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Lightning Phenomenon, Effects and Protection of Structures from Lightning

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Abstract: *Lightning is a sudden electrostatic discharge during an electrical storm between electrically charged regions of a cloud (called intra-cloud lightning or IC), between that cloud and another cloud (CC lightning), or between a cloud and the ground (CG lightning). Lightning is climate related, highly localized phenomena in nature known for dangerous consequences. 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 also may result in harm to people. This paper presents a review of lightning phenomenon, its effects and sets a methodology to be followed to provide a solution to both the direct and indirect effects of a lightning strike.*
Keywords: *Lightning, effects, protection.*

I. Introduction

Lightning is a natural phenomenon which develops when the upper atmosphere becomes unstable due to the convergence of a warm, solar heated, vertical air column on the cooler upper air mass. These rising air currents carry water vapour which, on meeting the cooler air, usually condense, giving rise to convective storm activity. Pressure and temperature are such that the vertical air movement becomes self-sustaining, forming the basis of a cumulonimbus cloud formation with its centre core capable of rising to more than 15,000 meters.

To be capable of generating lightning, the cloud needs to be 3 to 4 km deep. The taller the cloud, the more frequent the lightning. The centre column of the cumulonimbus can have updrafts exceeding 120 km/hr, creating intense turbulence with violent wind shears and consequential danger to aircraft. This same updraft gives rise to an electric charge separation which ultimately leads to the lightning flash. Figure 1 shows a typical charge distribution within a fully developed thunder cloud.

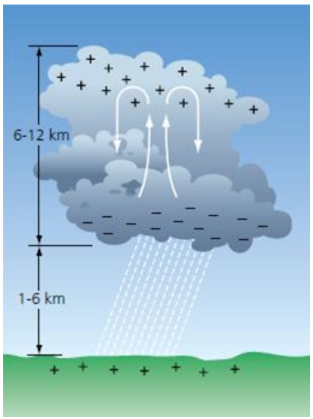

Fig1. Typical charge distribution in cumulonimbus cloud.

Lightning can also be produced by frontal storms where a front of cold air moves towards a mass of moist warm air. The warm air is lifted, thus generating cumulonimbus clouds and lightning in a similar mechanism to that described earlier. One major differentiation of this type of event is that the cold front can continue its movement and result in cumulonimbus clouds spread over several kilometers width. The surface of the earth is negatively charged and the lower atmosphere takes on an opposing positive space charge. As rain droplets carry charge away from the cloud to the earth, the storm cloud takes on the characteristics of a dipole with the bottom of the cloud negatively charged and the top of the cloud positively charged. It is known from waterfall studies that fine precipitation acquires a positive electrical charge. Larger particles acquire a negative charge. The updraft of the cumulonimbus separates these charges by carrying the finer or positive charges to high altitudes. The heavier negative charges remain at the base of the cloud giving rise to the observance that approximately 90% of all cloud-to-ground flashes occur between a negatively charged cloud base and positively charged earth (i.e. negative lightning).

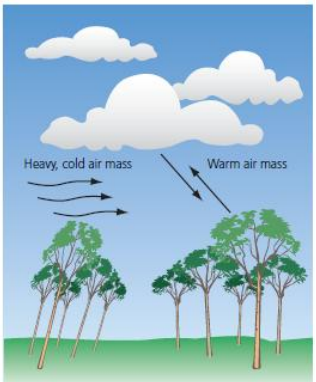

Fig 2. Cumulonimbus clouds generated by frontal storms.

II. 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

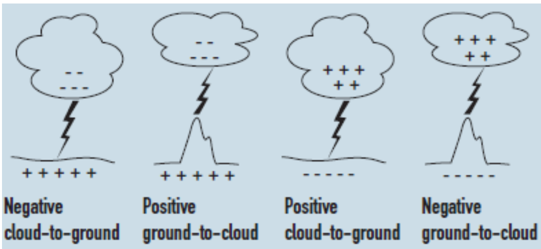

Fig3. Different types of ground lightning strike

Some lightning strikes take on particular characteristics; scientists and the public have given names to these various types of lightning. Most lightning is streak lightning. This is nothing more than the return stroke, the visible part of the lightning stroke. Because most of these strokes occur inside a cloud, we do not see many of the individual return strokes in a thunderstorm. The return stroke of a lightning bolt, which is the visible bolt itself, follows a charge channel only about a half-inch (1.3 cm) wide. Most lightning bolts are about a mile (1.6 km) long.

Cloud-to-cloud lightning: Lightning discharges may occur between areas of cloud having different potentials without contacting the ground. These are most common between the anvil and lower reaches of a given thunderstorm. This lightning can sometimes be observed at great distances at night as so-called "heat lightning". In such instances, the observer may see only a flash of light without thunder. The "heat" portion of the term is a folk association between locally experienced warmth and the distant lightning flashes.

Dry lightning: Dry lightning is a term in the United States for lightning that occurs with no precipitation at the surface. This type of lightning is the most common natural cause of wildfires.

Rocket lightning: It is a form of cloud discharge, generally horizontal and at cloud base, with a luminous channel appearing to advance through the air with visually resolvable speed, often intermittently. It is also one of the rarest of cloud discharges.

Cloud to ground lightning: Cloud-to-ground lightning is a great lightning discharge between a cumulonimbus cloud and the ground initiated by the downward-moving leader stroke. This is the second most common type of lightning, and poses the greatest threat to life and property of all known types.

Bead lightning: Bead lightning is a type of cloud-to-ground lightning which appears to break up into a string of short, bright sections, which last longer than the usual discharge channel. It is fairly rare. One of theories is the observer sees portions of the lightning channel end on, and that these portions appear especially bright.

Ribbon lightning: Ribbon lightning occurs in thunderstorms with high cross winds and multiple return strokes. The wind will blow each successive return stroke slightly to one side of the previous return stroke, causing a ribbon effect
.

Ground-to-cloud lightning: Ground-to-cloud lightning is a lightning discharge between the ground and a cumulonimbus cloud from an upward-moving leader stroke.

Ball lightning: Ball lightning is described as a floating, illuminated ball that occurs during thunderstorms. They can be fast moving, slow moving or nearly stationary. Some make hissing or crackling noises or no noise at all. Some have been known to pass through windows and even dissipate with a bang. Ball lightning has been described by eyewitnesses but rarely recorded by meteorologists.

Upper-atmospheric lightning: Reports by scientists of strange lightning phenomena above storms date back to at least 1886. However, it is only in recent years that fuller investigations have been made. This has sometimes been called mega-lightning.

III. Effects Of Lightning Strike:

Different effects

The effects of lightning are those of a high-strength impulse current that propagates initially in a gaseous environment (the atmosphere), and then in a solid, more or less conductive medium (the ground):

- visual effects (flash)
- acoustic effects
- thermal effect
- electrodynamics effects
- electrochemical effects
- effects on a living being (human or animal)

Lightning causes two major types of accidents:

- accidents caused by a direct stroke when the lightning strikes a building or a specific zone. This can cause considerable damage, usually by fire. In order to prevent any risk of accident, lightning air terminals should be used.
- accidents caused indirectly, as when the lightning strikes or causes power surges in power cables or transmission links.
  Hence the need to protect with Surge Protection Devices the equipment at risk against the surge voltage and indirect currents generated.

Direct effects

- **Thermal effects**: These effects are linked to the amount of charge associated with lightning strikes. They result in fusion points melting holes of varying sizes at the point of impact of materials with high resistivity. For material which is a poor conductor, a large amount of energy is released in the form of heat. The heating of water vapour contained in the material results in very high abrupt localized pressure which may cause it to explode.
- **Effects due to the initiation**: In the event of a lightning strike a substantial increase in the ground potential of the installation will occur depending on the grounding network and soil resistivity. Potential differences will also be created between various metal elements. Hence the need to pay particular attention when installing earth rods and inter-connection of metal structures adjoining the conductors.
- **Acoustic effects - thunder**: Thunder is due to the sudden increase in pressure (2 to 3 atmospheres) of the discharge channel developed by the electrodynamic forces during the lightning flash. The duration of a thunder clap depends on the length of the ionized channel. For high frequencies, propagation of the spectral components released by the shock wave is perpendicular to the channel. For low frequencies, propagation is omnidirectional; hence the different forms of rumbling or claps heard by an observer according to the distance and orientation of the successive channels used by the lightning flash.
- **Luminous effects**: A lightning strike nearby violently sensitizes the retina of an observer. The eye is dazzled and vision is lost for several long seconds.
- **Electrodynamic effects**: Electrodynamic effects between conductors and other parts occur due to large magnetic field of the lightning current. This results in substantial mechanical forces, both attractive and repulsive, that are all the stronger when the conductors are close together or the current is high.

- **Electrochemical effects**: The fleeting nature of lightning impacts (compared to stray ground currents) mean that these effects are highly negligible and without influence on earth rods.

Indirect Effects

The ever increasing use of sensitive electronics means that electrical equipment is becoming more and more vulnerable to transient overvoltages caused by lightning.The overvoltages are either of atmospheric origin or industrial origin. The most harmful are however atmospheric overvoltages which are the result of three main effects:

Conduction: An overvoltage that propagates along a conductor which has been in direct contact with the lightning strike. This effect is all the more destructive as the majority of the lightning energy is propagated through the entire network. This problem is resolved by fitting the installation with suitable device able to support high currents.

Induction: caused by the electromagnetic field radiated by the lightning strike. It generates an overvoltage on conductors within a range that is proportional to the power and the rate of speed variation of the lightning strike. Consequently, under the influence of abrupt variations in current, the cables, and even the ducts which act as aerials, may be subjected to destructive overvoltages. This is the reason that placing the network underground does not guarantee lightning protection.

Rising up from the ground: When a lightning strike hits, an overvoltage can rise up from the ground attempting to find a more favourable path to ground. This can, in part, be dealt with through a) equipotential bonding between the metal structures and ground of the entire installation of a structure. b) overvoltage protection installed on services.

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 are metal rods installed over a structure at preferred points for a lightning strike. These terminals are connected to a network of horizontal and vertical conductors that are terminated to earthing terminals. The network of rods, conductors and earth terminals covers the protected structure in a Faraday Cage. Various sizes and shapes of Franklin Rods are available to suit an application and we have capability to design and manufacture a custom system to fit your needs.

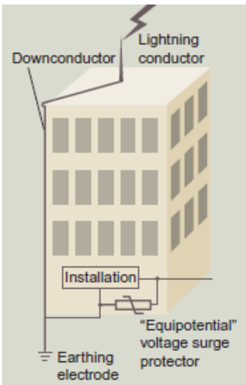

Fig4. Lightning protection of structure by Franklin rod

II) Lightning conductors with spark over device:

These are a development of the single rod. They are equipped with a spark over 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.

Fig5. lightning conductor with sparkover device.

III) Lightning conductors with meshed cage:

This protection involves placing numerous down conductors/tapes symmetrically all around the building. This type of lightning protection system is used for highly exposed buildings housing very sensitive installations such as computer rooms

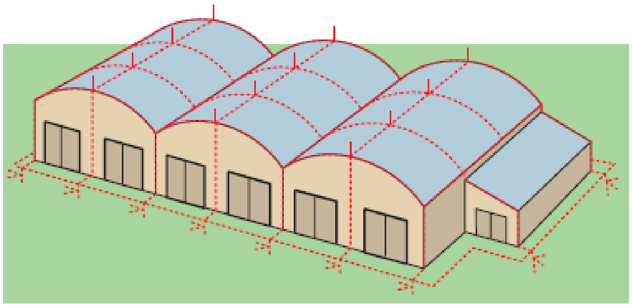

Fig6. Lightning conductors with a meshed cage

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.

Fig7. Lightning protection by shielding wires

b) Electrogeometric model:

The Electro-geometric model is one of the techniques that have been successfully employed to design a shielding system and to provide a scientific basis for calculating the annual number of lightning strokes to electric power components and buildings. This is also called as imaginary sphere model which defines the spherical volume that is theoretically protected by a lightning conductor according to the intensity of the discharge current of the first arc. The higher this current, the higher the probability of capture and the wider the protected area.

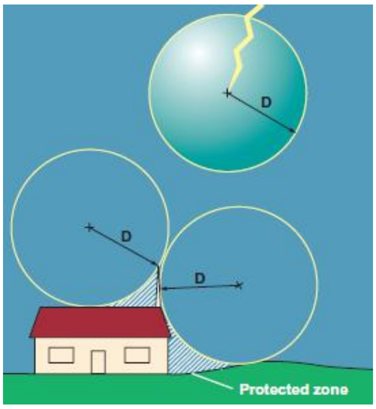

Fig8. Electro geometric model

b) Capture surface areas:

The site to be protected, when 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. 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 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:

Down conductors should be within the bounds of practical constraints take the most direct route from the air termination system to the earth termination system. The greater the number of down conductors the better the lightning current shared between them. This is enhanced further by equipotential bonding to the conductive parts of the structure. There should always be minimum of two down conductors distributed around the perimeter of the structure. Down conductors should whenever possible be installed at each exposed corner of the structure to carry the major part of the lightning current.

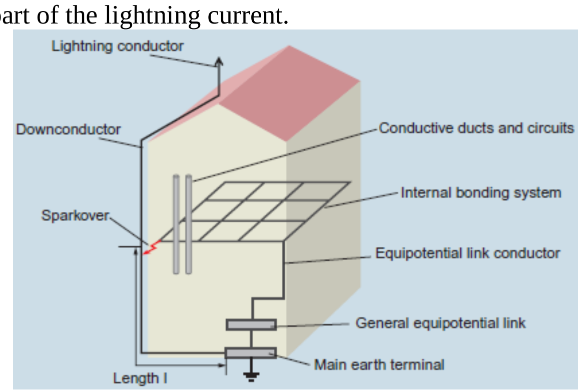

Fig9. Down conductor.

e) Earthing system:

This system is vital for the dispersion of lightning current safely and effectively into the ground. A good earth connection should posses the following characteristics:

-Low electrical resistance between the electrode and the earth. The lower the earth electrode resistance the more likely the lightning current will choose the flow down that path in preference to any other, allowing the current to be conducted safely to and dissipated in the earth.

-Good corrosion resistance. The choice of material for the earth electrode and its connections is of vital importance. It will be buried in the soil for many years so as to be totally dependable.

B) Internal protection:

a) Active and passive protection of the installation: Fuses and circuit breakers are the most commonly used protection devices. These devices are too slow in relation to the the phenomenon of lightning and they will not protect the electrical and electronic equipments from overvoltages caused by lightning. Voltage surge protectors provide active protection of the installation. The best use of these voltage surge protectors can be obtained only when they are installed carefully. Therefore the choice of the model, positioning, connection, etc are important factors to be considered. The other criteria to be fulfilled along with this is 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.
- Against electromagnetic interference up to frequencies in the region of several hundred kilohertz.

c) Lightning strike withstand of equipment: The energy produced by the lightning strikes is very high. Irrespective of this, the strike causes over voltages and current values that are dependent on the structure of the installation and where the energy is produced. 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

The final budget required is quite elevated, but for the structures a high lightning protection is required to protect the human life and all expensive equipments that serve the people and that is essential for day to day.

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