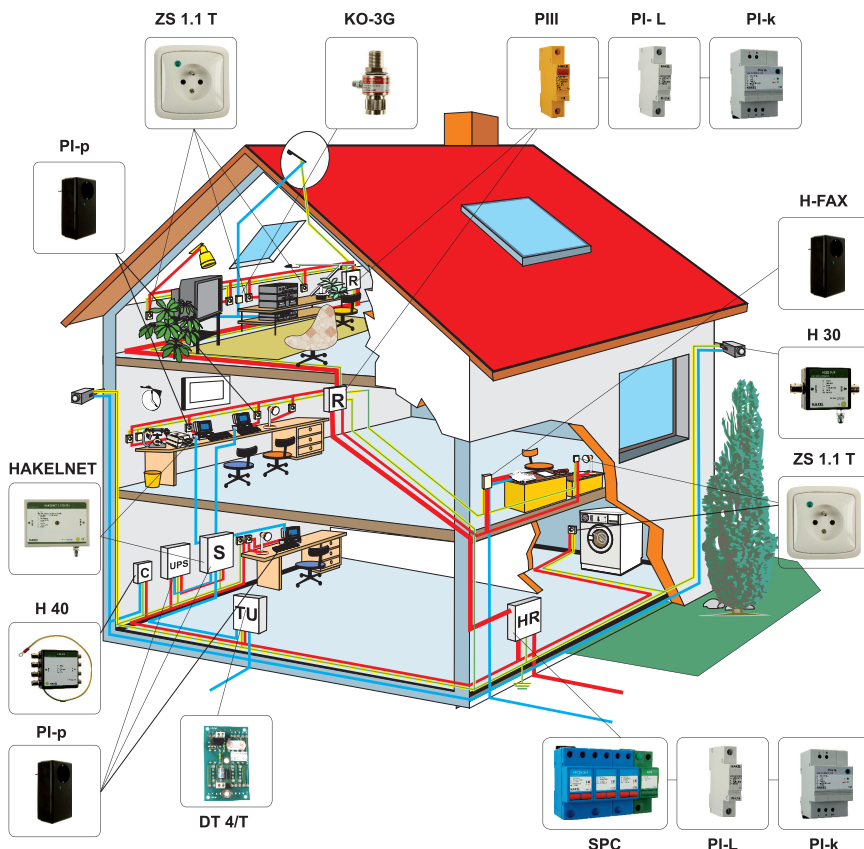
KO-3GN, KO-9P - antenna lead-in

H30, H40 - alarm and fire-control system

PI-p16 - hand electronic device

DT 4/T - incoming telephone line

Home and office application



Application:

H-FAX - fax, modem, telephone central

KO-3GN - antenna lead-in

ZS-1.1 - socket circuits (every fourth socket)

HAKElNET8 - 2RJ - 19" server switchboard input

HAKElNET1-2RJ - PC network card input

SPC3 - main switchboard

HR - Main switchboard

R - Subdistribution switchboard

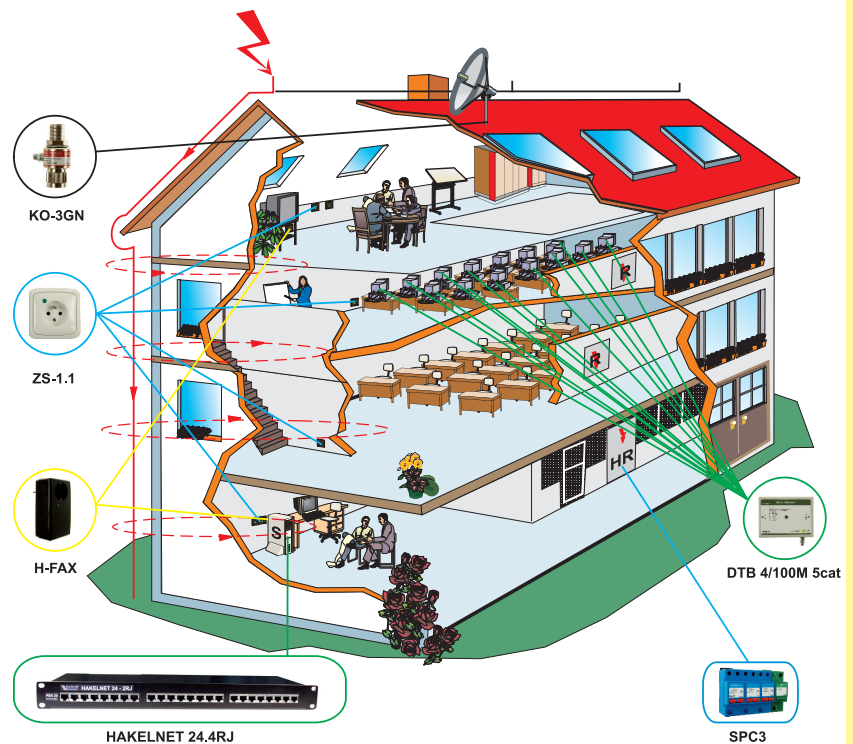
S - Server computer

C - Security system

TU - Telephone central

TR - Power supply

School application



Apartment block application

Application:

HS45 - main switchboard, in front of the electrometer and between L/N system TNS, L/PEN system TNC or

PIV - main switchboard, behind the electrometer and between L/N system TNS, L/PEN system TNC

B80 - main switchboard, between N/PE only

PIIIT - subdistribution switchboard on each floor, between L/N system TNS, L/PEN system TNC

B20/C - subdistribution switchboard on each floor, between N/PE only

ZS-1.1 - socket circuits

PI-L - separating impedance between 2nd and 3rd stage of surge protection, in case of the spacing up to 10m

PI-k16, PI-k8 - subdistribution switchboard, supply circuit for electronic-controlled home appliances

KO-3GN, KO-9P - antenna lead-in

