Chapter 17
Lightning Protection

Abstract The purpose of lightning protection systems is to protect structures and, to some extent, the people within them, as well as power systems, electronics, and other infrastructures from damage by lightning strike as well as by electromagnetic transients that may accompany lightning strikes. This chapter will discuss the basics of lightning protection systems and its history, proposed modifications that have not proven to live up to their claims, and pose ethical questions where providing partial protection may be the best decision for available resources. Surge protection will not be covered.

17.1 Introduction

As discussed in many of the previous chapters, lightning can cause significant damage not only to people and livestock but also to buildings, utility systems, industrial installations, banking, sensitive electronics, aviation, military and naval operations, shipping, forestry, and many more industries. Lightning causes fires, downtime, costly repairs, structural damage, power interruptions, and data losses, all of which can result in significant economic loss, particularly in developing countries.

"Lightning protection" (LP) is different from lightning safety or lightning injury prevention. Lightning protection nearly universally means protection of structures. While international codes take into account human injury, few lightning protection codes claim to protect people or animals within the buildings, especially small buildings. Obviously, if prevention were possible, most people, businesses, and governments would prefer to minimize lightning damage. Most developed countries have building codes that specify lightning protection for certain structures, usually depending on their function such as a school or hospital. In the developing world, even if a code is specified by the nation's bureau of standards, it may not implemented at the construction level because of lack of familiarity with the codes, lack of experienced protection engineers, availability of code-compliant materials, and especially the expense where income may be only US$1 to $10/day per person. For villagers who construct their own homes, lightning protection is seldom part of their knowledge base.

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It is not the purpose of this chapter, nor this book, to discuss lightning protection system (LP) design. There are widely available extensive publications on the topics such as those by Golde (1973), FAA (1990), Rakov and Uman (2003), Uman (2008), and Cooray (2010), and there are internationally recognized lightning protection codes, most notably International Electrotechnical Commission (IEC 62305–1,2,3,4). Proper lightning protection design is complex and must be customized to the structure being protected depending on:

1. The function that the building serves such as a financial institution, school, munitions factory, hospital, or a church
2. Whether people or only structures are to be protected
3. The risk/benefit of protection versus replacement of an unprotected structure and other considerations

This chapter will cover not only what a lightning protection system consists of and its function but also some of the reasons that most people, businesses, and governments find judging claims of lightning protection systems to be confusing and arduous. There are well-recognized codes that should serve as the basis for the design of lightning protection whenever it is considered. Only trained specialists who design lightning protection systems as their daily work should be employed. Most electrical engineers, electricians, and others have little or no real knowledge of lightning protection and lightning protection codes regardless of the term "electric" appearing in their title. This chapter will also consider current controversies in lightning protection and "junk" science employed by some manufacturers.

17.2 Parts of a Lightning Protection System

There are three basic parts of any effective lightning protection system that are illustrated in Fig. 17.1:

1. *Air terminals*, commonly called lightning rods or arrestors, which intercept or serve as an "attachment" point for lightning, the first part of diverting the lightning from damaging the structure
2. *Down conductors* that connect the air terminals to a grounding system in order to harmlessly channel the lightning energy around a structure from the air terminals to the ground or, in the case of boats, water around a structure
3. *Ground terminals* or electrodes, also called earthing, which effectively dissipate the lightning energy into the ground or water and away from the structure and its contents

This three-part system serves to divert the energy and shield a structure from damage. To some extent, it will also minimize the electric and magnetic fields within the structure that are generated by lightning. If the structure to be protected contains electronics, communication and power systems, or other sensitive equipment

Fig. 17.1 Installation of (**a**) air terminal, (**b**) down conductor, and (**c**) ground terminal at school in Uganda. (Courtesy of ACLENet)

that need protection, surge protection may also be necessary. Surge protection will not be discussed in this book.

17.3 How Lightning Protection Works

Originally, people thought that lightning protection would *prevent* lightning strikes, including Benjamin Franklin, who invented the first effective lightning protection in 1752. Various theories were developed that the charge from the ground would somehow travel upward through the system and leak into the air above the structure, slowly dissipating atmospheric charges to prevent the rapid and often violent lightning strike.

Observers soon learned that lightning would strike "protected" buildings in spite of LP installation. As a result, they began studying the best ways to conduct the energy from the inevitable lightning strike harmlessly around a structure using the three-part system: air terminals, down conductors, and ground terminals.

17.4 Barriers to Lightning Protection

Lightning occurs all over the world, in high or low places and in nearly all climates, except for Antarctica (Chap. 11). Lightning has been called the weather hazard "most commonly experienced by most people in the world." Unlike other weather hazards such as hurricanes, tornadoes, and tsunamis, damage from lightning is largely a preventable risk with proper lightning protection.

However, until a disaster happens where there are multiple deaths, an extensive fire or a power outage affecting thousands of people, there is often a lack of foresight based on the rarity of the event. Both individuals and governments usually have issues that are of much more concern to them than lightning. There may be a general fear of electricity and lack of knowledge of how LP works, with some continuing to believe that lightning protection attracts more lightning strikes to a building or an area.

Some may feel that lightning injury is an "act of God," inevitable and unpreventable, or that it is sinful to attempt prevention. In many cultures, it is believed the lightning can be called down by witches to punish an enemy. Still other communities feel that a family who has suffered a lightning incident is cursed, and the family may be shunned, forcing them to move away and start over in a place where they are not known. Still others will believe, or at least act like, lightning disaster will never happen to them.

Lightning protection codes may be perceived as too complicated, and there is often a lack of qualified designers and installers. LP costs may be prohibitive compared to other priorities. Those who have done lightning protection with copper or aluminum may have had repeated thefts, with expensive replacement costs.

17.5 Risk Reduction and Lightning Protection Codes

Lightning protection is required by building codes in many parts of the world and almost unknown in others. The most widely accepted international code for lightning protection, IEC 62305–1,2,3,4 (International Electrotechnical Commission), lists four types of loss that are to be considered in determining the level of LP design:

- L1: loss of human life (including permanent injury)
- L2: loss of service to the public (such as utilities, power and communications, aviation)
- L3: loss of cultural heritage
- L4: loss of economic value (structure, content, and loss of activity)

Risk, depending on the lightning density and many other factors, can be assessed for each of these (Table 17.1). The need for lightning protection is often specified for different industries, in building codes, and other resources. Protection may be needed for industrial parks, manufacturing plants, churches, schools, banking centers, hospitals, military installations, historic landmarks, emergency centers, sport-

Table 17.1 Risk assessment factor assigned to the level of protection required for different situations (International Electrotechnical Commission)

Protection level	Current (kA)	Energy (kJ/Ω)	Efficiency (%)	Type of damage	Risk assessment factor
I	200 or more	10,000	98	Loss of lives (high human level concentration)	10^{-5}
II	150	5600	95	Loss of essential public services (telecommunications)	10^{-3}
III	100	2,500	90	Loss of cultural assets (monuments)	10^{-3}
IV	<100	<2500	80	Areas with low human presence, no public services, and no cultural interests	10^{-2}

Fig. 17.2 Typical rural housing in Africa and many other developing countries, consisting of mud brick walls with roofs of generations-old, tinder-dry thatch or sheet metal held down by stones. The walls do not contain wiring or plumbing, and these buildings are not considered lightning safe. (2015 Zambia photo ©M.A. Cooper)

ing complexes, correctional facilities, corporate centers, chemical plants, oil refineries, nuclear plants, and many other facilities.

Although petitions have been made recently to the IEC for development of more specialized LP codes, currently they do not exist for:

1. Small structures, including homes, commonly found in rural areas (Fig. 17.2)
2. Protection or people and animals, especially in fields and other open areas
3. Small boats, which may double as a family's home in addition to work area in some parts of the world

17.6 Ethical Versus Practical Considerations

In developed countries, it is easy to insist on nearly 100% assurance of safety by recommending substantial housing and fully enclosed metal vehicles as safer areas when thunderstorms are in the area and to vehemently dismiss partial measures.

However, in developing countries where families are often at risk 24/7/365, is it reasonable and ethical to compromise for partial protection that may save some lives? These topics are addressed by Rakov (2000), Hartono and Robiah (2007), Kumarasinghe (2008), Gomes (2010), Gomes and ab Kadir (2010), and Gomes et al. (2012). For example:

1. For developing countries, code-compliant LP designs may cost more than a family's yearly income. Can less expensive materials be used that will still provide adequate protection? Is there a significant loss in the safety margin?
2. Grounding or earthing of lightning can be incredibly difficult under the conditions of the dry seasons in some countries. Is it permissible to protect structures well for the wet seasons, when thunderstorms are more likely, but sacrifice the quality of the grounding systems in the dry season, when there is little chance of lightning or thunderstorms, because adequate year-round grounding in some areas is so difficult to achieve? Is partial safety better than none at all?
3. The integrity of the LP installation and ground resistivity should be assessed at least every 2 years. What are the ethics, versus the reality, of installing lightning protection systems but not being able to ensure regular maintenance and testing or of communities not being able to maintain lightning protection on their homes and schools due to its expense?
4. Can villagers be taught to install lightning protection, to use alternative materials to decrease cost, and to pass the instruction on to others accurately? Alternatively, is this a recipe for disaster if standards are not met, connections for the down conductors are not followed or understood by the villagers, or other materials or installation errors are made?
5. How many lives could be saved by promoting the use of rubber-soled shoes or sleeping mats and mattresses to at least partially protect from ground current in developing countries, even though they do not meet the standards that we insist on in the United States and other developed countries, and scientific testing has not been made as to their value?

Questions to Explore

Some testable projects are the following, courtesy of John Gookin, Ph.D., an experienced survivalist in such locations as Africa, Patagonia, and the Arctic: How much would one-half inch of closed cell foam insulation (flip-flops) below a standing human reduce ground current effect? How much does

(continued)

one-half inch of closed cell foam insulation (thin sleeping pad) below a sleeping human reduce ground current effect? What would be the effect of a circular conductor, such as a chain, loosely laid near the ground/soil surface and pinned to the ground with small metal tent stakes or bent nails, in reducing ground voltage differential to a human standing or lying down inside of it? Does a person sitting on bare ground with random hand and foot placement receive less ground current than a person lying flat on the ground with random foot and hand placement?

17.7 Difficulties Evaluating Product Claims: Frauds and Fakes

As in any area requiring highly specialized technical expertise, the public, governments, and industry may not have a knowledge sufficient to judge the adequacy of lightning protection design, installation, or choice of materials. Unfortunately, there is:

1. A lack of a perceived need for lightning protection resulting from a supposed rarity of strikes
2. The lack of engineers and architects trained in the very specialized nature of lightning protection engineering
3. Often the lack of industry standards governing LP purveyors and installers

As a result there is no "common knowledge" by the public or by most industry or governments that would allow them to temper the "scientific" claims, much less judge bids or discover the price gouging that can occur, including marketing of outright frauds and fakes (Uman and Rakov 2002).

Sometimes, the simplest is the best. The old-fashioned Franklin rod, plain, simple, and straight, with no arms, radioactivity, brushes, balls, colored globes, or other additions, remains the standard for lightning rods, with all others tested against it. However, there have been many challenges to this approach.

Table 17.2 lists some of the names used by purveyors of these scientifically unproven systems. Because many of these names are specifically condemned by internationally accepted lightning protection codes, sellers and manufacturers have attempted to deceive buyers by frequently changing the names and acronyms they use. Anyone seeking lightning protection should be wary and check out the claims of sellers.

17.7.1 Early Streamer Emitters: The Theory Versus the Reality

In the 1960s and 1970s, due to the high price of copper and other metals used in lightning protection, some proposed a technique that was said to reduce the number of air-terminations and down conductors that were prescribed in the international standards.

Table 17.2 Some names of unproven lightning protection systems

Early streamer emitters (ESE)
Lightning eliminators
Charge dissipation Array (CDA)
Dissipation Array systems (DAS)
Charge transfer system
Spline ball ionizer
Lightning suppressor

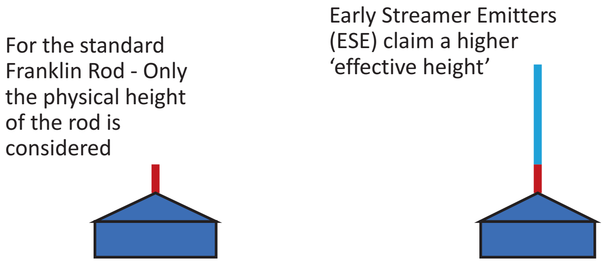

Fig. 17.3 Due to the addition of components that were claimed to emit upward streamers earlier to meet the down-coming lightning leader, it was hypothesized that ESE rods would have a higher "effective height" than the old-fashioned Franklin rod that was the recognized standard. (Courtesy of C. Gomes)

The Early Streamer Emitters (ESE) concept added components to the air terminal that were theorized to launch an upward streamer/leader much earlier than the conventional Franklin rod did. This terminal would attach to the downward leader earlier, making the "effective height" of the rod "taller" than it actually measured (Fig. 17.3). Being taller enabled a wider radius of coverage, necessitating fewer rods and down conductors to cover the area of concern, theoretically making the system less expensive (Fig. 17.4).

Variations of the ESE to induce the streamer included adding radioactive sources, electronic devices that were to inject voltage pulses, piezoelectric devices that were to generate voltage pulses, complex electrode systems, and others where the electric field was supposed to be modified by the shape of the tip. Figure 17.5 shows a variety of ESE variations. Other modifications included different shapes, adding arms or spikes, metal balls, golden metal coatings, colored glass globes, and all sorts of visual candy that added nothing to the function of the ESE.

The scientific community had doubts about these claims and would not accept them until the claims were tested. Independent testing did not support the ESE claims, and researchers stated that any slight effect of an ESE was not significant enough to justify the reduction in the number of rods.

The US lightning protection standards, codified and named after the National Fire Protection Association (NFPA780), accepted only the Franklin rod. A panel

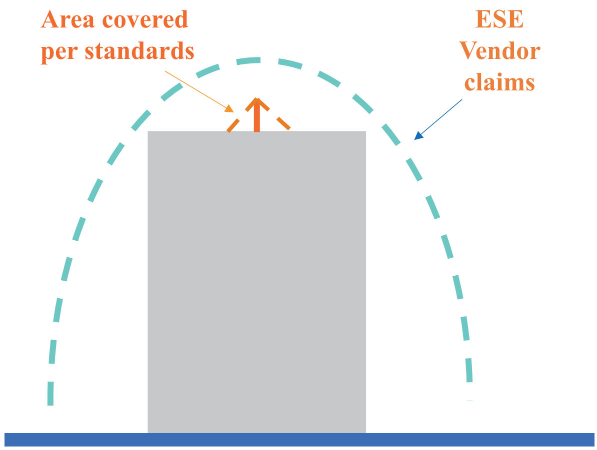

Fig. 17.4 ESE manufacturers claimed that by having a higher effective height, a larger radius of coverage was achieved, necessitating fewer rods to cover the area to be protected. This was proven to be a false claim in independent scientific trials. (Courtesy of C. Gomes)

was appointed in the early 1990s to investigate the possibility of including ESE in the standards (Draft NFPA781). In 1993, the panel declined to approve the proposed draft NFPA781, but ESE makers responded by taking the matter to court, claiming NFPA781 had just as much scientific support as the Franklin rod. In a settlement, the NFPA agreed to have ESE technology reevaluated by an outside panel. This independent panel confirmed that there was no scientific basis for NFPA 781, and ESE claims were again rejected. Eventually, ESE manufacturers and purveyors packed the NFPA committee and voted to include the unsupported claims so that NFPA has ceased to be a respected lightning code. Unfortunately, ESE devices were included in the French National Standards (NF C17–102) in the mid-1990s. Spain followed France and adopted ESE concept in their standards as well. As a result, the French and Spanish codes are NOT accepted standards.

While the ESE is no better than the plain Franklin rod of the same height, it is no worse either. The problem arises when the sales persons tell the buyer that they can save them money with their *improved* technology by decreasing the number of air terminals and down conductors. However, sellers often make up more than the difference by charging more for the fancy knobs, points, radioactivity, or shiny balls that are part of the claimed “improved” technology of the ESE design. Sophisticated marketers will use the same calculations and statistics as the standards but then substitute their shinier ESE and charge more than a standard Franklin rod installation. Others, who understand very little of the physics, will claim that ESE’s avert or prevent lightning strikes by “discharging the electric field in the thundercloud.” Extensive crucial evaluation of the ESE design is found in Becerra and Cooray (2007, 2008), and Hartono and Robiah (2006).

Fig. 17.5 Two ESE air terminal designs. (Photos courtesy of the National Lightning Safety Institute)

17.7.2 Lightning Eliminators: Not Accepted by Any Code

Another device proposes to repel or neutralize a lightning leader so that it causes no harm to the protected site. A "charge dissipation array" is used instead of a standard air terminal (see Fig. 17.2 for other names). Sellers of this product claim that a large amount of space charge is rapidly generated when a stepped leader is present, and either the opposite charge in the leader is neutralized or the "large space charge" repels the downward leader, preventing or eliminating the lightning strike. These "repellers," "dissipators," and "eliminators" are easily recognizable for their dozens or hundreds of fibers (Fig. 17.6). Not a single standard in the world has accepted this concept, but they are still frequently marketed to the unwary buyer.

17.8 Building Resilience/Decreasing Costs

It is unfortunate, but true, that the areas of the world that need lightning protection the most (Chap. 11) are the ones least likely to be able to afford it. What do we tell people in the rural or other unprotected areas to do and how do we make lightning protection affordable? Some ideas include:

1. Investigate alternative materials that can be sourced locally instead of importing European manufactured materials, saving both import and shipping fees, sometimes exorbitant prices and value-added tax (VAT). This includes recruiting recognized experts to design code-compliant LP with these materials.
2. Train local engineers and installers to install the systems instead of using expensive or untrained contractors.
3. Test and certify trained people so that the public can expect quality and code compliance.
4. Train and use local parents and students for the labor-intensive portion of an LP installation on schools, such as digging trenches around the buildings for laying the grounding circle, as well as discussing the principles of LP with those who are interested.
5. Collaborate with agencies from other countries in fund-raising to provide lightning protection for schools and other community buildings.

Questions
What other ideas could be used and tested to decrease cost but still provide code-compliant lightning protection?

Fig. 17.6 "Lightning eliminators" – not accepted by any lightning standard. (Courtesy of HCFP Pte. Ltd.)

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