

Chapter-5

Lightning, a Breakdown Phenomenon in Atmospheric Air, Its Effects and Protection

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Objectives

- Development of breakdown phenomenon in extremely long gap air
- Deleterious effects of lightning
- Protection of living beings and structure from lightning
- The rare phenomenon of ball lightning
- Prevention/protection from ball lightning

Introduction

Our earth is like a huge natural capacitor. The electric charge acquired by the clouds form the ‘high voltage electrode, and the earth the ground electrode.

- The atmospheric air in between provides the dielectric. Under thundery conditions, the clouds acquire excessive charge within a short period of time.

The high potential gradient or the electric field intensity gives rise to a wide scale ‘partial breakdown’ phenomenon beneath the clouds in air.

- During lightning strike, the clouds evacuate a huge amount of charge through the least resistance path .

The impact of lightning is least, if discharged current find the passage to ground through some conductor. It may cause havoc (fire, blast, killing, etc) if this current is unable to find passage to go inside ground.

- The lightning activity is much higher near the equator region as more severe temperature gradients develop resulting in more number of thunderstorms.

Mechanism of Development of Lightning

- The electric field intensity below the cloud limits in air increases considerably due to the static charge acquired by the clouds.
- An estimation of the electric field intensity distribution by FEM in the space between a large plane surface electrode simulating the clouds and a metallic object, on the ground revealed the existence of a very high intensity field just below the cloud limits covering a large area and another peak of lower intensity, the second peak intensity, just at the tip of the sharp electrode on the ground.

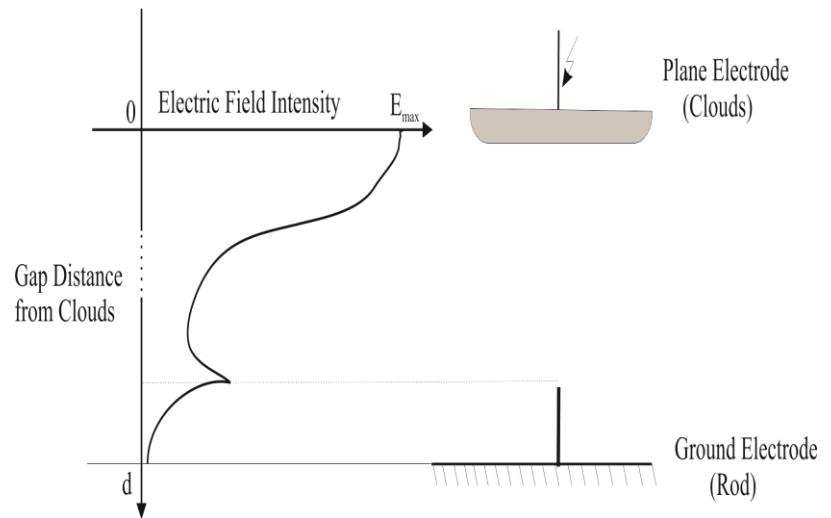


Fig.1 Schematic of Electric field estimation in the gap between a high voltage plane and a grounded rod electrode system

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- When the potential acquired by the clouds rises above the level required for the inception of partial breakdown (PB), first a wide spread streamer corona begins to take place in the air just below the cloud limits, the region of highest field intensity. Fig. 2 shows where the clouds are simulated by a big plane electrode
- The streamer channels are given rise by above critical amplification of avalanche process in which the electric field assisted ionization as well as photo-ionization take place.

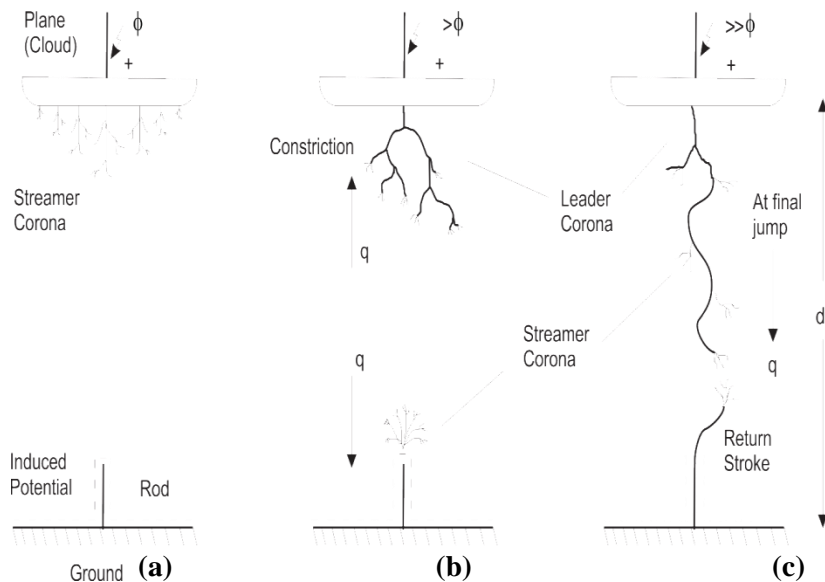


Fig.2 Schematic of the development of breakdown in long air gap



Fig.3 A photograph of lightning strike on the ground developed with streamer and stepped leader. Courtesy Photo by Jandr  van der Walt taken at Jeffreys Bay, South Africa

Damaging Effects of Lightning Strikes

➤ Loss of Life

- According to the Federal Centres for Disease Control and Prevention, USA, out of about 300 people struck by lightning nearly 100 are killed each year in USA.
- A large number of people, estimated to be 60% of deaths, sustain injuries but survive.
- The chances of survival after getting struck by lightning is much lower in India due to the lack of awareness about the first-aid to be given to a person after struck by lightning.



(a)



(b)

Fig.4 Streamer pattern on human body as burnt scar due to lightning bolt strike courtesy (a) Dave Stancliff and (b) Gear Diary

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➤ Fire Hazards due to Lightning

- In dry weather conditions lightning often ignites fire in the jungles all over the world.
- A lightning strike may inject anything between a few to hundreds of kA of impulse current (charge) in a short duration of milliseconds.
- Insulating materials, having very high resistance, of the order of hundreds and thousands of mega ohms, result in intense temperature rise due to high I^2R losses.
- The sudden generation of heat ignites fire in insulating materials.



Fig. 5 Charred core of a pine tree struck by lightning at Botanical Garden, IIT Mandi

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➤ **Blast Created by Lightning**

- The lightning is known to be attracted to strike on the sharp metallic objects terminating in free air, for example, rods, tin shed-edges, pipes etc.
- Consider such an object projected on the terrace of a cement concrete building structure struck by lightning.
- If it terminates within the building, the charge injected by the lightning strike is easily conducted inside the building up to the level of its termination.
- Finding no conducting path beyond, the charge may get trapped within the structure.
- The surface resistivity of the concrete walls being much lower than the volume resistivity, the charge floats restlessly over the wall surfaces in search of least resistance path.
- If it encounters metallic objects, for example, nails, screws, frames, etc. on the walls, the charge is attracted towards them even if they are floating.
- Finding no other way of consumption of electrical energy, the charge attracted towards these floating metallic bodies is injected in to the air. The air being an insulating material goes through a sudden expansion process creating a ‘blast’.

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(a)



(b)

Fig. 6 (a) Assembled Shiv Lingh with Butter and Sattu at Bijli Mahadev, Kullu, Himachal Pradesh, India (b) Shive temple at Bijli Mahadev.

Lightning Protection

➤ Protection of Lives

- Every lightning strike is unique and peculiar in itself. If hit by direct lightning strike, usually only a miracle can make the living being survive it.
- The high potential difference across the body of a living being causes injection of current. It can lead to ventricular fibrillation (unsynchronized muscle operation of the heart), causing respiratory arrest and neurological damage or even total burning of the body.

The Recommended Human Safety Measures

- When the thunder roars, go indoors.
- When in open, one should never take shelter under a tree in thundery conditions.
- Any metallic object carried by a person in open attracts lightning.
- Caught by thunder in the wide open, the best would be to sit on the ground with the two feet close to each other and the head bogged down and the ears covered with hands.
- If caught in a vehicle by lightning strike, it is advisable to remain inside and not touch the metal body.
- When there is an active thunder, it would be advisable not to bathe in open water.

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➤ Protection of Buildings and Structure

- **Air Termination Network**
- ✓ Consist of a vertical or horizontal conductor system on the surface or a combination of both .
- **Down Conductor Network**
- ✓ The down conductor is defined as the conductor connecting the air terminal to the earth electrode.
- ✓ It suggests copper, aluminium and their alloys, galvanized steel, etc.
- **Earth Termination System**
- ✓ Combined resistance to earth of the whole lightning protective system should not exceed 10Ω .

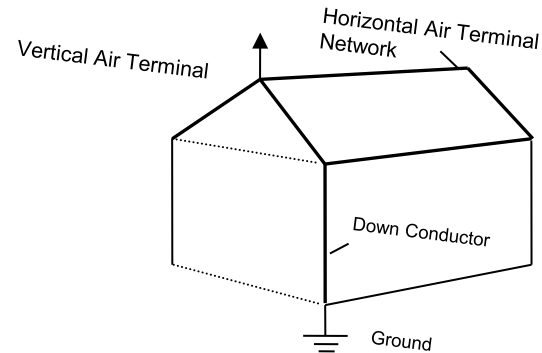


Fig. 7 A simple lightning protection system for buildings

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➤ The Zone Under Protection

▪ Protected Volume Determined by a Cone

- In case of a single mast type vertical lightning conductor, the volume under protection is evolved by simple geometry. It is considered to have the shape of an inverted cone whose height is the height of the mast and the circle at the base having radius equal to the height of the rod.
- Thus the angle of protection works out to be 45° , as shown on the right hand side in Fig. 8 (a).
- For stringent protective schemes the specifications recommend to adopt this protective angle not exceeding 30° .
- If two or more vertical conductors are required to be installed to provide protection to objects spread in a large area, the protective angle within the space bounded by the conductors is permissible to be 45° , but towards outside it must not exceed 30° , as shown in Fig. 8 (b).

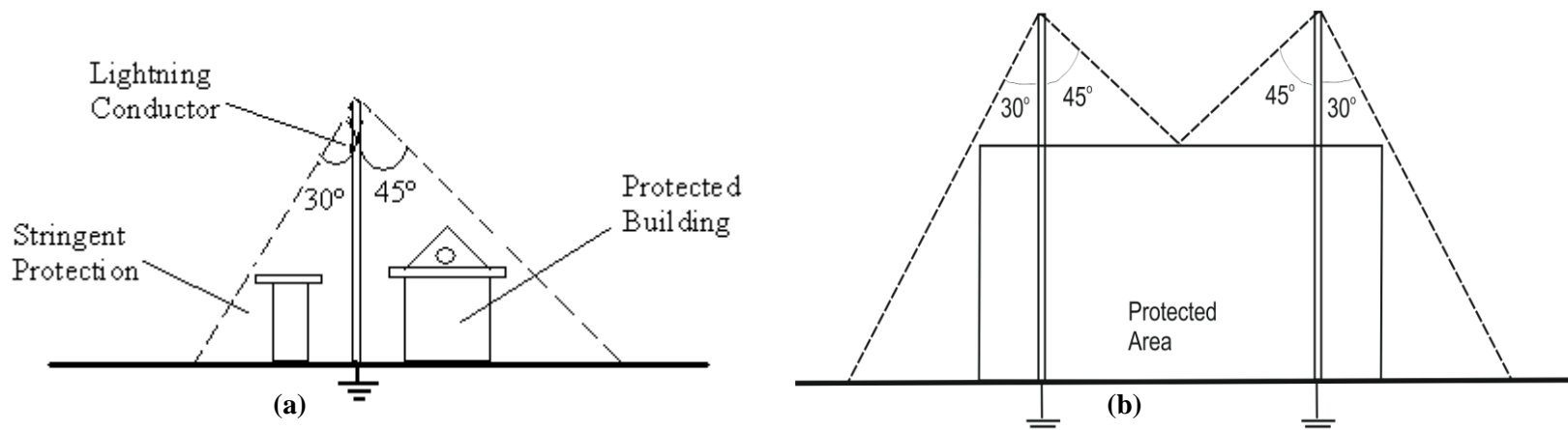


Fig. 8 (a) Protected zone by a single vertical lightning conductor, (b) Zone protected by twin vertical conductors

The Phenomenon of Ball Lightning

- It is described as a cluster of luminous particles emitting orangish-red colour light, having a near spherical shape and size ranging from that of a tennis ball to football or even bigger, whirling and waving slowly and independently through air, often in horizontal direction above the ground.
- The phenomenon of ball lightning, also known as ‘fire ball’, has been reported to take place in open air.
- **Injurious Effects of Ball Lightning**
- Ball lightning is reported to cause damage to insulating bodies/materials by overheating or even burning, for example, dress fabric, plastics, hair, etc.
- **Repeated Incidents of Ball Lightning without Lightning Strike**
- Weather and climate conditions
- Man-Made Sources of Charge/Current
 - ❑ Electric traction
 - ❑ Power theft
 - ❑ Current in neutral and ground wires

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❑ **Electric traction**

- The single-phase power supply to *electric traction* at 25 kV by two-phase, 132 kV transformers introduces highly unbalanced conditions in the distribution network.
- The return path for the current from the moving trains completes its circuit path over the rails towards the power supply substation.
- Power supply substations are located at a distance of every 40 km all along the electric track.
- The rails are made responsible for providing the return path for the huge amount of load current, of the order of a few hundred amperes, drawn continuously from each substation.
- For the highest possibility of four engines being simultaneously supplied power from a substation, the current measured was around 900 A.

❑ **Power theft**

- An estimate revealed that at certain locations even 40% of the power supplied is stolen and accounted for as 'losses'.
- All single-phase power thefts are accomplished by providing the return path for completing the circuit by simple connection to the ground, instead of through the neutral wire.

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- It renders the three-phase distribution system more unbalanced and hence an increase in the neutral conductor current, which goes normally to the ground.

□ **Current in neutral and ground wires**

- The *neutral grounding* in the three-phase power distribution system is another source which could flow on the surface of the ground under adverse conditions of soil resistivity.
- The last source of electric charge on the ground from the power distribution network is by the *ground wire* provided for safety in the single-phase power supply.
- It carries continuously the charging/leakage current of the insulation system of the single phase loads and also the short circuit current in case of the failure of insulation to the ground.

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➤ **Protection from Ball Lightning**

- The incidents of sighting of ball lightning have reduced over the century.
- Due to more metal on the ground and more number of grounded metallic objects to provide conducting path for the charged particles.
- The prevention of occurrence of the rare phenomenon of ball lightning from manmade charges can be achieved by making the grounding in electrical installations more effective particularly during the adverse conditions of dry season.

➤ **Mythical Interpretation of Ball Lightning in India**

- In the darkness of nights when people would have seen the ‘ball lightning’, the ‘fire ball’, they would have interpreted it as *naga mani*.
- It is said that the *naga* takes the *mani* out whenever in a good mood, especially during the monsoon rains during the month of *Sravana* (August) and dance putting it on its the hood.

Summary

- The loss of insulating properties of atmospheric air which results in its breakdown when a very high potential is developed on the clouds, especially under adverse atmospheric conditions, such as thunder storm.
- Protection and prevention of damage to property and life requires simple measures applied to the right directions.
- The rare phenomenon of the development of ‘Ball Lightning’ is unheard of by most of the people in this world. It is known to some from the incidents of its unusual sight and damaging effects.
- Lightning and ball lightning, myths, religious and colloquial, prevails due to lack of scientific knowledge all over the world.
- In this chapter, a mechanism of development of breakdown phenomenon in extremely long gap in air, as in case of lightning and deleterious effects of lightning has been discussed.
- Lightning protection techniques of living beings and structures has been discussed in detail.

Thank You & References

- Ravindra Arora and Bharat Singh Rajpurohit, "Fundamentals of High-Voltage Engineering" Wiley India, 2019.
- High Voltage and Electrical Insulation Engineering, By R. Arora, W. Mosch, IEEE Press, August 2011.
- High Voltage Insulation Engineering: Behaviour of Dielectrics ; Their Properties and Applications by R. Arora, W. Mosch, New Age International, 1995