Personnel Hazards Resulting from Lightning Effects

John M. Tobias P.E.; U.S. Army Communications-Electronics Command Safety Office
Fort Monmouth, New Jersey

Keywords:

Lightning, step potential, flashover, personnel protection, rolling sphere model

Abstract

In this paper, personnel hazards resulting from lightning effects are explored. Most personnel injuries come from indirect lightning electromagnetic effects, rather than direct lightning strikes. Lightning characteristics and propagation are reviewed to help provide a better understanding of protective measures and factors affecting the probability of strike. Personnel protective measures, as listed in the National Fire Protection Association (NFPA) Lightning Protection Code are also discussed.

## Introduction

Many injuries and fatalities occur every year due to lightning strikes. Certain studies suggest that there is a 30% fatality rate for people struck by lightning and persons active in the outdoors (camper, farmers, golfers and construction workers) are most at risk (ref. 1). Many of these accidents are preventable by applying basic lightning awareness and precautions. To do this, we will first discuss the way lightning attaches to objects on the ground. Understanding the basic attachment process is important in understanding some of the preventative measures that we will discuss later in the paper. After the discussion on lightning attachment, we will proceed to a discussion on the various electric effects in the vicinity of the lightning strike. Along these lines we will then examine the interaction of these effects with the human body. In closing we will examine protective measures for personnel.

## Lightning Attachment Process

Let us examine how lightning interacts with the ground and how it attaches to objects on the ground. Most lightning that reaches the ground (over 90%) is negatively charged. It begins to intercept the ground by lowering a stepped leader - a precursor to the actual lightning discharge. This leader progresses in steps toward the ground and is comprised of electric charge. It completes this process in a length of time measured in tens of milliseconds. Below the leader is a region of very high electric field. As the leader approaches the earth, the high electric field induces objects on the ground to emit leaders of opposite polarity charge. Since opposite charges attract, the path of the downward leader is influenced by an upward leader of opposite polarity. Upon connection, the actual current discharge associated with lightning begins as shown in figure 1.

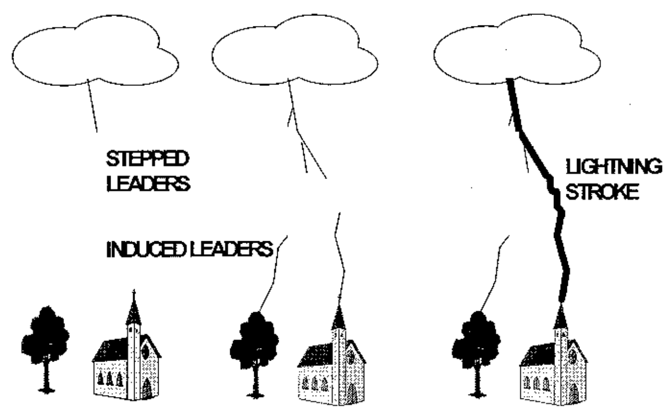


Figure 1 - Illustration of Lightning Attachment.

## Rolling Sphere Model of Lightning

The final step in the lightning attachment process occurs at a point during the downward leader progression, when the leader "decides" toward which upward leader it will travel. The prevalent model of lightning propagation used today to represent this final step is the rolling sphere model as illustrated in figure 2. As the downward leader approaches the objects on the ground, it is attracted to upward emitted leaders.

Once the downward leader is within a certain radius, known as the striking distance, the upward and downward leader attract and connect. The striking distance is defined in the NFPA 780 as the distance over which the final breakdown of the initial lightning stroke occurs. This distance is specified as 150 feet for standard structures or 100 feet for structures containing flammables (ref. 2). Examining the

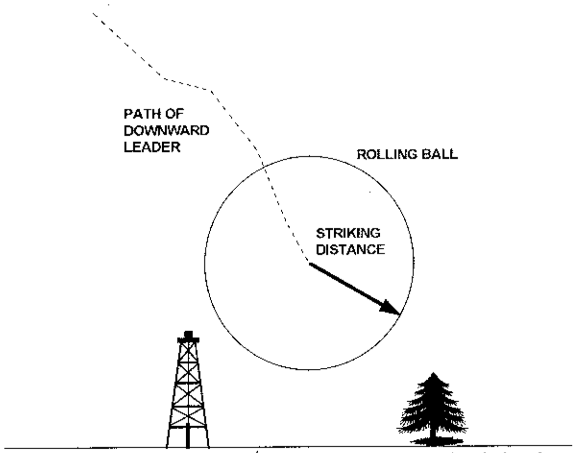


Figure 2 - Rolling Sphere Model of Final Lightning Attachment Step.

model, we see that the sphere will eventually intersect an object on the earth's surface. This object can be a tree, structure or person. At that time, we expect that the tip of the leader located at the center progresses rapidly toward the object intersecting the sphere. Note that it is entirely possible (but unlikely) for the final striking distance to be in an upward direction. While it does not account well for the upward leader progression and has been observed to be somewhat inaccurate for low-energy lightning strikes, it is probably the best model for our purposes.

We note that metallic objects electrically connected to the ground that are comparatively sharp emit the leader better than other objects such as trees and people. Taller objects generally have an advantage since they are closer to the stepped leader and begin to emit their own leader sooner.

Electric Effects - Direct Strike

Obviously there is significant hazard from the electric current developed if a person were subject to a direct lightning strike. This hazard is manifest when lightning attaches to a person as in the process described above.

Electric Effects - Flashover

Flashover occurs when lightning attaches to something that has a relatively high impedance path to ground. A good example of such an event is lightning striking a tree. The tree presents a path to ground, but the path has a high impedance compared to that of a properly installed, well grounded lightning protection system. If we model the lightning as a current (I) source and the object through which it is passing as a general impedance (Z) we see that a significant voltage can develop on the object. If this voltage exceeds the air breakdown value (approximately $10^6$ volts/meter) the lightning current may jump from that object to another grounded object in the vicinity.

In figure 3, we illustrate the flashover effect. If lightning were to attach to a tree current would flow through the tree to ground. This usually

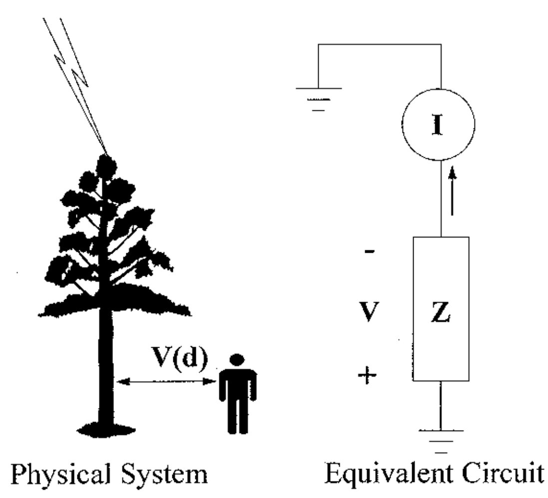


Figure 3 - Flashover Model.

causes significant damage to the tree from the rapid heating and expansion of moisture within the tree. Note we are modeling the current flow as upward, since we have mentioned that most cloud to ground lightning is negatively charged. By Ohm's law, V = IZ, as current flows through the tree, a voltage is developed. If this voltage exceeds the air breakdown value to a nearby object (or person), the lightning current will likely seek a path through the air to the nearby object or person. If a person is touching the tree to begin with then the breakdown value is governed by the skin impedance (which would be quite low in comparison) and the person would find themselves as part of the circuit. A typical lightning strike might produce 20,000 amperes of current and a typical tree might have a 100 ohm impedance. In this case, the voltage developed would be 2 million volts, enough to flashover to objects 2 meters away. Many lightning injuries occur from the flashover hazard. Most common is from being in the vicinity of trees during lightning storms or near electrical conductors that are subject to lightning current. Common sources of this injury occur when a person is near a residential telephone line and it is energized by a distant lightning strike (ref. 3).

## Electric Effects - Step Potential

We can expect a significant voltage difference near the point where lightning current enters the earth. In figure 4 we model the current injected flowing outward through thin "shells" in the earth, each with an incremental resistance, which develops an incremental voltage, dV, over the surface of the earth. This is known as the **step potential**, named after the potential drop across human (or animal) feet in the space of a step. Step potential developed from lightning effects, or even large fault currents, can be lethal. Figure 4 also illustrates the hazard from step potential. If current on the order of tens of thousands of amperes (a typical lightning event) is injected in the center of figure 4, the resulting potential (voltage) difference over the illustrated step length, along the radial distance from the center, can easily be tens of thousands of volts.

The step potential hazard is manifest in situations where people perceive that they are safe. Many step potential accidents occur when people are gathered in a tent, under a tree, or other unprotected structure (like the huts on golf courses) that is hit by lightning. Even though there is no direct strike to personnel, injuries and fatalities from the resultant electrical shock can (and do) occur.

## Human Body Interactions

To further explore these effects on the human body, let's examine an electrical model of the human body. Generally, electrical body models have two parts - contact impedance and the resistance within the body. The contact impedance is a function of the skin moisture and if the skin is covered. For example, in the case of step potential, the contacts would be the feet.

The contact impedance is then modified by the shoes. In figure 5, we see a contact impedance model (ref. 4). Since the capacitance, C, is parallel with the resistance, R, the contact impedance can be much lower at high frequencies such as that of lightning. In general, the contact impedance will be quite low

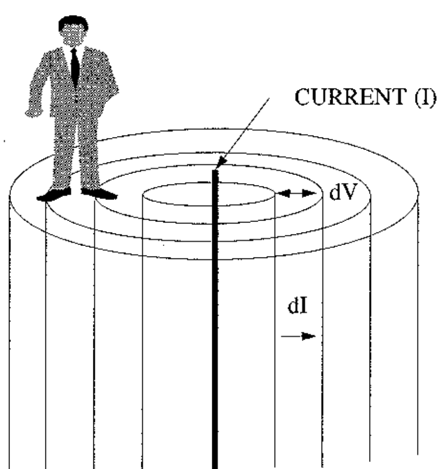


Figure 4 - Step Potential.

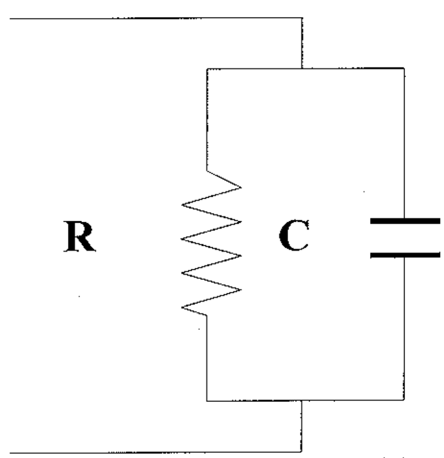


Figure - 5 Contact impedance model.

for lightning events due to it's frequency dependent nature.

Body resistance is on the order of 1500 ohms to 2000 ohms depending on the path chosen through the body (ref . 5). A significant point is that some paths are more damaging than others, for example the path across the chest cavity. This path is the most damaging since it exposes vital organs, most notably the heart, to exposure to current. Another significant point is that higher frequency currents, such as that of lightning, tends toward the surface of the object over which it passes due to an electromagnetic phenomena called skin effect. Consequently, as general rule, there is a higher survival probability for higher frequency electrical shocks.

## Protective Measures

To prevent these hazards, a number of protective measures are available. In our discussion, we will basically summarize the protective measures found in the NFPA 780, Standard for the Installation of Lightning Protection Systems. Most will seem like "common sense" now that we have characterized the hazards from lightning.

First, remaining in an area that is protected against lightning is an obvious recommendation. What is such an area? It is an area in which you are physically shielded from lightning effects, such as in a large building with a lightning protection system or in an automobile that is completely enclosed. Another good example is on a city street, where tall buildings surrounding the street provide a protective zone against lightning. Tents and the like do not provide good protection against lightning. There are several incidents where lightning attached to the center pole of a large tent, inducing a step potential on the ground in the tent, which in turn injured the occupants.

Certain locations are especially hazardous. We can guess at these locations from our discussion of the lightning attachment process. Tops of hills or tall buildings would by likely dangerous places. Keep in mind that relative height is important in the lightning attachment process, therefore any location in which a person is the tallest local object is risky including open fields (such as golf courses) and parking lots. A lone tree in a field is also quite hazardous - even though it provides physical protection, it is likely that persons near it while lightning attaches will be exposed to step potential or flashover hazards. A long fence in a pasture is a hazardous location since it may be struck at a distant point and this will energize the entire fence, possibly causing injuries miles from the point of attachment (ref. 6).

While in the outdoors minimize risk by seeking low ground and maintaining a low physical profile. This advice comes from an understanding of the attachment process, where we have noted that taller objects emit induced leaders first and consequently have lightning attach to them. In the case of a forest, it is better to be in dense woods since the overall probability of lightning attaching to any one tree is low over all of the trees in the area.

Systems are available that detect the onset of lightning conditions. These range from storm warnings to devices that detect the electric field conditions conducive to lightning. It is best to have an electric field sensitive device, since lightning conditions sometimes develop before the onset of a storm.

Finally the advice to crouch down with feet close together and put hands on knees is offered as a means of minimize a person's physical signature for lightning attachment and reduce "footprint" on the ground to minimize the effects of step potential.

## Summary

Each year lightning accidents cause a number of injuries and fatalities. Protective measures (physical or procedural) are available to minimize risk. Lightning attachment processes as a basis for the hazard of direct lightning strike were reviewed. Step potential and flashover, the indirect lightning effects that are hazardous to personnel were also discussed. Finally, we summarized basic protective measures in light of the potential hazards. We hope to have made the safety professional somewhat more cognizant of the hazards to personnel due to lightning and we hope to have provided some guidance for reducing risk.

Understanding lightning behavior and prior planning are essential in managing the lightning risk. In this paper we endeavor to expose some of the hazards and protective procedures but individual and group planning is essential. When planning outdoor activities, such as an afternoon of golf, a camping trip, or a sporting event or fair, personnel precautions in the event of lightning need consideration.

## Disclaimer

The findings and data in this paper do not constitute an official position of the United States Government or any agency thereof. Information within this paper does not constitute advocacy of any particular manufacturer of lightning protection systems or devices or related equipment.

No statement in this paper is intended to represent a position of the National Fire Protection Association's Technical Committee on Lightning Protection, nor is an official interpretation of the Standard for the Installation of Lightning Protection Systems, NFPA 780.

No statement in this paper is intended to represent a position of the International Electrotechnical Commission (IEC), nor is an official interpretation of any IEC Standard.

## Suggested Reading

*Standard for the Installation of Lightning Protection Systems*, NFPA 780, 1995 Edition, National Fire Protection Association, Quincy, MA, 1995.

*Lightning Protection,* R.H. Golde, Chemical Publishing Co., New York, 1973.

*Electrical Stimulation and Electropathology*, J. Patrick Reilly, Cambridge University Press, 1992.

## References

1 Jepsen, Dennis L., "How to Manage a Patient with Lightning Injury," *American Journal of Nursing*, August 1992, p. 39.

2 Standard for the Installation of Lightning Protection Systems, NFPA 780, 1995 Edition, National Fire Protection Association, Quincy, MA, 1995.

3 Golde, R.H., "A Plain Man's Guide to Lightning Protection," *Electronics & Power*, March 1969, p. 84.

4 Reilly, J. Patrick, *Electrical Stimulation and Electropathology*, Cambridge University Press, 1992., p.449.

5 *Ibid.,* p. 40.

6 Purposeful electrical discontinuity is suggested in this case. See NFPA 780 1995 Edition, page 31.

## Biography

John M. Tobias, P.E.
U.S. Army Communications Electronics
Command Safety Directorate
ATTN: AMSEL-SF-SEP
Phone:(732)532-0084 x6412
Fort Monmouth, New Jersey 07703-5000
Fax: (732)542-7161
Email: tobias@mail1.monmouth.army.mil

John Tobias is a senior engineer for lightning protection applications and electrical safety at the U.S. Army Communications-Electronics Command and is a Principal Member of the National Fire Protection Association's Lightning Protection and National Electrical Grounding Research Project Technical Committees. He also serves the United States' National Committee of the International Electrotechnical Commission as the Deputy Technical Advisor for Lightning Protection (Technical Committee 81). Mr. Tobias is a recipient of the degrees of B.S., Physics, Seton Hall University, M.S., Electrical Engineering, University of Maryland and is a licensed Professional Engineer. Professional recognition for Mr. Tobias includes the U.S. Army Materiel Command Federal Engineer of the Year 1994 and the Department of the Army System Safety Professional of the Year 1994 awards. He is a regular contributor to System Safety Society Conferences in the field of lightning protection, has published several related studies in government and scholarly literature, and has one patent and one patent pending for designs related to lightning protection.