THE NEW, MODERN, INTEGRATED APPROACH TO AN EFFECTIVE, EXTERNAL AND INTERNAL, LIGHTNING AND OVERVOLTAGE PROTECTION

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Key words: atmospheric discharge, lightning stroke, lightning protection, overvoltage protection,

Abstract: Overvoltage protection requires a comprehensive, systematic approach: understanding atmospheric discharges and the origin of lightning; the way of catching the stroke and conducting it to the earth; and protecting the building, equipment and people against its influence. For simulation of a lightning stroke in the laboratory, two basic transient-current wave shapes are used: 10/350 μs and 8/20 μs. These waves are also used as the criteria for current absorption over overvoltage protection elements, and cover most of the events of lightning.

Nov, moderen, integriran pristop k učinkoviti, zunanji in notranji zaščiti proti prenapetosti in streli

Kjučne besede: atmosferske razelektritve, udar strele, zaščlita pred strelo, prenapetostna zaščita,

Izvleček: Zaščita pred prenapetostjo zahteva celovit sistemski pristop, razumevanje atmosferskih razelektritev in izvor strel, načina zajema udara strele in njenega vodenje v zemljo ter razumevanje zaščite zgradbe, opreme in ljudi pred njenimi vplivi. Za simulacijo udara strele v laboratoriju uporabljamo dve osnovni obliki tokovnega impulza : 10/350 us in 8/20 us. Oba dokaj ustrezno opišeta ta naravni pojav in ju uporabljamo kot kriterij pri oceni zmogljivosti absorpcije toka skozi prenapetostne zaščitne elemente.

1. Introduction

The overvoltage level, as the consequence of atmospheric discharge, has to be reduced to a sufficiently low safety value for electric and electronic devices. The main reason for involving external protection is that it conducts half of the lightning value into the earthing system and is prescribed as mandatory in the majority of European countries.

The lightning discharge happens when a quasi-static electric field between the cloud and the earth creates a stepped conductor and moves progressively from the cloud to the earth. The down-conductor approaches the earth and the electric field increases to the point of initiation of the upward-streamers. The upward-conductor propagates towards the down-conductor to complete the ionised path between the cloud and the earth. When the field strength at lightning terminals reaches the critical breakdown threshold, the streamer is launched towards the approaching conductor and both connect the lightning channel.

An air terminal, which is mounted on the highest point of the building, provides the preferred attachment point for the lightning discharge and controls the passage of the substantial atmospheric discharge current safely to the earth. The earthing is important for personal safety, equipment protection (essential to the proper operation of SPDs) and lightning dissipation.

2. Methods of protection

To cover systematically and efficiently all effects of atmospheric discharge, a six-level protection plan is used, composed of the following steps:

1. Capture the lightning stroke by a designed air terminal at a preferred point;
2. Conduct the lightning to the earth via a designed down-conductor;
3. Dissipate the energy into the earth with minimal rise of the earth potential;
4. Bind to create an equipotential ground plane and eliminate the earth loops by the lowest possible impedance of the earthing system;
5. Protect the incoming power circuits, the building, the people and the equipment at the power supply side;
6. Protect the telecommunication and data circuits to prevent equipment damage and the cost of operational downtime.

The six-level protection plan can handle almost any situation, and provide solutions e.g. for ships or boats and yachts, for oil platforms, oil refineries, gas pipelines, common small family houses as well as tall buildings. Other protection solutions cover TV- tower antenna systems, industry, hospitals with very sophisticated electronic equipment, railway centres, photovoltaic systems, wind power electro generators, water power plants, etc.

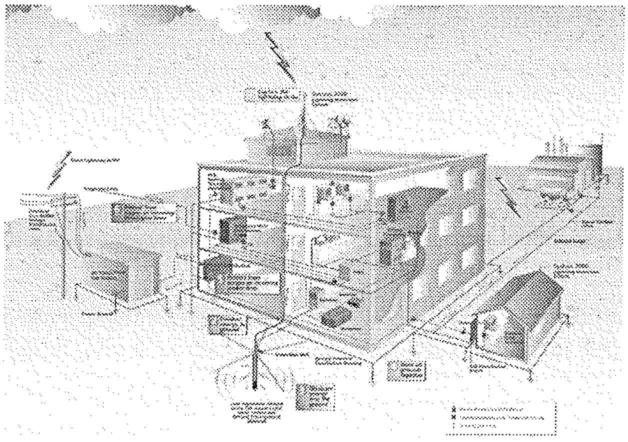

Fig. 1: Telecommunication centre protected by six system points.

There are many other cases of protecting small telecommunication centres with different equipment such as digital telephone exchanges and main distribution frame, power supply, broad-band terminals, such as ADSL, ISDN, and radio equipment for global mobile telephone systems.

2.1 Capture the lightning stroke by a designed air terminal at a preferred point

The most commonly used are the lightning rods of the Franklin-type system. Many of them and many down-conductors must be used on tall and large buildings to obtain protection zones in 1 and 2 with local Faraday cages on concrete.

The new approach is presented by an active up-conductor functioning in dynasphere, and one special down-conductor in the system 3000.

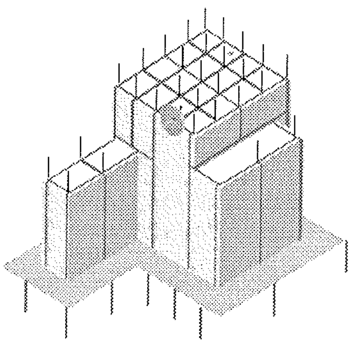

Fig. 2: Franklin-type system

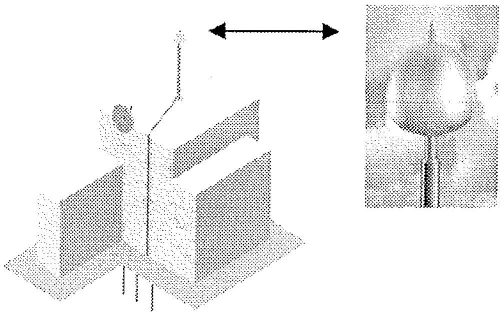

Fig. 3: Dynasphere system 3000

The difference between them lies in creating an ambient electric field high in the sharp upper point:

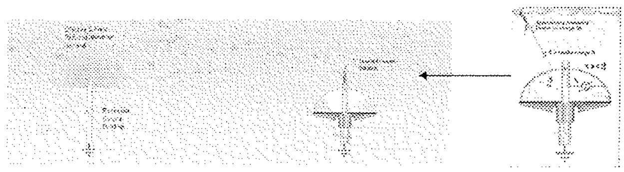

Fig. 4: Franklin rod on the left, and dynasphere on the right.

The corona on a Franklin rod masks the ambient electric field, while a dynasphere does not, and the electric field from a dynasphere is high enough to support the lightning leader's propagation.

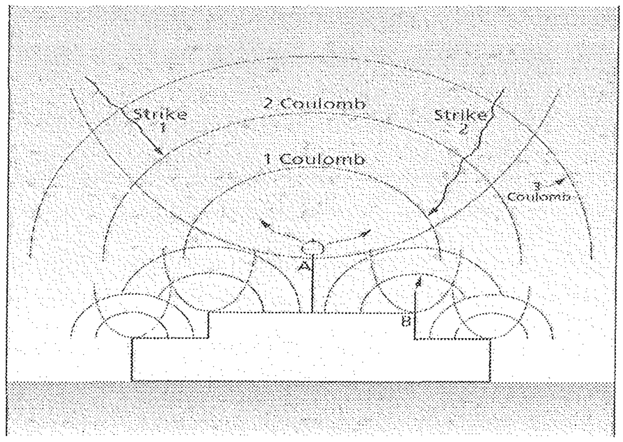

Fig. 5: With dynasphere a greater volume of lightning capture collection of potential stroke points on a structure (building) is possible.

2.2 Conduct the lightning to the earth via a designed down-conductor

The down-conductor with high impedance creates dissipation and high inductivity. The armoured earthing cable has 50-times lower impedance and creates no inductive voltages. To prevent inductive effects of the lightning over the down-conductor and diminish the inductivity and resistance of the down-conductor, the earth conductor is composed of twisted Cu wires, special isolation and shielding.

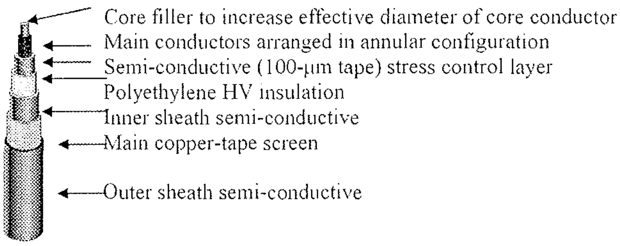

Fig. 6: A core shielded down-conductor. Screened, insulated down-conductors convey the lightning discharge current to the earth with minimal danger of side flashing.

2.3 Dissipate the energy into the earth with minimal rise of the earth potential

The connections must have an appropriate mass and material resistant to corrosion, in order to maintain the original low resistance for as long as 40 years. The rod's resistance depends on the length, the surroundings and the integrity of joints. Very important for the earthing is soil resistivity that ranges from 1 Ohm to 50 Ohm per meter in loam and up to 10,000 Ohm per meter in limestone or granite and basalt. Here the effect of temperature is to be considered. With low temperatures, the resistivity of the soil increases dramatically.

2.4 Bind to create an equipotential ground plane and eliminate the earth loops by low impedance of the earthing system

Bonding means interconnecting of all earth electrode systems: the electrical earthing system, the lightning earthing system, the cable-earthing system and the telecommunications earthing system. This connection of all conductive objects, internal and external, to the facility, will ensure a voltage difference close to zero during the rise of earth potential.

The interconnecting components: earth bars, earth plates, ring earthings; fence and gate jumpers; equipotential mesh and mats; masts, water pipe clamps; transient earth clamps.

2.5 Protect the incoming power circuits, the building, the people and the equipment at the power supply side

The installation, coordination and isolation categories and classification of the lightning and overvoltage arresters in the power supply net

In the protection zone 0/1 at the building entrance before the electrical counter or after it, depending on the rules of the electrical distribution company, the SPDs for direct lightning stroke of Class I are installed. The varistor SPDs Class II follow in the distributor box in the protection zone 1, and the Class III SPDs before the protected equipment. The SPDs must sustain the isolation coordinates from 6 kV, 4 kV, 2.5 kV to 1.5 kV, always in step with the residual voltage U_{res} for the next lower category. Thus, according to the IEC standard 616431, Class I SPDs must have residual voltage < 4 kV, Class II SPDs < 2.5 kV and Class III < 1.5 kV.

Choose and design. The Surge Protection Devices must include the following starting parameters:

The bases are given in the risk assessment according to the IEC 62305-2 Ed. 1 draft standard's maximum connecting voltage:

a. Expected loading of transient appearance. Impulse current, I_{imp} and rated surge current;
b. Desired protection level U_p or permitted residual voltage due to the protected equipment or installation;
c. In the case of damaging the power system, which occurs at temporary overvoltage TOV from the mains and telecommunication system, what situation can be expected?
d. Coordination with other SPDs and fuses in the protection system;
e. Maximum permissible current;
f. Frequency ranges;
g. Contact fields between SPDs, lines and equipment;

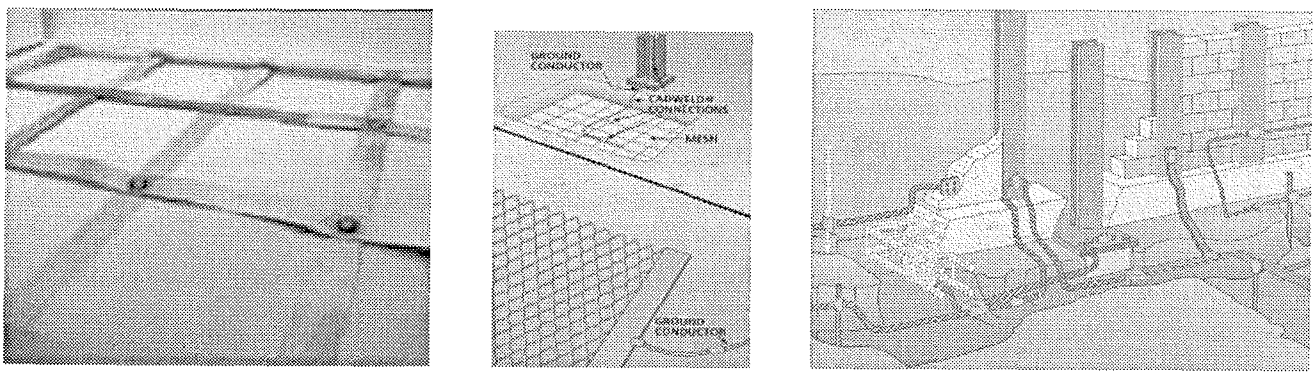

Fig. 7: Examples of earthing

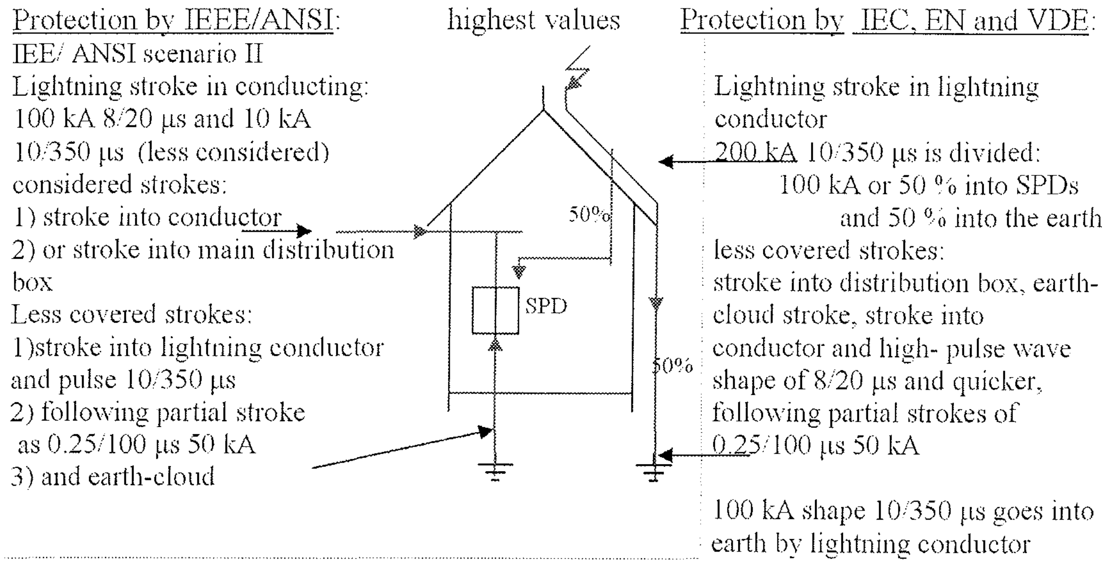

Fig. 8: The main difference between the IEC standard by TC 81 and the IEEE/ANSI standard. The IEC standard protects against lightning stroke into a lightning conductor that conducts half of the current value into the earth and the other half is disposed by metal conductors. The IEEE standard protects against lightning strokes that come through conductors into the building, and strokes from the earth to SPDs.

First the structure of the building must be considered and where the protection is required.

SPDs in power systems:

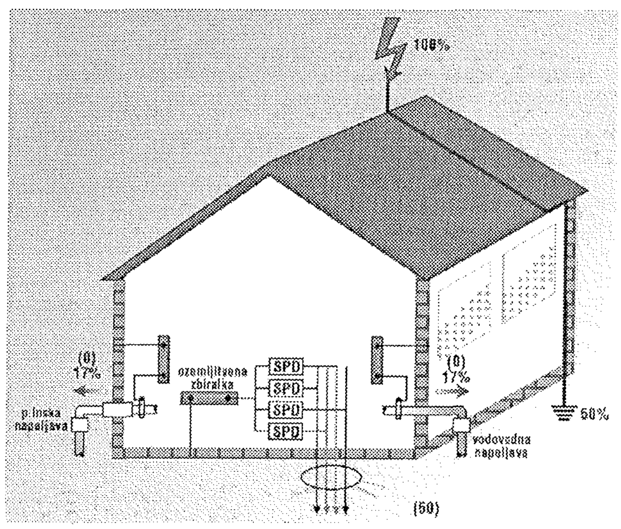

Fig. 9: Examples of diversion of lightning current into the external services (TT system IEC 61643-12) in the building.

In the case of a very rare 200 kA direct lightning stroke of a pulse of 10/350 µs shape into the building, 50 % or 100 kA would go to the ring earth electrode through points 1-4 of the protection plan, 17 % or 34 kA to the metal water pipe and 17 % to the metal gas pipe. The remaining 16 % or 32 kA would go into two SPDs with 8 % or 16 kA each on the phase and neutral conductor. In the case there are no metal pipes, 50 % would go to the earthing ring and 50 % or 100 kA would go to the SPDs.

The device is composed of five groups of 5 x 6.5 kA 8/20 µs varistors and five tripolar gas tubes on five thermal disconnection fuses. Such device can be replaced in future by a double-sided single-varistor SPD in combination with a new gas tube. The dimensions of the above-mentioned American SPD are 882,000 mm^3. Ours has 94,000 mm^3.

The selection of protecting level U_p depends on the maximum continuous operating voltage U_c of the protecting elements and SPD, and on the testing IEC category current pulses:

I_{imp}	Class I	test with wave shape - 10/350 µs
I_n	Class II	test with wave shape - 8/20 µs
U_c	Class III	test with wave shape - combination of 1.2/50 µs and 10/350 µs

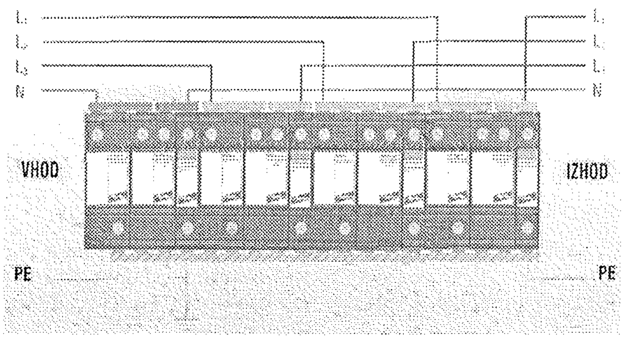

Fig. 11: For the rural net with 36 A in TNC-S systems with four-pole protection SPDs for I_{imp} total 100 kA 10/350 µs are used in three steps: lightning arrester - Class I; inductive coupling - 36 A; and varistor - Class II for each conductor. Total width of the 63 A version is 26 TE to 30 TE, depending on the producer, or 432 mm to ca 500 mm, and up to 2,200,000 mm^3.

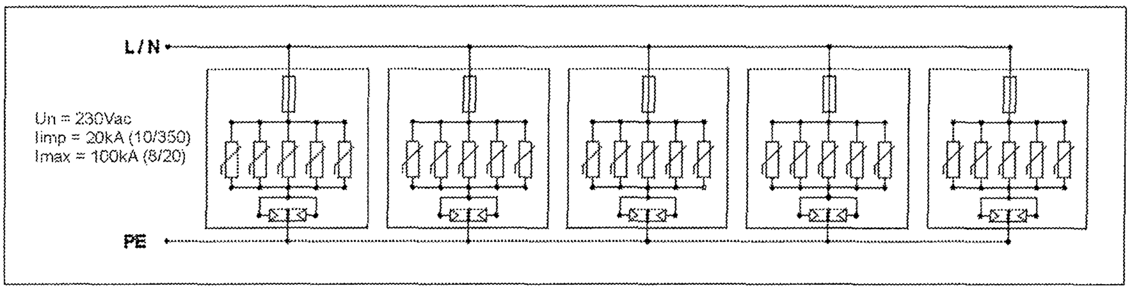

Fig. 10: Electric circuit of the one-pole active SPD with different protection components. The SPD for one conductor, developed in America and Australia, has 100 kA 8/20 μs capability and 20 kA of 10/350 μs.

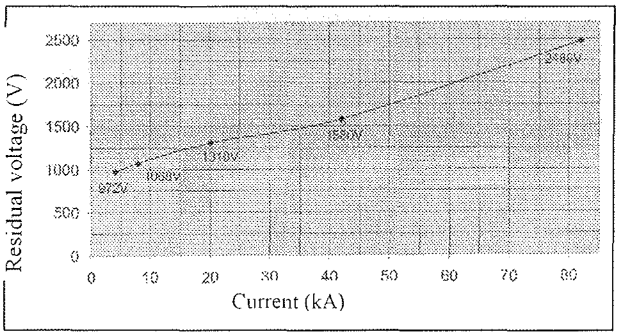

Fig. 12: Diagram of a varistor SPD's residual voltage

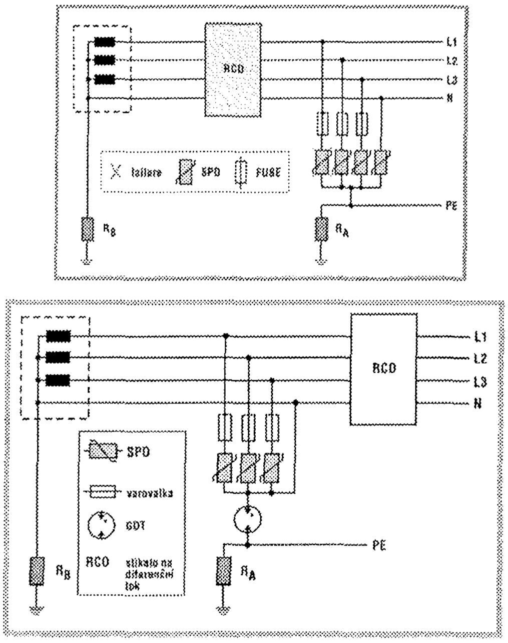

Fig. 13: The correlation between the SPD and the protecting elements in TT systems

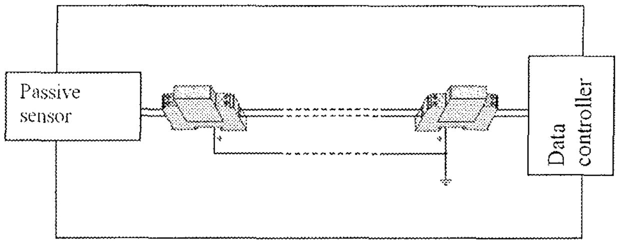

Fig. 14: Protection by SPDs in information

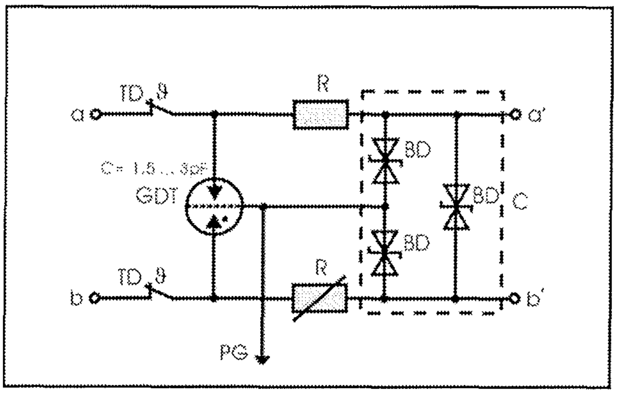

Fig. 15: Typical information protection circuit

2.6 Protect the telecommunication and data circuits to prevent equipment damage and the cost of operational downtime

SPDs in IT systems

The information technology is considered to sustain lesser strokes and SPDs of maximum 40 kA 8/20 μs pulse.

SPDs in Telecommunications

If a telephone exchange has many telecommunication lines 2.5 to 5 kA of 8/20 μs per conductor would do. However, external lightning protection in points one to four and a properly chosen point five for power supply protection must be completed. Telecom equipment is also highly endangered from the power supply side. It often includes very tall aerials that attract the direct stroke of lightning into the building.

In such cases, in a well-protected building with pipe metal lines and protection Faraday cages, only gas tube GDT protection with current protection for possible "power contact" from the mains is allowed, according to the ITUT standards K20 and K44. For terminal protection at least 10 or 20 kA 8/20 μs pulse rigidity is recommended and SPD protection in several stages to lower the residual voltage.

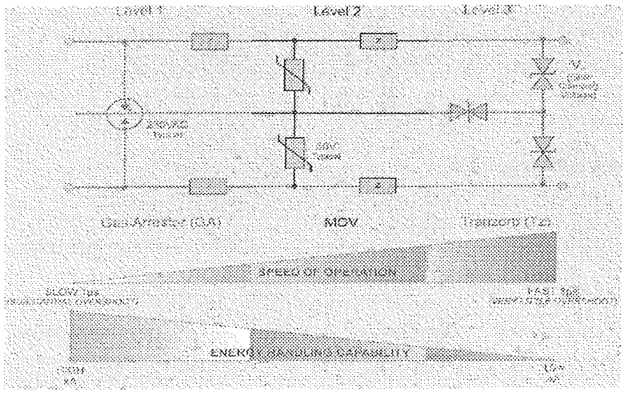

Fig. 16: The working conditions of protecting elements in telecommunications along the line. Coordinated components lower the residual voltage before the entry of the protected equipment.

SPDs as equipotential sparks based on own Gas Discharge Tubes (GDTs)

When the equipotential levels on the earthing electrodes from different buildings are not the same as usual, the electrodes should be connected together by a conductor.

In such a case a galvanic current would flow and, with time, damage the electrodes by corrosion. To prevent this, SPDs must be inserted between the electrodes and the lightning. They are available in two versions: incapsulated in an insulation tube or open.

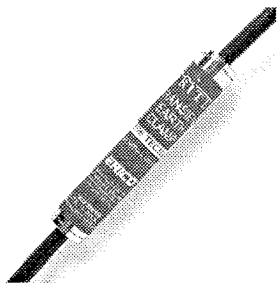

Fig. 17. Own earth 100 kA gas discharge tube

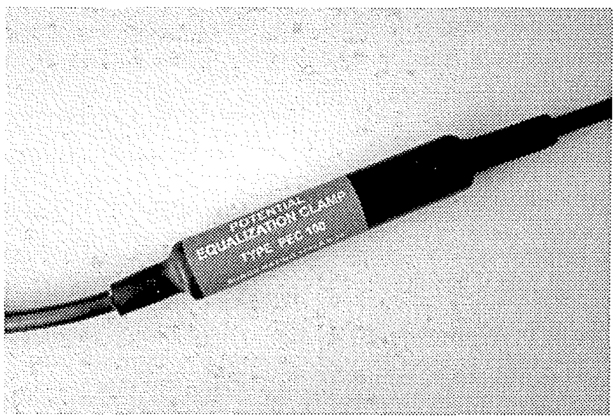

Fig. 18. Incapsulated in insulation tube

3. Conclusion

Statistical level of maximum atmosphere discharges / international standards:

Parameter	Protection class		
	I	II	III-IV
Pulse current I (kA):	200	150	100
Energy W/R (MJ/Ω):	10	5,6	2,5
Charge (pulse) (As):	100	75	50
Charge (duration) (As):	200	150	100
Effectively:	98%	95%	80-90%

Insurance companies statistically survey the damages caused by discharge and overvoltage. In Germany, the average costs in the apartment buildings through the years were given by GDV e V, Berlin, in 2001. The average costs of the damages through overvoltages in the past years in Germany were ca 30 %. However, 19 % came from unknown causes, and half of the probability 51% could also be attributed to overvoltages.

A brief comparison between different SPD components:

spark gaps, metal-oxide varistors and semiconductive protective elements, quick diodes and thyristors

- Self-standing spark gaps open in ca 1 μs' time and the residual voltage is high, ca 4 V;
- Varistors open in 0.0025 μs, the residual voltage at U_n of a 320 V varistor is lower, with ca 1000 V on the same I_{imp} 25 kA 10/350 μs; and
- Quick diodes open in picoseconds, but deal with lower powers and voltages only.

Spark gaps have a huge potential of current and energy, but they frequently provoke high short currents after ionisation. These, coming from the mains, are very often several times higher than the lightning current itself that opens the spark gap. After a certain period of strokes, the metallization of the internal parts of airgaps can be expected. Because of their voltage-depending characteristics, varistors do not have the follow-up current inconvenience, but with strokes they lose their properties and must have thermal protection against fire and TOV. To avoid thermal runaway and destruction, they should be over-dimensioned.

Protective quick-response diodes are still too weak in energy consumption and are mostly used in groups to multiply their capabilities, or with other protection components.

Thyristors work like switches. After clamping voltage, the voltage to continue the high conductivity is very low. Stroke values of ca 300 A at 10/700 μs on 300 V thyristors are common, but the self-extinguishing effects for mains protection applications are not properly present.

Thus the best way is to combine the good and the bad properties of each component in an SPD. To explain all existing solutions would be a long story.

First of all, some modelling of the lightning protection system is new:

Modelling of the lightning channel;

Modelling of the lightning protection structure;

Modelling of the earth conductor;

The first leads to modelling the current of lightning and the electric field due to the lightning stroke. The lightning protection structure is modelled similarly to the static state on protected zones. The incoming current is the base of mathematical simulation and calculation of the earth resistance or transient impedance.

The present-day procedures for lightning protection are based on a lightning channel in the frequency domain, lightning catching rods and earthing structures. The transient impedance of the earthing electrode was calculated by approximation of the conductor line. The problem of the earthing impedance can be modelled precisely only through the model of the antenna theory, where the radiation principles are really involved.

The new, complete model is based on the frequency and time analysis. The latter is more practical and less sophisticated, since the transformation from one into the other would cause several ten thousands of transformations.

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