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Effect of Lightning on Building and Its Protection Measures

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***Abstract*---- A lightning strike can cause significant structural damage to a building. It can lead damage to machinery and equipment, both inside and outside the building and may result in harm to people. This paper presents a review of lightning protection principles and set out a methodology to be followed to provide a total solution to both the direct and indirect effects of a lightning strike.**

Keywords: lightning, effect, protection.

I. INTRODUCTION

Lightning is one of those natural events which catches people's imagination with its obvious violence and the destructive power attributed to it. Thunder and lightning was believed to the expression of the wrath of the gods. Lightning fascinates and frightens us. The considerable damage it causes to property and it's unfortunate victims plainly demonstrate that the imaginary is based on a phenomenon that is very real and can be fairly well explained, but cannot be combated. Only modest attempts can be made to control its effects and the consequences.Lightning can be likened to a disruptive electrical discharge due to the dielectric breakdown of the air between the clouds or between the clouds and the ground. Certain clouds (cumulo nimbus) create meteorological conditions that are favourable to the accumulation of electrostatic charges. Breakdown, which is visible in the form of the lightning flash, itself has a very complex phenomenology (precursor, leader stroke, return discharge, etc.). It is accompanied by a sound wave, thunder, caused by the sudden expansion of the air which is overheated by the electric arc. When lightning reaches the earth, it generally does so directly on natural elements (trees, hills, water, etc.) but also occasionally on structures, buildings, pylons and other man-made structures.

A distinction that leads to the division into two separate types of effect:

- Those described as **"direct"** which are due to the circulation of the intense current (several tens of thousands of amperes) which heats materials and causes considerable damage (calcinations, fire, dislocation or even collapse)
- Associated, **"indirect"** effects which produce over voltages by conduction, induction or increasing the earth potential.

II. MECHANISM OF LIGHTNING

The mechanisms of lightning are very complex, but can be explained in simple terms as involving a very high energy electrical discharge caused by the difference in potential between clouds or between the clouds and the ground.

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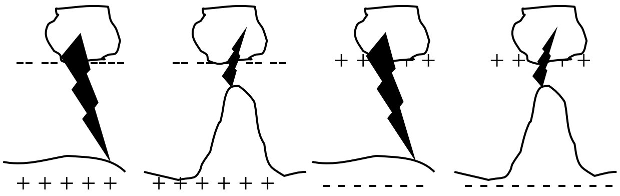
Lightning currents are more than 20 kA in 80% of cases and can reach values in the region of 200 kA (or even more) with rise times of a few microseconds.

Different types of ground lightning strike:

Depending on the direction in which the charge develops (cloud-to-ground or ground-to-cloud) and whether the charge is negative or positive, there are four different types of ground lightning strike.

i. Negative cloud-to-ground
ii. Positive ground to cloud
iii. Positive cloud to ground
iv. Negative ground to cloud



Negative Cloud - to- Ground	Positive ground -to- cloud	Positive cloud -to- ground	Negative ground - to- cloud

The discharge current varies from a few tens of kA to a hundred or so kA. A **"precursor"** traces a conductive channel descending from the cloud to the ground and the lightning discharges as "feedback" from the ground to the cloud. When the precursor is ascending, the lightning strike is said to be from ground-to-cloud. Positive ground-to-cloud lightning strikes, which occur more frequently in winter, are more rare (10 %), and are also more violent (several hundred kA). They develop starting from a natural or artificial prominence.

III. EFFECTS OF LIGHTNING

The effects of lightning are commonly divided into direct and indirect effects.

A) Direct effects (strikes on structures)

A direct strike to a building or structure will seek a path to ground either via the structure's lightning protection system or via any other metallic path via a series of flashovers which may quite unpredictable. As well as direct strike to buildings and structures, lightning may directly strike power lines, antennas, antenna feeders and overhead telephone cables as well as mechanical services like water and gas piping. Direct lightning strikes may be connected. The aim then must be to intercept these impulses as they enter the building and bypass them to earth.

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B) Indirect effects (network overvoltage)

As well as direct lightning strikes, indirect effects can also be damaging. For example if lightning strikes a building or any of the services mentioned above, transient over voltages maybe caused through resistive, inductive and capacitive coupling. The following serves to illustrate this point:

a) Over voltages caused by feedback from earth

The lightning current that falls on a lightning conductor causes an increase in the earth potential of the installation, which will cause an overvoltage between the earthing system (foundations) and the internal lines (power, telephone, TV) within the installation. This overvoltage spreads to neighbouring installations via the distribution network. When a lightning strike hits the ground or an item near the building (prominence, tree, post, etc.) directly, there is a similar increase in the earth potential causing over voltages in installations near the strike, via their earthing electrodes, within a radius of approximately 50 m. Close to the lightning strike, the overvoltage, said to be "fed back from earth", spreads (is feedback) from the earth to the network via the installation. In the case of lightning strikes on a lightning conductor or in the immediate vicinity of the installation, the effects are extremely destructive if there are no voltage surge protectors (breakdown and destruction of equipment connected to the network). The overvoltage U spreads via the network to the neighbouring installations and can then cause destructive secondary sparkovers between the live conductors and the exposed conductive parts of equipment in those neighbouring installations whose earth is referenced to a different potential. This type of phenomenon is often observed in installations close to churches or very tall buildings. To limit the consequences of such phenomena, which are always difficult to foresee, you should:

- Equip all installations supplied by the same LV network with voltage surge protectors
- Make all the bonding systems equipotential via interconnected earthing electrodes. This solution is possible on groups of buildings (industrial sites), but is unrealistic in the home. It should be noted that the neutral conductor, when properly earthed, provides certainequipotentiality. In TT earthing systems, the earthing electrodes which are separate for the network and the installation impair this equipotentiality and are sources of voltage differences. In this respect, the TN earthing system, which has only one earthing electrode for the power supply and the installation, is more favourable. It must also be remembered that although they are naturally protected against direct effects, underground distribution networks can also induce feedback from earth.

b) Voltage induce by electromagnetic induction

The lightning discharge current, whether by direct strike or carried by a lightning conductor down conductor, generates a field whose electrical and magnetic components reach considerable values: several kV/m and several tens of microtesla (μT). This radiation is received by all the conductors, forming a more or less appropriate aerial, which becomes the focus of the induced currents. It is particularly on the conductors which make up loops with large surface areas that the effect of magnetic induction (field H) is predominant. The field generated by the current i (several kA) in the lightning conductor downconductor connects to the loop formed by the conductors in the building, generating a voltage U of several kV. This phenomenon also occurs, though to a lesser degree, when there is a strike some distance away, even as far as several hundred metres

IV. PROTECTION OF STRUCTURE FROM LIGHTNING

Lightning protection systems, essentially lightning conductors (protection of structures) and voltage surge protectors (protection against overvoltage), offer effective protection if they are defined and installed with care.

A) External protection

a) Protection system (lightning conductors)

The purpose of these is to protect structures against direct lightning strikes. By catching the lightning and running the discharge current to earth, they avoid damage connected with the lightning strike itself and circulation of the associated current.

Lightning conductors are divided into four categories:

I) Single rod lightning conductor (franklin rods)

These consist of one or more tips, depending on the size of the structure and the downconductors. They are connected either directly to the earthing electrode of the installation (foundation), or, depending on the type of protection and national work practices, to a special earthing electrode (lightning conductor earthingelectrode) which is itself connected to the earth of the installation.

II) Lightning conductors with spark over device

These are a development of the single rod. They are equipped with a sparkover device which creates an electric field at the tip, helping to catch the lightning and improving their effectiveness. Several lightning conductors can be installed on the same structure. They must be interconnected as well as their earthing electrodes.

III) Lightning conductors with meshed cage

The meshed cage consists of a network of conductors arranged around the outside of the building so that its whole volume is circumscribed. Catcher rods (0.3 to 0.5 m high) are added to this network at regular intervals on projecting points (rooftops, guttering, etc.). All the conductors are interconnected to the earthing system (foundation) by downconductors.

IV) Lightning conductors with earthing wires

This system is used above certain buildings, outdoor storage areas, electric lines (overhead earth wire), etc. The electrogeometric model of the sphere applies to these.

b) Electrogeometric model

The choice and positioning of lightning capture devices requires a specific study of each site, the objective being to ensure that the lighting will preferably “fall” at one of the predefined points (lightning conductors) and not some other part of the building. There are various methods for doing this, depending on the type of capture device (lightning conductor) . One of these, called the **“electrogeometric model”** (or imaginary sphere model) method, defines the spherical volume that is theoretically protected by a lightning conductor according to the intensity of the discharge current of the first arc.

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The higher this current, the higher the probability of capture and the wider the protected area.

c) Capture surface areas

When the site to be protected consists of several buildings or extends beyond the range of a single capture device (lightning conductor), a protection plan must be drawn up for the area, juxtaposing the different theoretical capture surface areas. It is always difficult to achieve total coverage of a site when it is made up of structures of different heights. Superimposing the protection plan over the layout of the area makes it possible to see areas that are not covered, but above all it must assist in-depth consideration taking account of:

- The probability of lightning strikes by determining the main strike points (towers, chimneys, antennae, lamp posts, masts, etc.)
- The sensitivity of the equipment housed in the buildings (communication and computer equipment, PLCs, etc.)
- The potential risk linked to the business or the types of material stored (fire, explosion, etc.)

It must also be remembered that the numerous links between the buildings (computer networks, remote monitoring, communications, alarms and power) can create interference as a result of the effect of the lightning's electromagnetic field or that of the voltage gradient generated in the ground. There are two ways in which these links can be protected:

- Shielding or use of Faraday cages which will, as well as protecting against these fields, primarily maintain the equipotentiality of the link (adjacent earthing conductor, twisting, conductor screen, etc.)

- Galvanic decoupling, which will separate buildings electrically (optocouplers, fibre optics, isolation transformers, etc.).

d) Down conductors

These provide the link between the lightning conductor itself (rod, cage, wire) and the earthing electrode. They are subjected to intense currents and must therefore be of an adequate cross-section (min. 50 mm2 copper), flat (HF current), firmly fixed and follow the shortest possible route. They must have no rises or sharp angles. The conductors can be fitted with lightning strike counters.

In buildings with several floors, it is recommended that the lightning conductor downconductor(s) are connected to the bonding systems on each floor. If this is not done, the voltage difference that occurs between the downconductors and the internal exposed conductive parts could cause a sparkover through the walls of the building. The circulation of the HF lightning current may in fact cause a significant voltage rise in the downconductor (several hundred kV) due to the increase in its high frequency impedance.

The consequences in the installation of the effects caused by circulation of the lightning current in the downconductors can be minimised by:

- Increasing the number of downconductors in order to divide the current and limit the effects caused
- Ensuring that the downconductors are interconnected with the bonding systems on all floors in the building
- Creating equipotential bonding systems incorporating all conductive elements, including those that are inaccessible: fluid pipes, protection circuits, reinforcements in concrete, metal frames, etc. - Avoiding placing downconductors near sensitive areas or equipment (computing, telecommunications, etc.).

e) Earthing system

This is an essential element in protection against lightning: all the exposed conductive parts, which are themselves interconnected, must be connected, and the system must be capable of discharging the lightning current, avoiding a voltage rise in the earthing system itself and the surrounding ground. Although it must be low enough (< 10 O), the low frequency resistance value of the earthing electrode is less important than its shape and size as far as the discharge of the high frequency lightning current is concerned. As a general rule, each downconductor must end in an earthing electrode which can consist of conductors (at least three) in a crow's foot layout buried at least 0.5 m deep, or earth rods, preferably in a triangular layout.When possible, it is always advisable to increase the number of downconductors and linking points (each floor), and thus to increase the overall scale of the equipotential bonding system. At the same time as this, the earthing system must of course be capable of discharging the lightning currents in order to limit the voltage rise of the bonding system as much as possible.

When the equipment to be protected is particularly sensitive (electronic with 0 V referenced to the bonding network, telecommunications, computing shielding, etc.), or when it is not possible to establish an effective high frequency earthing electrode (for example, rocky ground) or if the scale of the installation is such that there are numerous voltage feedback points, additional measures must be taken to provide protection against a high frequency voltage rise in the bonding system involving all circuits interconnected with it.

B) Internal protection

a) Active and passive protection of the installation

The most commonly used protection devices such as fuses and circuit breakers are too slow in relation to the phenomenon of lightning and can in no way protect electrical or electronic equipment from overvoltages caused by lightning. Voltage surge protectors are necessary for this. Voltage surge protectors provide active protection of the installation. But they are only fully effective when installed carefully and correctly: choice of model, positioning, connection, etc. In addition to this initial requirement, other criteria connected with physical characteristics of the installation (scale, equipotentiality, earthing system, separation of circuits, etc.) are also determining factors. They are grouped together under the term passive protection. Voltage surge protectors are also involved in protecting equipment.

- Against the risks of overvoltage from operations, that may occur statistically more often than overvoltages caused by lightning. Although their energy level is much lower, these overvoltages can also damage a large amount of equipment.
- Against electromagnetic interference up to frequencies in the region of several hundred kilohertz, such as interference caused by frequent starting of inductive or capacitive loads, or even the operating modes of some devices (repetitive starting of welding stations, high-pressure washers, contactors, radiators, air conditioning units, heaters, etc.). Although their energy level is low, these types of overvoltage can also cause accelerated ageing of very sensitive equipment (computers, modems,

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TVs, HiFi systems, etc.). However, the purpose of voltage surge protectors is not to:

- Protect equipment against high-frequency interference, for which filters must be used.
- Protect an installation against the risks of temporary overvoltages due to faults on the high or low voltage supply, such as neutral breaks.

b) Lightning strike withstand of equipment

Irrespective of how the energy of the lightning strikeaccesses the installation, it causes overvoltage and current values that are dependent on the structure of the installation and where the energy is generated. The need to protect equipment against overvoltages must be based on a comparison between the prospective value of the lightning strike according to the installation conditions and the impulse voltage withstands value (overvoltage category) of the equipment.

V. CONCLUSION

Lightning is an important and essential part of the earth's ecosystem, but can be destructive at times. It is sometimes hard understand why some places seem to be prone to lightning. Very tall objects are frequent targets because they represent the shortest path from a cloud to earth. Injury, damage, and fires are usually the result of lightning not being able to find a quick and easy path. A good lightning protection system helps provide that path, thus reducing the probability that damage will occur to people or animals.

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