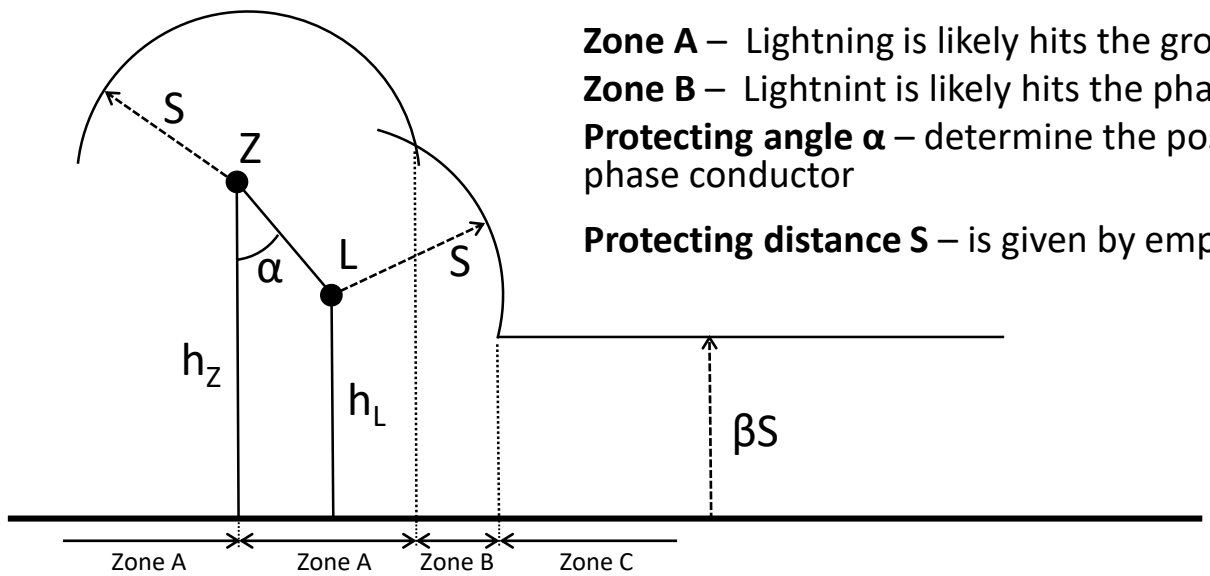
Overvoltage Protection

Overvoltage Protection of Overhead Lines

- Usage of ground wires -> likelihood of ground wire striking is higher than the likelihood of phase conductors striking -> just prevention of the worst case, overvoltage can be still induced to the phase conductors
- Arrangement of ground wires on line is based on the theory of protecting zones



Zone A – Lightning is likely hits the ground conductor

Zone B – Lightnint is likely hits the phase conductor

Protecting angle α – determine the position of ground conductor above phase conductor

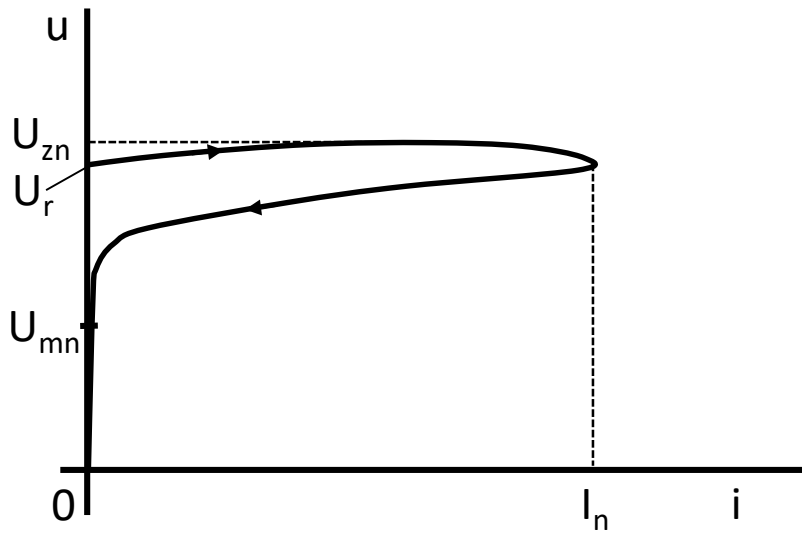
Protecting distance S – is given by empirical formula $S = 10I^{\frac{2}{3}}$ [m; kA]

Overvoltage protection

- Fundamental classification
  - Spark (rod)-gaps
    - Air spark-gaps with preset spark distance, connected between phase conductor and ground, permanent arc burning occures during the action-> failure state -> protection relays have to switch off the electric circuit
  - Gapped surge arresters
    - Gap and nonlinear resistor (SiC material) in series, current is limited to few amps after the overvoltage
  - Metal oxide surge arresters
    - Gapless surge arresters, cylindrical blocks of nonlinear resistors in parallel, Metal-oxide resistors (90% zinc oxide and 10% of various additives (Bi, Sb, Co, Mn)

Gapped surge arresters

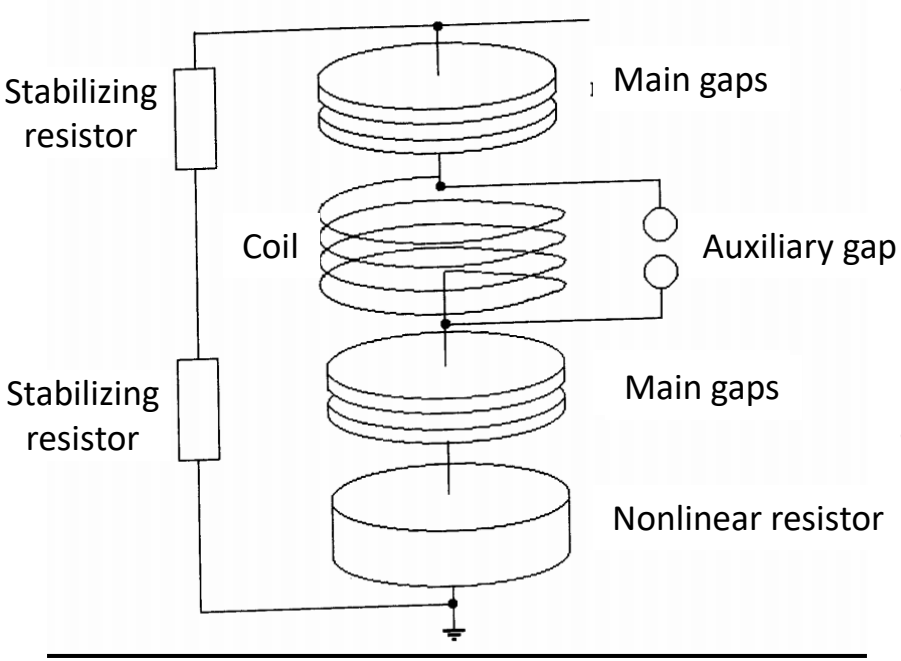
- V-A characteristic and important parameters



$\mathbf{I_n}$	Peak value of rated discharge current
$\mathbf{U_{mn}}$	vrcholová hodnota jmenovitého napětí
$\mathbf{U_{zn}}$	rated residual voltage
$\mathbf{U_r}$	rázové zapalovací napětí

Gapped arresters (Valve type arresters)

- Construction



- Both main gaps are ignited when the overvoltage occures at the terminals of arrester. At the same time, the current flows through the coil and nonlinear limiting resistor
- The current increase causes voltage across the coil , which iniciate ignition of auxiliary gap and bridging of coil
  The impadance of arrester is then given only as voltage drop across the nonlinear limiting resistor
- After the overvoltage decrease the impedance of coil decrease as well -> extinguishing of auxiliary gap and conection of coil into the circuit
- The magnetic field created by coil pushes the arc of main gaps to quenching chambers

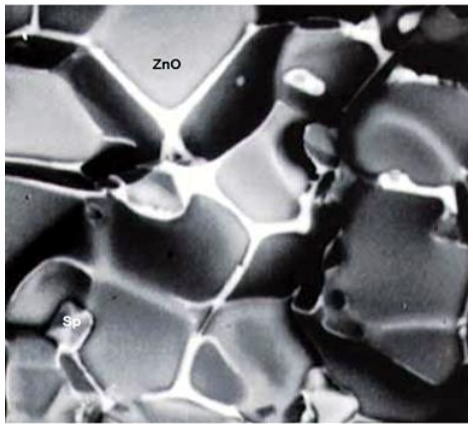
Gapped Arresters

- Main parameters of gapped arresters
  - Rated ignition voltage at lightning impulse (1,2/50 µs)
    - The lowest peak value of impulse which will causes the action of surge arrestor
  - Residual voltage
    - Voltage drop caused by current impulse 8/20 µs
  - Rated discharge current of arrester
    - The peak value of impulse 8/20 µs (1,5 kA, 2,5 kA, 5 kA, 10 kA, 20 kA, 40 kA)
  - Rated voltage of gapped arrester
    - Highest RMS value of power frequency voltage across the arrester terminals at which the arrester is closed
  - AC ignition voltage of surge arrestor
    - RMS value of AC voltage at which the arrester opens

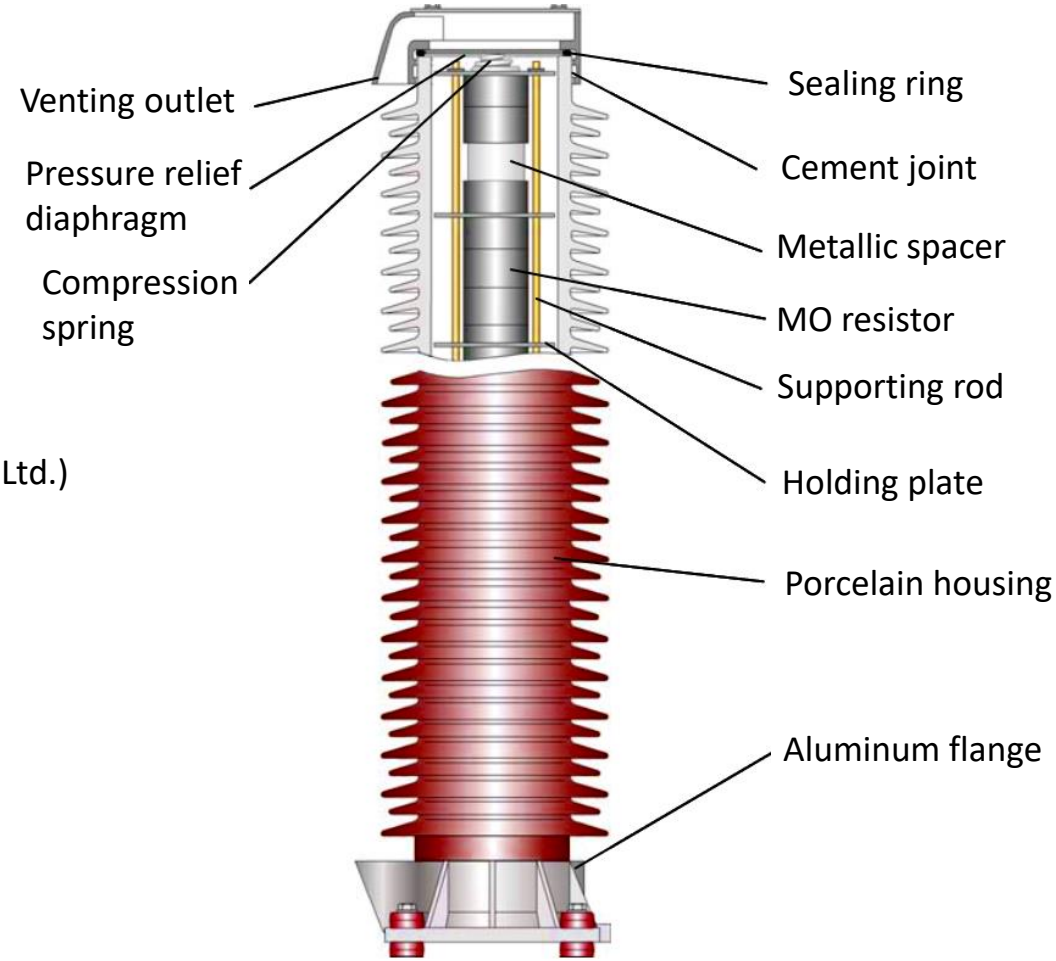
MO Surge Arresters

- Construction

Metal-Oxide (MO) resistors (ABB Switzerland Ltd.)



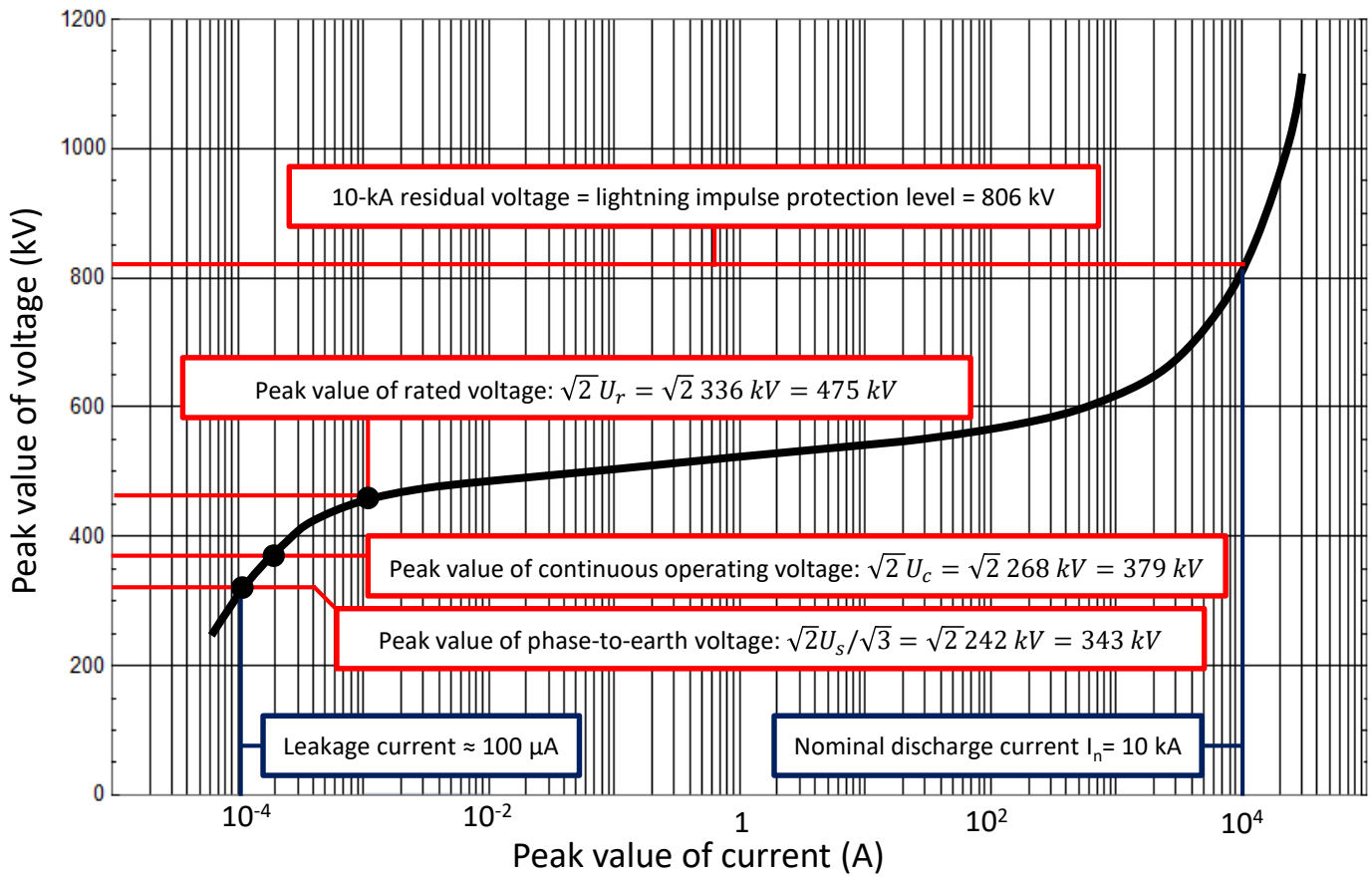
MO structure with grains and
the boundaries between them (ABB Switzerland Ltd.)



Source: Volker Hinrichsen, Metal-Oxide Surge Arresters in High-Volgate Power Systems

MO Surge Arresters

- V-A characteristic



MO Surge Arresters

- Main parameters of MO Surge Arresters
  - Continuous operating voltage U_c
    - Maximum rms value of power-frequency voltage, which the arrester can be operated at, without any type of restrictions. U_c is equal or more than maximal operating voltage in the place where the surge arrester is mounted
  - Rated voltage U_r
    - Maximum rms value of power-frequency voltage under the temporary overvoltage conditions. It is usually given as amplitude of equivalent overvoltage U_{eq} with a time period 10 s:

$$U_{eq} = U_t \left(\frac{T_t}{10}\right)^m,$$

where U_t is the amplitude of temporary overvoltage, T_t is the overvoltage time duration and m is a constant that depens on surge arrester construction (roughly 0,02)

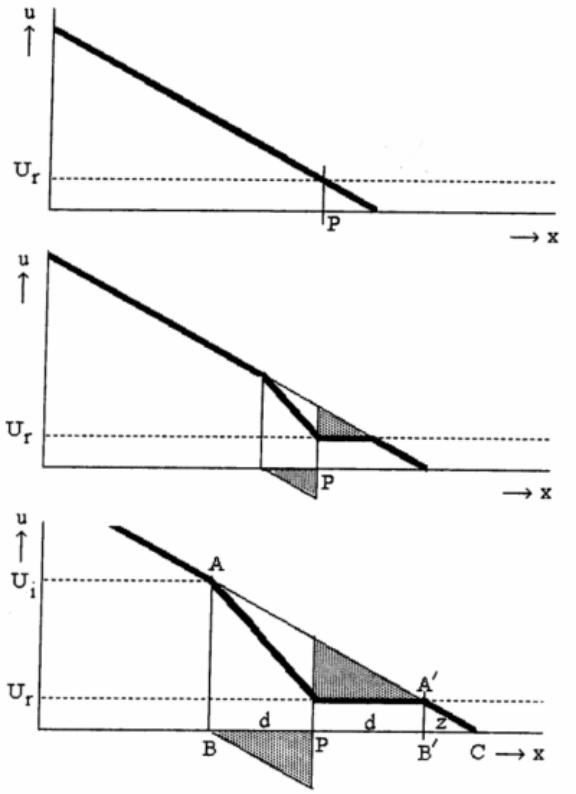
    - Usually, the ralatio between U_c and U_r is:

$$\frac{U_c}{U_r}=0{,}8$$

  - Nominal discharge current I_n
    - The peak value of lightning current impulse. It is used for surge arrestor classification when the current impulse 4/10 µs (which the surge arrester must withstand) is assigned to each nominal lightning current impulse 8/20 µs, e.g. : (10 000 A - 100 kA), (5 000 A- 65 kA)

Traveling wave processes

- A surge arrester is always placed as close as possible to protected object to eliminated an influence of reflected voltage waves
- The surge arrester protects objects which are inside of so called protective zone (distance) before and behind of surge arrester



- Surge arrester placed in point P has an ignition and residual voltage U_r
- After the steep voltage wave reaches the interface in point P one part of the wave is reflected and the second part is penetrated through the interface
- The penetrated wave is limited to U_r and the reflected wave has a shape of original wave but with opposite polarity
- The superposition of reflected and original wave causes that the voltage before surge arrestor is lower than would be from comming original wave
- Considering an insulation level of equipment U_i then the protective distance d can be found for given wave steepness S, i.e. the distance in which no voltage higher than U_i will occures

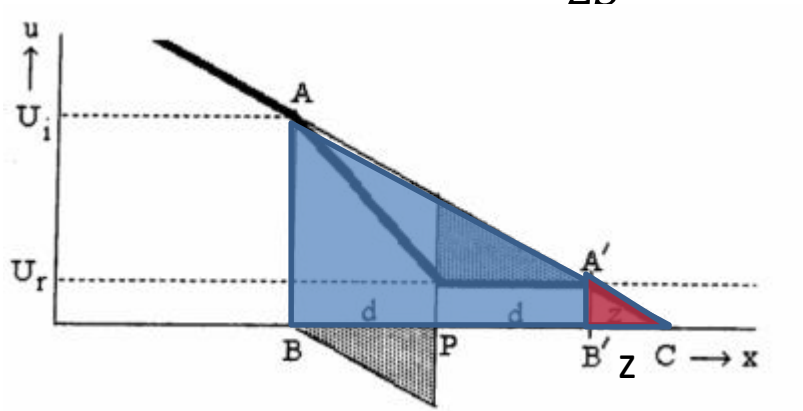
Protective distance of surge arrester

- The protective diastance of a surge arrester can be determined from the similarity of ABC and A´B´C triangles
- If *z* is the distance, which a voltage wave traveled by velocity *v* in time, in which the wave reaches U_r after comming to point P, then $z = \frac{U_r}{S} v$ and from the similarity of triangles:

$$\frac{U_i}{2d + z} = \frac{U_r}{z}$$

- The protective distance can be derived as:

$$d = \frac{U_i - U_r}{2S} v$$

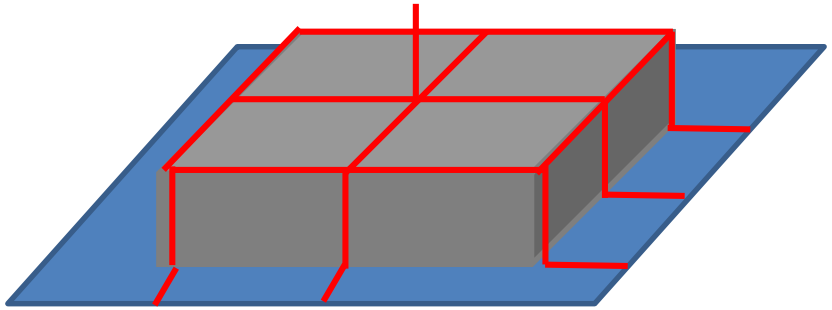


Protection of electrical systems within structures against lightning

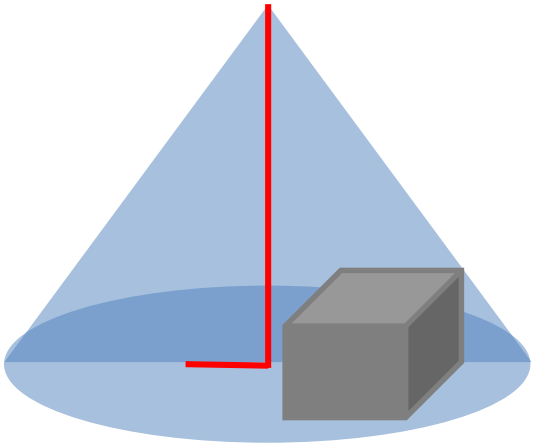
- Lightning protection systems classification
  - External lightning protection system
    - Lightning conductor including connection to internal terminal for equipotential bonding needs
  - Internal lightning protection system
    - Set of measures inside of building to prevent uncontrolled iniciations of flashovers and breakdowns (including connected electric appliances)
- Equipotential bonding
  - Is a part of internal lightning protection, which incorporates direct connection of all conductive parts together and connection of live conductors through surge arresters

External lightning protection system

- Capture device
  - Meshed cage
  - Lightning rods (simple or with triggering system)
- Earth down-conductor
  - Electrical connection of capture device with earthing system
- Earthing system
  - low voltage drop when the lightning current flows to ground



Meshed cage lightning conductor



Air-Termination Lightning Protection System

Internal lightning protection system

- Set of measures to the reduction of electromagnetic impulses effects caused by lighning current inside a protected object:
  - Equipotential bounding
  - Usage of surge arresters
  - Electromagnetic shielding
- It is impossible to reach the effective protection by only one measure -> cascaded or selective protection
- Surge arresters are divided into four classes from A to D

Class	Way of usage
A	For overhead line instalation
B	Lightning current surge arresters for the main potential balancing, zone interface ZBO 0_A and ZBO 1
C	Surge arresters, overvoltage protection in fixed electrical wiring
D	Surge arresters, overvoltage protection in fixed or flexible electrical wiring

Internal lightning protection system

- Selection of surge arrester class is done with respect to lightning protection zones and residual voltage
- Lightning protection zones conception
  - ZBO 0A – external unprotected area
  - ZBO 0B – protected by captured devices, direct lightning stroke is impossible
  - ZBO 1, ZBO 2, ZBO 3 – internal areas
- Surge arrester types
  - Gas filled spark gaps
    - Function depends on steepness of voltage impulse, time response approx. 100 ns
  - Varistors
    - Bipolar elements with voltage dependency (SiC, ZnO), minimal consequent current, time response approx. 20 ns
  - Voltage supressors
    - Special types of Zener's diod, TRANSZORB, ZAP, TRANSIL

Internal lightning protection system

- Cascading (coordination) of lightning protections from the main distribution power panel