Fundamentals of Lightning Protection Systems

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1. Introduction

In this lesson, you will learn the fundamentals of how lightning protection systems function. The intent of the lesson is not to discuss the detailed design requirements presented in various codes and standards for lightning protection but to understand the basic physics associated with lightning protection systems and how they affect the system design.

2. Historical Vignette

Lightning protection systems have been in use in one fashion or another for over two hundred and fifty years, well before electricity was harnessed as a usable form of power. In the past one hundred years, progressive scientific study has contributed to the body of knowledge concerning lightning and its behavior. Engineering and construction standards for lightning protection have been published in the United States for over one hundred years. During the past century, various governmental and private organizations keeping statistics on the performance of lightning protection systems have found that they are highly effective. Underwriter's Laboratories statistics showed that these systems prevented damage due to lightning approximately 99% of the time, when installed in accordance with accepted engineering standards.

3. System Overview

Lightning protection systems (LPS) have five distinct subsystems. They are:

- Strike Termination Subsystem
- Conductor Subsystem
- Grounding Electrode Subsystem
- Equipotential Bonding Subsystem
- Surge Protection Subsystem

Figure 1. Representative LPS.
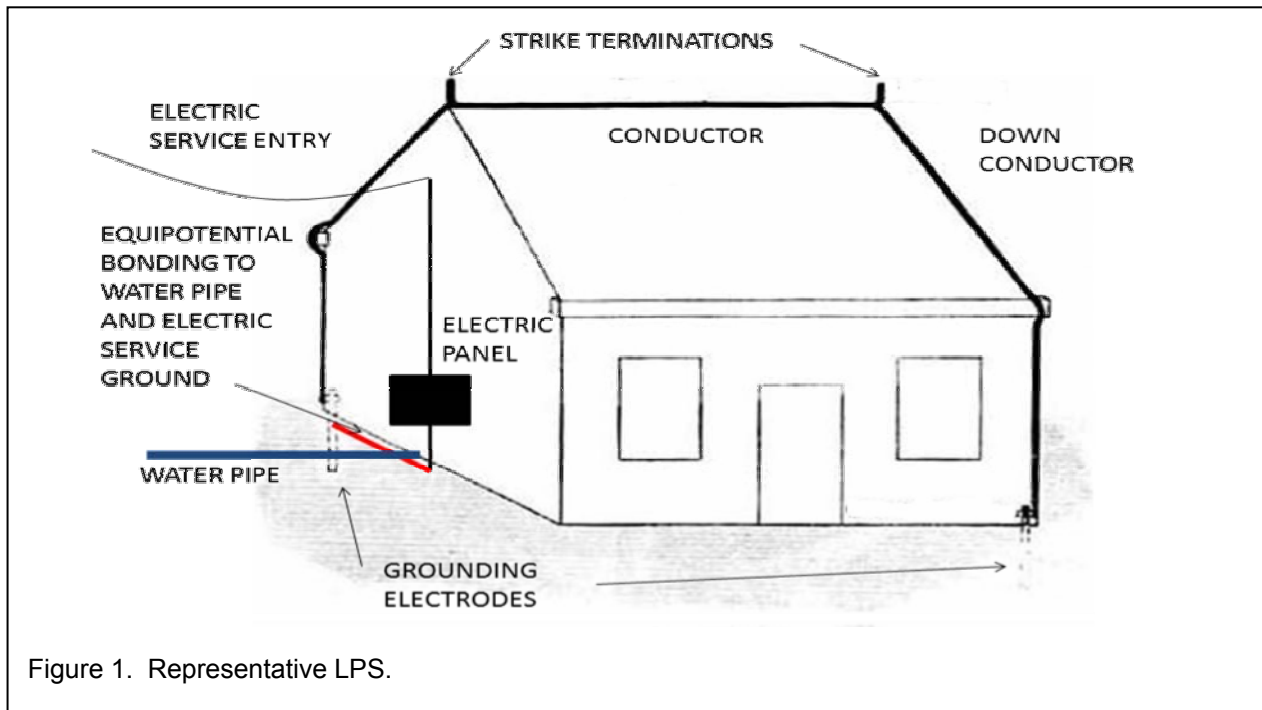
These subsystems function in a complimentary fashion to protect a structure from the damaging effects of lightning. Figure 1 illustrates a simple representative LPS that might be installed on a small structure. Each will be reviewed in turn and how they function will be discussed.

4. Strike Termination Subsystem

The purpose of the strike termination subsystem is to intercept the lightning event and course it harmlessly into the conductor subsystem. The strike termination subsystem can take many forms specified by the various engineering standards available. In general, it is a metal device that is connected in an electrically and mechanically robust fashion to the conductor subsystem. A common specific type of strike termination is an air terminal. The air terminal is a device listed for the purpose by a Nationally Recognized Testing Laboratory (like Underwriter's Laboratories, for example) consisting of a metal rod protruding above a structure. These are commonly known as 'lightning rods' but this term is generally not used in the lightning protection industry. Other types of strike terminations are commonly used consisting of overhead wires and structural steel parts of a building.

a. Operation of the Strike Termination

The strike termination is a device that responds to the electric field of an approaching thunderstorm. When thunderstorm conditions emerge, electric charge is lowered from the cloud, generally in the form of a line charge. This is called the downward leader and is the precursor of a lightning strike. These may be several of these at any given time and could have a range measured in kilometers. Polarity of the downward leader is negative approximately 90% of the time but 'positive strikes' do occur. However, the behavior of negative and positive strikes are identical, as far as we are concerned in this lesson. As the downward leader approaches the ground, the electric field under it becomes very intense.

In response to the heightened electric field intensity, the strike terminations emit an upward streamer. It is important to point out that any object can emit an upward streamer of charge under the conditions of high electric field intensity. Trees, power lines, buildings without lightning protection systems and even people can emit upward streamers and can, consequently, be struck by lightning. However, the strike termination is designed to receive lightning current intentionally, unlike other parts of a structure. These upward streamers have a maximum range of some tens of meters but their range is generally shorter as it depends on the amount of charge present in the downward leader. Because this range is limited, having strike terminations and a lightning protection system does not increase the chances that a structure will be struck by lightning, as is sometimes thought.

Figure 2. Leader and streamer during onset of lightning strike.

The upward and downward streamers are of opposite charge and are therefore attractive. When they connect, the lightning channel is completed and a large amount of charge stored in the thundercloud flows to earth, to the strike termination, through the lightning protection system, to equalize charge in the earth. A large amount of current flows and we hear the characteristic noise of thunder when this occurs.
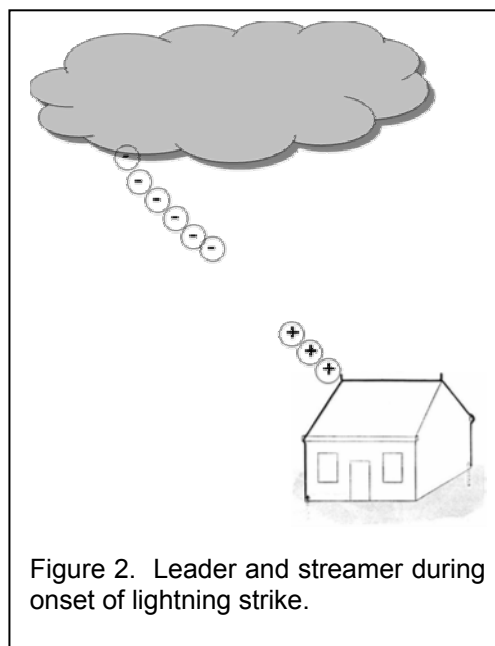
b. Zone of Protection Concept

Since the strike termination is intended to intercept the downward leader, it implies a region of protection. This is called the 'Zone of Protection' (ZOP) and is based on models of lightning behavior. The ZOP is defined as 'the space adjacent to a lightning protection system that is substantially immune to direct lightning flashes.'

All of the available engineering and construction standards use three types of model for the determination of the ZOP. They are the 'roof rule' method, rolling sphere method and the protective angle method. These methods are ways to determine placement of strike terminations and to find a ZOP.

c. Empirical 'Roof Rules'

For some simple structures, design standards list empirical roof rules that may be applied to protect structures from direct lightning strike. Figure 3 illustrates some examples of these types of rules. In the application of these rules, there is usually a height limitation of the structure on which the rules can be applied. Typically, structures are limited to an eave height (the distance above grade to the lower edge of the roof, where it joins the vertical wall) of 50 feet.
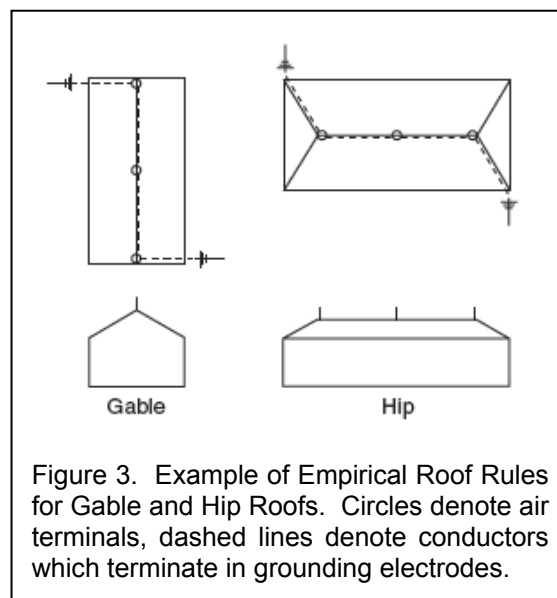

Figure 3. Example of Empirical Roof Rules for Gable and Hip Roofs. Circles denote air terminals, dashed lines denote conductors which terminate in grounding electrodes.

In the application of the roof rules, the ZOP is considered to be the volume extending under the roof vertically from where the eave extends. (Lower roof levels may be protected within the protective angle method, which is discussed later.) So one can see, that this type of model can only apply to the simplest structures and is somewhat limited. Fortunately, models to account for more complicated structures are available.

d. Rolling Sphere Method

The Rolling Sphere Method (RSM) is one way to determine strike termination placement and the ZOP of lightning protection systems. It is the most general of the methods. It is formulated by correlating the radius of the sphere with the average amount of charge present in the downward lightning leader. For most applications, the radius of the sphere is 150 feet (46 m). This correlates to the 'striking distance' of over 90% of all lightning events. For more critical applications, a smaller sphere of 100 feet (30 m) is used, correlating to over 97% of all lightning events.

How this method is applied is to begin with an imaginary sphere of the desired diameter (usually 150 feet) and 'roll' it over the affected structure. Areas under the exterior of the sphere between points of contact become the ZOP. This method is illustrated in figure 4. It is assumed that strike terminations are needed wherever the sphere contacts the structure, installed in accordance with accepted engineering standards. The sphere must consider all directions of approach to the building although we have really just illustrated two directions (from the left and right) of the building in figure 4. In addition, there are analytical methods to apply RSM.
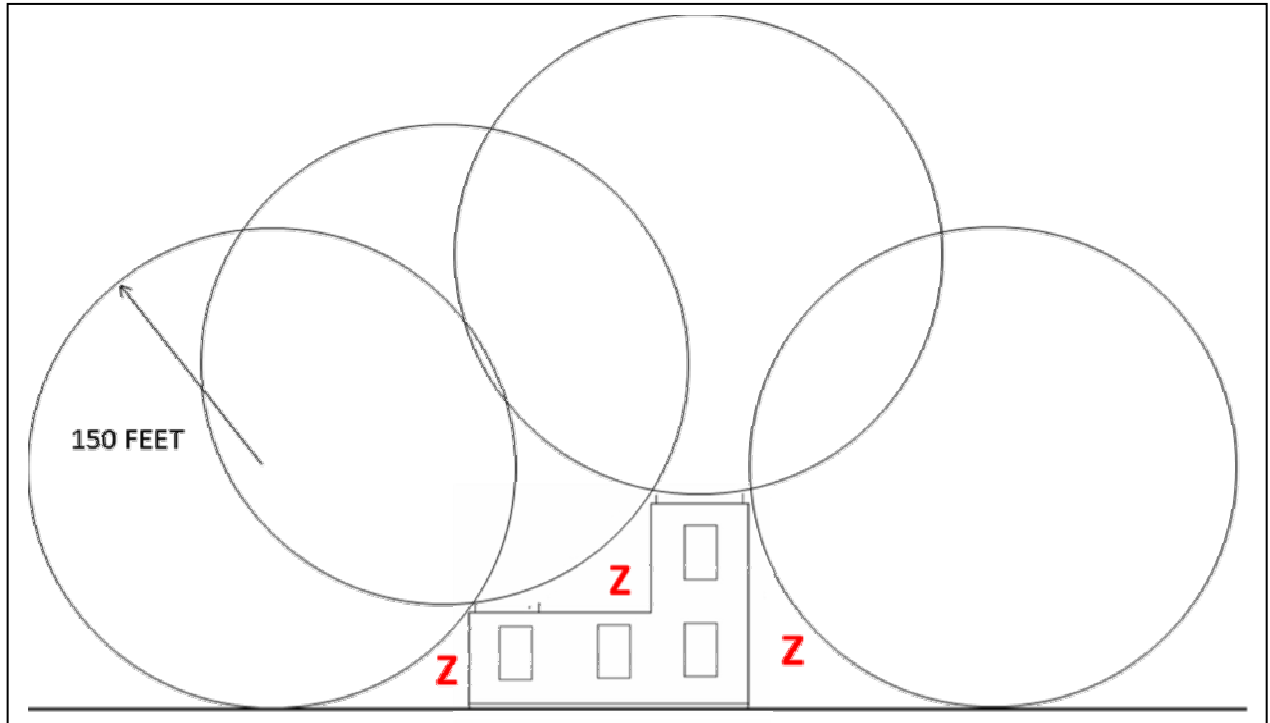
Figure 4. Illustration of Rolling Sphere Method. Areas under the curves denoted by 'Z' indicate a zone of protection.

d. Protective Angle Method

An older and simpler way to determine placement of strike terminations is the Protective Angle Method (PAM).   This method is a simplification of the RSM for structures that do not exceed 50 feet in height. For structures less than 25 feet in height, a 60 degree, or 1:2, angle is permitted. For structure over 25 feet but not in excess of 50 feet, a 45 degree, or 1:1, angle is used. This is illustrated in figure 5.
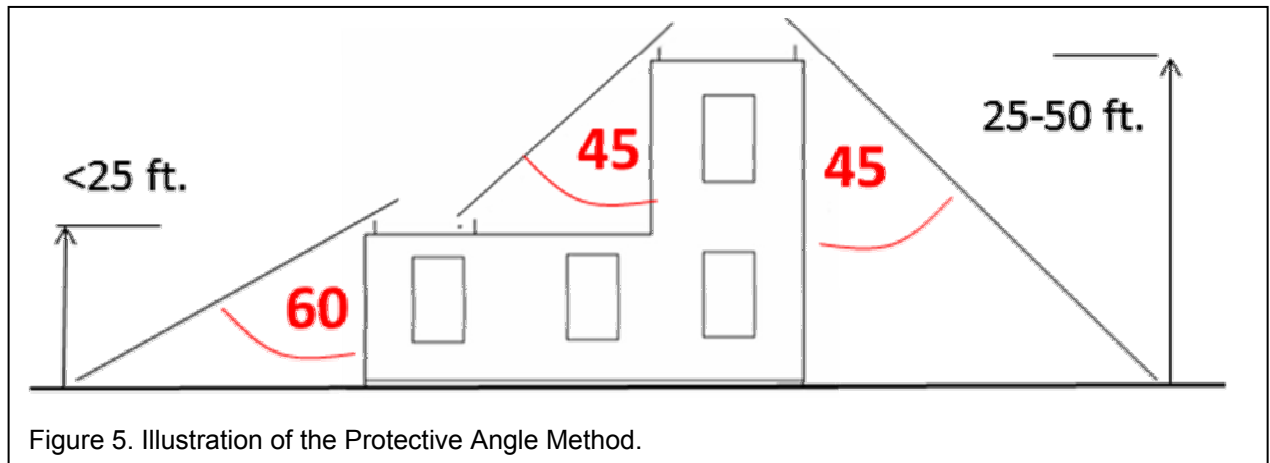

Figure 5. Illustration of the Protective Angle Method.

The protected angle method is also used with the empirical roof rules so lower attached may be protected. Detailed information to determine zones of protection are found in lightning protection design standards.

e. Notes on Strike Terminations

While these methods dictate the placement of the strike terminations to determine zones of protection, other design rules for specific placement apply depending on the type of strike terminations. More details will be found in the engineering standards documents commonly used for lightning protection. For example, if air terminals (a common form of strike termination, sometimes termed 'lightning rods') are used, they have to be placed so that they extend ten inches above the protected structure, within two feet of the edge and no more than 20 feet apart. In addition, other strike terminations may be needed to protect objects that are typically installed on roofs, such as Heating, Ventilation and Air Conditioning (HVAC) equipment. Alternatively, some structural metal components commonly used in buildings may serve as strike terminations. It is essential to have a thorough understanding of these details to emplace an effective lightning protection system.

Once the strike termination intercepts the lightning event, it is then directed into the conductors that are part of the system.

5. Conductors

The conductors confine and direct the lightning event toward eventual dissipation into the earth. In general, there are two types of conductors in lightning protection systems: main conductors and bonding conductors.

a. Types of Conductors

1) Main conductors are intended to carry current. They are sized accordingly and are installed in a fashion to be conducive to conducting the lightning event. Often, robust metal structural materials of a building are used for this purpose.

2) Bonding conductors are intended to equalize the voltage, or electrical potential, between conductive parts and are therefore designed to prevent current flow. Recall that (nominally) all points on a conductor are at the same voltage. By connecting metal parts together electrically, bonding conductors minimize the voltage between them. This is essential to prevent the development of electric arcing between the LPS and other metal parts of the structure. However, they are installed and sized in such a fashion that they can carry some of the lightning current.

b. Special Considerations for Lightning Conductors

In the conductor subsystem, lightning is now electric current. However, it is quite different in behavior than electric power that we may be more familiar with. This is because the lightning event is initially a pulse of very high current up to hundreds of thousands of amperes in magnitude for durations of tens of microseconds. This behaves in a fashion similar to a high frequency signal. It then decays into a continuing current that more resembles direct current, lasting for up to a second. Multiple pulses commonly occur during a single lightning event. The conductors in a lightning protection system must account for these effects brought on by the lightning waveform, which we shall now discuss.

c. The Lightning Waveform

A maximal lightning event begins with a high current pulse of up to 200,000 amps that can last 500 microseconds. A commonly used lightning waveform illustrating this is presented in figure 5. Examining the waveform, we can correlate different effects of the waveform applied to lightning conductors.

1) The A and D Components contribute to electromagnetic forces and the development of high voltages due to the fast rise time of the pulse and the high peak current. The construction of the conductors and their associated installation practices have to account for these effects. Electromagnetic forces, can damage or even break conductors. The inductive reactance of conductors, usually ignored in most power system considerations becomes a major contributing factor in conductor failure.

2) Sideflash is when an arc occurs between a lightning protection system conductor and another conductive item. It occurs when a voltage on the conductor becomes high enough to exceed the dielectric breakdown value of air (or other material) through which the lightning current can arc to another grounded metal body. It is usually result of a point of high resistance or inductive reactance in the conductor (such as a loose connection or a sharp bend in the conductor) or just from having another metal body in close proximity. This is very undesirable and is considered a failure of the lightning protection system. The resulting arc from sideflash can ignite materials and can be catastrophic if a flammable atmosphere exists. Design guidelines for the materials for lightning protection conductors and method for their installation are given in detail in the applicable engineering standards.
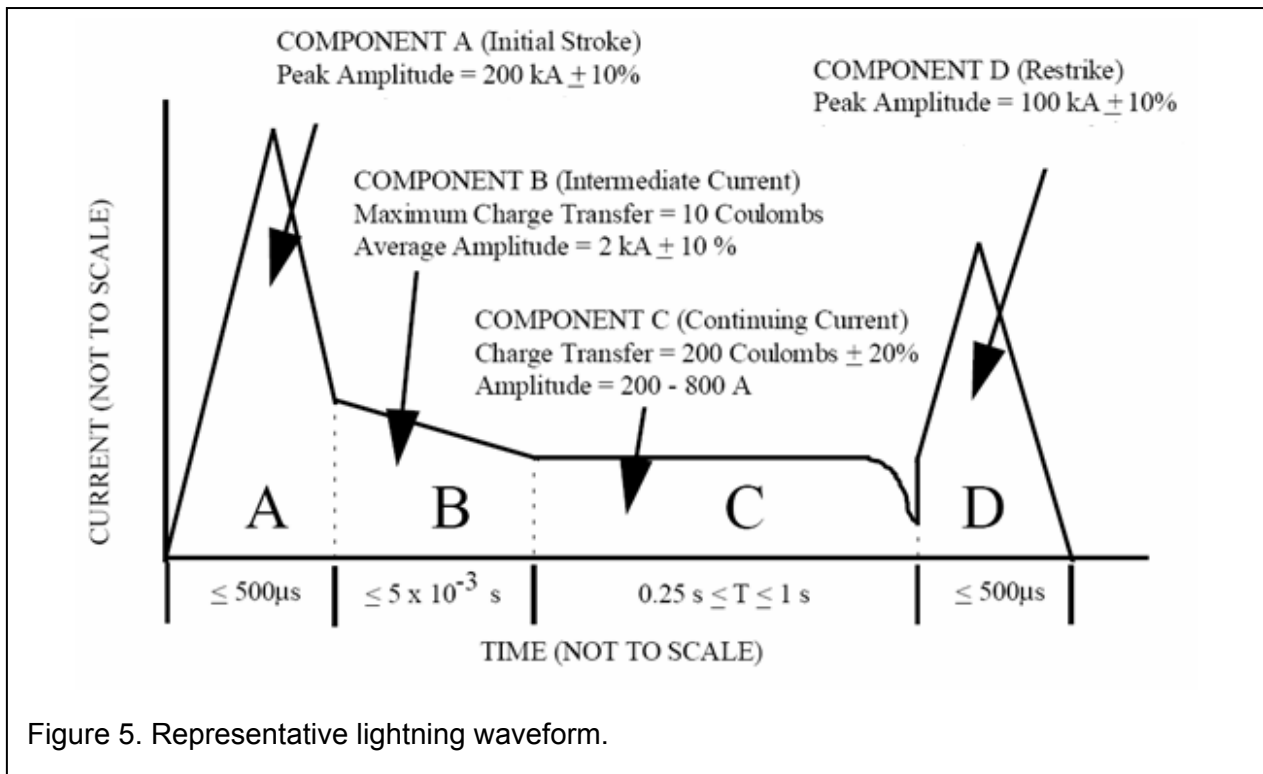

Figure 5. Representative lightning waveform.

3) The B and C components of the lightning waveform are responsible for the heating and other ohmic effects on the conductor. Far more charge is transferred during the B and C components of the lightning event compared to the A and D components. While lightning

conductors are of robust construction or heavy enough gauge of low resistivity material, which minimizes liberation of heat, any point of high resistance can cause melting and failure. For example, a corroded or loose connection or a frayed conductor can cause a failure from ohmic heating.

d. Conductor Electrical Properties

In light of the lightning waveform we must now consider the properties of the conductors used in lightning protection systems. Any electrical conductor has an impedance, which is comprised of resistance, inductive reactance and capacitive reactance. Most often in electrical design for power systems, only resistance is accounted for especially over short distances. However, for lightning conductors, the inductive reactance becomes significant. Capacitive reactance is negligible and therefore ignored.

1) <u>Resistance</u> is a property of the conductor that is dependent upon its physical configuration and material. As a figure of merit, lower resistance is better in any conductor system. The material property that affects the resistance of the conductor is resistivity. For most lightning protection applications, materials with low resistivity are specified, e.g., copper or aluminum. Resistance in a conductor is given by the following formula:

$R = \rho l / A$ [ohms]

Where: *l* = length, A = cross-sectional area, [ρ] = resistivity, ohms - meter

One can see that lower resistance can arise from enlarging the cross-sectional area or reducing length given similar materials. In addition, enlarging the cross-section to account for higher resistance is possible. These techniques are used in lightning protection conductor design rules. For example, conductor runs have maximum length limits to minimize resistance. Another example is structural steel used as a LPS conductor which has greater cross-sectional area than copper conductors of much lower resistance.

2) <u>Power dissipation</u> occurs due to resistance in a conductor as does a voltage drop. Both are a function of current, given by:

$V=IR$; $P=I^2R$

Where: I = current [amperes], R = resistance [ohms], P = power [watts]

Typically, the power dissipation and voltage drops are not calculated in lightning protection system design but we discuss these relations here to underscore an important physical point. In power systems, the power dissipation and voltage drop is usually negligible. Consider when lightning currents of tens or hundreds of thousands of amperes flow, the power dissipation and voltage drop becomes very large. Ohmic heating results from the dissipation of power in the conductor.

3) <u>Inductance</u> is a property of any conductor and is a function of the geometry and configuration. One may be familiar with an inductor, which is often a coil of wire perhaps wrapped around a ferrous core material. While the direct current resistance of the inductor remains low, the inductor impedes alternating current flow (or a current pulse) due to magnetic effects.

4) <u>Inductive reactance</u> becomes significant due to the fast rise time of the initial lightning pulse, the A-component which behaves like a high-frequency signal. The inductive reactance for a conductor subject to a lightning pulse is:

V = (di/dt) L

Where: di/dt = rate of current rise [amperes/sec], L = inductance [henries]

Typical lightning conductors may have an inductance of a few microhenries. However, the di/dt can be on the order of 10^{10} amperes/sec or higher. Consequently the voltage induced on a lightning conductor can be momentarily very high, tens or hundreds of thousands of volts. Once this voltage exceeds the breakdown value of the material between the conductor and another grounded object, sideflash may occur to the grounded object.

e. Conductor Summary

Conductors in an LPS serve to confine and direct the lightning electrical energy. There are generally two types, main and bonding conductors. These conductors must be sized and installed in accordance with the design rules found in an authoritative lightning protection design standard. These design rules account for the various effects of the lightning waveform on conductors. In general, it is essential to minimize resistance and inductive reactance in the conductor subsystem of a lightning protection system.

6. Grounding

The grounding subsystem of the lightning protection system is designed to transfer the lightning current from the conductor subsystem into the earth. An additional function is to 'clamp' the electrical potential of the system as close to zero volts, or ground potential, as possible.   In this section we explore the purpose and function of the grounding subsystem.

a. Grounding Electrodes

Grounding electrodes are placed in contact with the earth and electrically connected to the lightning protection system. A grounding electrode can have a variety of different configurations but it's a corrosion resistant conductor that is intentionally placed in close physical contact with the earth, typically buried.   The most common and familiar grounding electrode is a ground rod, which is a conductor placed generally vertically into the earth.

One can think of the grounding electrode as the electrical bond of the LPS to the earth. Given that bond, the LPS is ideally held at the same electrical potential as earth. Ideally ground is at zero volts, however, this is seldom achieved in practice because of the non-ideal electrical properties of the conductors, the grounding electrode and earth, namely, impedance.

b. Grounding Electrode System Impedance

A grounding electrode has an impedance, Z, like a conductor.   However, the variables that drive this impedance depend on the grounding media as well as the electrode itself. The impedance of the grounding electrode will depend upon:

- • Electrode configuration
- • Depth of burial
- • Resistivity of the soil

In practice, only electrode resistance is considered quantitatively.

1) <u>Electrode configuration</u> is a strong variable in the final impedance value of the earth electrode.   In many cases, standard ground rods are used which are generally eight to ten feet

long and approximately 5/8 inch in diameter. However, there are many different configurations possible including ground loop conductors, horizontal conductors and arrays of ground rods. Imagination is the limit. Arrays of multiple ground electrodes are possible and are often used. In this case, more is generally better in lowering the final grounding system resistance but progressively smaller improvements results from additional ground electrodes.

Spacing of the electrodes is also an important variable.   In general, spacing the electrodes twice to four times their burial depth results in optimal results.   If the electrodes are spaced too close to each other, they begin to (electrically) function as a single electrode and any improvement is lost.

Detailed configurations and methods to compute the resistance of electrode systems can be found in the Institute of Electronics and Electrical Engineers (IEEE) Standard 142-1991, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*, commonly known as the 'Green Book.'

Figure 6. Decrease of resistance as function of depth for a representative ground rod.

2) <u>Depth of burial</u> is an important variable. In general, resistance decreases with depth of burial.   For example, deeper ground rods develop lower resistance – to a point. After a certain depth (unless one penetrates a layer where the resistivity is substantially lower) no improvement is gained.   An example of this is illustrated in figure 6.[i]
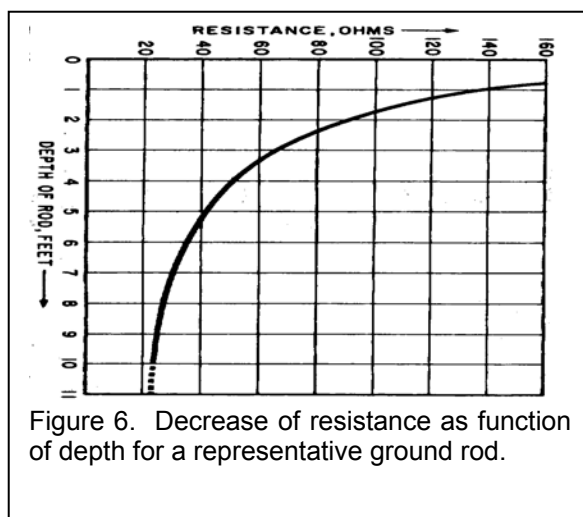
3) <u>Soil resistivity</u> is the single most important property that affects the final grounding resistance developed. In turn, several variables affect soil resistivity:

3a) Soil composition ranging from loam rich in organic material to clay to composites of basaltic rock and granites can range from 100 Ω-cm to 10^6 Ω-cm.

3b) Moisture content varies the soil resistivity considerably. Orders of magnitude changes occur between zero moisture content up to 30%. After a point, the soil saturates and no additional improvement is seen as this situation resembles immersion in water.

3c) Mineral content can also improve the soil resistivity. This technique is often used in areas where poor resistivity soils are encountered. A mineral back fill is added to the soil surrounding the electrode. Many commercial alternatives exist, although common salt can improve the soil resistivity by up to two orders of magnitude. Beware of local environmental regulations before choosing a backfill, however.

3d) Temperature is a strong factor. Colder temperatures degrade soil resistivity. Resistivity of any soil will generally double between 70°F and 32°F.   Once the soil freezes (moisture content turning to ice) the resistivity will immediately triple and get progressively more resistive as the temperature goes down. Often, it is specified that ground electrodes get installed below the frost line as a result of this phenomena.

c. Ground Potential Rise (GPR)

Due to the large magnitude initial current pulse (A-component) of the lightning event, a voltage is induced upon the surface of the earth when the current flows through the grounding system into the earth. In figure 7, imagine a lightning current injected into a simple grounding system, like a typical ground rod. As the current flows into the rod, it then flows outward into the earth through incremental shells of soil. As it flows through these shells, each with a resistance, a voltage drop occurs just as it would for any conductor. In reality, the outward current flow is not uniform as a function of depth. The distribution depends upon several variables including the soil resistivity as a function of depth and the inductive reactance of the grounding system. There is significant evidence that much of the current actually flows near the surface of the earth.
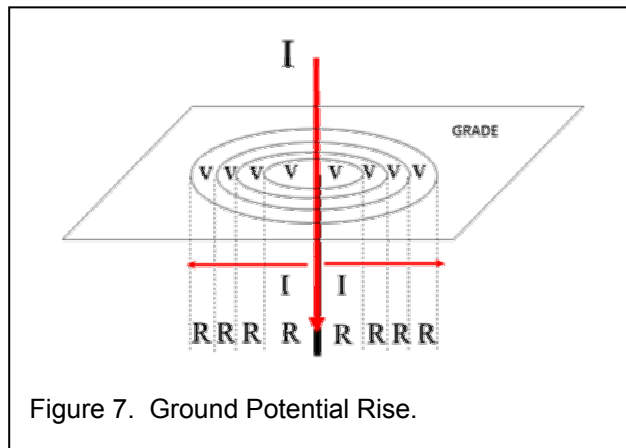

Figure 7. Ground Potential Rise.

Whatever the distribution, a voltage drop occurs across each incremental shell of soil, which becomes manifest as a voltage gradient radiating from the grounding electrode.   GPR then is this potential or voltage rise in the earth near the grounding electrode. The GPR can have harmful effects, notably the step potential. Step potential is the voltage difference that occurs over the space of an average persons' stride. During the high current A-component pulse, this voltage could easily be tens of thousands of volts, occurring for the duration of the A-component. In turn, this poses a serious shock hazard to people nearby.

d. Grounding Subsystem Summary

1) LPS connection to earth is through the grounding electrode subsystem. The grounding subsystem also is intended to hold the LPS system at ground potential, or zero volts.

2) Low impedance is desirable for the grounding subsystem. In practice, only resistance is measured and/or calculated. Impedance is considered in the geometric configuration of the grounding electrodes.

3) Many factors govern electrode impedance.   Configuration, number of interconnected electrodes, spacing of the electrodes and soil resistivity are all variables that affect the design and performance of the grounding system.

4) Ground Potential Rise (GPR) occurs from the lightning event. The earth near the grounding system becomes significantly energized during the lightning event, which could result in harmful step potentials.

7. Potential Equalization and Surge Protection

a. Potential Equalization

Having equipotential between parts of the LPS and/or any dead metal parts in a structure is essential.   As was discussed earlier, severe voltages can arise through the normal function of the LPS.   If severe voltage differences occur, arcing can take place which becomes an ignition

hazard. Two considerations exist for the potential equalization subsystem of the LPS, they are bonding and surge protection.

Recall from the discussion on conductors, that they have an impedance consisting of resistive and inductive components. When current from the lightning pulse flows through a conductor, there is voltage drop from this impedance. If this voltage becomes high enough, it can exceed the dielectric breakdown value of the medium surrounding the conductor. This material could be air, wood or some other structural material. When that occurs, an arc (commonly termed as sideflash) is formed. It is desirable to prevent arcing and sideflash in lightning protection systems because the medium through which the arc occurs, like wood, for example, could be ignited.
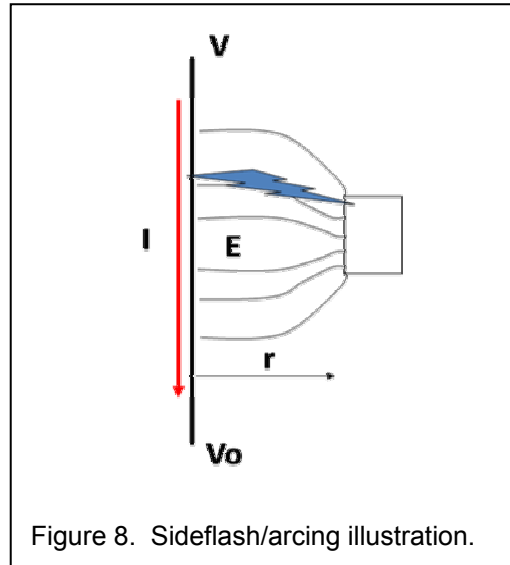

Figure 8. Sideflash/arcing illustration.

This situation is illustrated in figure 8. In our hypothetical conductor on the left of the figure, a current, denoted by I, flows to ground. Since the conductor has an impedance, a voltage V, greater than the ground voltage V_0 is induced on the conductor. Since the conductor is energized to this voltage V, an electric field, denoted by E, results and terminates on a nearby metal object. (A magnetic field, not illustrated here, will also occur surrounding the conductor as a part of this process.) In practice, this metal object could be a window frame or metal piping, etc. Metal objects in structures, most notably water piping, is commonly grounded to earth in some fashion, either intentionally or incidentally. So once the voltage difference between the conductor and metal object exceeds the dielectric breakdown value of the medium between them, an arc will occur at the point of the strongest electric field between the objects.

1) Bonding is the intentional electrical connection between the LPS and dead metal parts of other systems that may be in the structure. These include but may not be limited to water piping, gas piping, electrical system ground and telecommunications grounds. An interconnection is usually best implemented as close as possible to the entry of a structure. This situation is similar to the electrical bonding that is required of the electrical service ground and the water piping, for example. Bonding as close as possible to the entry attempts to hold these systems at equipotential, preventing arcing between systems. However, for lightning protection, additional bonding may be required.
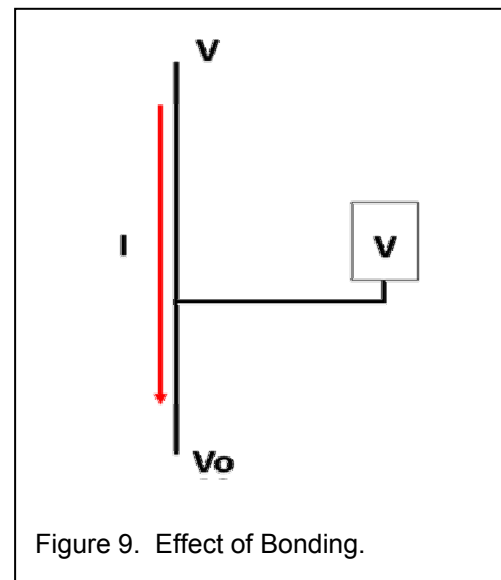
2) Prevention of current flow is actually the objective of bonding. This situation is illustrated in figure 9. Bonding conductors in LPS are to keep items at equipotential, ideally preventing current flow to or

Figure 9. Effect of Bonding.

between those parts. In the figure, the electrical connection keeps the metal part at the same voltage as the conductor. (In actuality it will minimize the voltage difference.) This, in turn prevents or at least minimizes the electric field between the two as well preventing arcing. Since the metal part is 'floating' or not connected to ground, current does not flow through it. In some

cases, the metal structural part, piping system, etc., may be incidentally connected to earth ground, in which case some current may be imposed upon it. Usually this current will be significantly less than the amount that lightning injected due to current division and the (ideally) lower impedance of the lightning protection system. In general, conductors intended for bonding are of smaller cross-section than those intended for the main flow of lightning current.

3) Additional bonding is often needed between dead metal parts and the LPS within a structure. The requirement is defined when dead metal parts are within a certain proximity of the LPS conductor and from the configuration of the LPS. Detailed methods for determination of bond implementation are given in lightning protection installation standards.

4) Roof and intermediate level equipotential bonding is also required. This is a consequence of the development of voltages in conductors subject to lightning current flow, as we have learned. Essentially, it is necessary to establish a 'ground plane' or an area of equipotential at the roof and at intermediate levels for a tall building.

b. Surge Protection

Surges are induced in power and communications services as a consequence of lightning. Obviously, if lightning enters into a power conductor there will be a surge transferred into the power system. However, it is far more common that the surge is induced by the severe electric and magnetic fields that occur during the lightning event. Consider that the conductors and grounding electrodes produce these fields when lightning current flows through them. While bonding helps to minimize the impact of surges, often surge protection devices are needed for full protection.

1) Surge Protection Devices (SPDs) operate by shunting undesired energy to ground. Essentially, in normal operation, an SPD has low pass-through impedance but high resistance to the ground circuit. When a voltage event occurs above the threshold voltage of the SPD this situation reverses. The pass-through impedance becomes high but the ground circuit resistance becomes low, sending the following current into the ground circuit.

This function is illustrated in figure 10. In the upper SPD, we see an input signal resembling as sine wave, which could be power, for example. In this regime, the SPD has a low pass-through impedance (Z_1) but Z_2, the impedance to ground, is essentially an open circuit. When a fast rise time transient occurs, as illustrated in the lower case, the pass-through impedance becomes high and the ground impedance become low, diverting the surge energy to the grounding circuit. For this reason, it is critical that the ground circuit impedance is as low as possible for the SPDs to function correctly. The best SPDs are useless without a good grounding circuit.
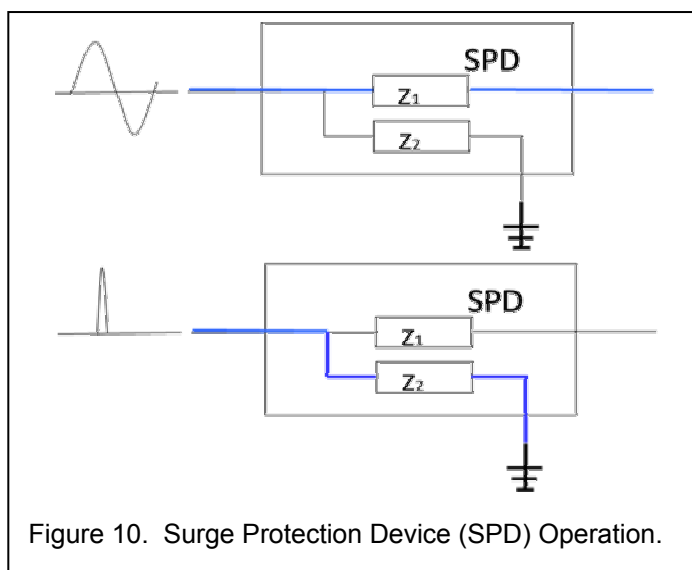

Figure 10. Surge Protection Device (SPD) Operation.

2) <u>Figures of merit</u> for SPDs are important considerations for device selection. These include:

- The maximum current or nominal discharge current capability.
- Maximum cutoff voltage (MCOV) or the voltage above which the device initiates.
- Short circuit current rating.
- Bandwidth and insertion loss, for high frequency communications SPDs.

Available lightning protection standards and other literature provide requirements and guidance for the selection of SPD devices.

3)   <u>Coordination</u> with other building/structure services and utilities (electrical, telecommunications) are essential for implementation of effective surge protection. Moreover, the installation requirements of the National Electrical Code © or other local requirements for electrical installations must be met during the installation of these devices.

8. Standards for Lightning Protection

A few lightning protection standards are available for use.   These documents provide the details for the installation and implementation of the components of the LPS. Typically one, or more, of these standards will be specified for the installation of lightning protection systems in the United States.

- National Fire Protection Association's (NFPA) Standard for the Installation of Lightning Protection Systems (NFPA 780.)
- Underwriter's Laboratory Installation Requirements for Lightning Protection Systems (UL 96A)
- Lightning Protection Institute's Standard of Practice for the Design - Installation - Inspection of Lightning Protection Systems (LPI 175)

All of these standards provide detailed guidance for the selection of materials and installation requirements for the lightning protection system. Additional topics are discussed such as personnel protection, protection for various special occupancies, which includes large smokestacks, structures housing flammable and explosive materials. Inspection methods and maintenance topics are also discussed.   In the first document, NFPA 780, risk assessment methods are offered to better understand and quantify if any particular structure is at significant risk from lightning.

9. Summary

In this lesson, we discussed the fundamentals of lightning protection systems and how they operate. We reviewed the LPS subsystems which are:

- Strike Termination Subsystem
- Conductor Subsystem
- Grounding Electrode Subsystem
- Potential Equalization Subsystem
- Surge Protection Subsystem

The basic function of each of these subsystems was discussed with a view toward the concept of how they operate. In closing, a list of commonly used engineering standards for the implementation of the LPS was provided. Detailed guidance for the installation of lightning

protection systems are contained in these standards.   Adherence to these engineering standards is essential for an effective LPS.

Using this knowledge, you will be better able how to understand and implement lightning protection systems using one of these engineering design standards.

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[i] Getting Down to Earth, Biddle Instruments, 1990.