Lightning Protection at Ground Level

by Kim Loehr

Packing up to 100 million volts of electricity, a lightning bolt has the power to rip through roofs, explode walls of brick and concrete, and ignite deadly fires. Discounting the obvious safety risks, the economic consequence of this natural charge of atmospheric electricity is staggering.

Lightning is responsible for massive property damage each year, as a powerful strike can produce extensive property damage by sparking a fire or by surging through circuitry. According to Underwriters Laboratories (UL), this force of nature accounts for more than one billion dollars in annual structural damage to...
U.S. buildings. However, unlike threats posed by tornadoes, hurricanes, or floods, lightning can be controlled on a specified path.

When lightning's electricity is confined to a properly designed conductive path, damage can be minimized or eliminated. Destruction results when electricity encounters 'resistance,' which can be similar to what occurs during arc welding. When electrical current runs through an arc welder, the resistance it encounters when arcing through air generates the heat necessary to melt steel. The highly conductive copper and aluminum materials used in a lightning protection system provide a low resistance path through which lightning can travel.

It is common for lightning to travel via conductive matter it finds along the way, including plumbing, flashing, structural members, and/or wiring for power, communication, or data. When a protection system (e.g. roof network, grounding, bonding, and/or surge protection) is in place, a lightning strike is intercepted and directed to the ground without impact to a structure or its contents. Providing this low-resistance path means the lightning does not try to fight its way through non-conductive building materials like wood, brick, rubber membranes, glass, and plastic en route to the ground. Since the resistance encountered in these materials is what produces heat, fires, and even explosions, specifying an appropriate protection system can help safeguard a building from the resultant effects of lightning.

No grounding is one-size-fits-all
There is much more to lightning protection than installing a rod on a rooftop. Since the key purpose of a lightning protection system is to dissipate electrical current safely into the earth, it is only as good as its grounding. Systems and their associated grounding must comply with the requirements of national lightning protection safety standards. The authorities governing these standards are:
- Lightning Protection Institute (LPI) 175, Standard of Practice;
- National Fire Protection Association (NFPA) 780, Standard for the Installation of Lightning Protection Systems;
- UL 96A, Installation Requirements for Lightning Protection Systems; and
- UL 96, Standard for Lightning Protection Components.

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Bolt fittings are an important part of lightning protection systems. These parallel cable connectors help ensure continuity.

The 2004 NFPA standard defines a ground terminal as the portion of the system installed for the purpose of providing electrical contact with the earth. This could include a ground rod, ground plate, or ground conductor.

In most installations, grounding is achieved via ground rods at least 2.4 m (8 ft) long, composed of copper, copper-clad steel, hot-dipped galvanized steel, or stainless steel. All these materials are acceptable and approved metals for grounding per the safety standards. Performance and cost are relatively the same—the choice usually comes down to installation or specification preferences.

These ground rods extend vertically at least 3 m (10 ft) into the earth and must be free of paint or other nonconductive coatings. Electrical systems and telecommunication grounding electrodes should never be used as a substitute for lightning ground rods, as they do not meet the requirements for effective grounding of lightning's magnitude. (The ground devices are typically the same for all systems, but the wiring in electrical and communication systems is not large enough to accommodate lightning.)

While ground rods are the typical products employed, some projects may call for an alternate application to ensure an effective ground termination is achieved. Factors such as soil content, environmental challenges, and structural characteristics can dictate grounding applications and methods. It is important to understand that grounding is not a cookie-cutter application. Project-specific systems are necessary, as certain situations can often dictate special requirements.

**Deep clay soil**

In situations where deep clay soil is present, the lightning conductors or ground rods should extend vertically to ensure proper burial in most ground conditions.

**Sandy or gravelly soil**

In sandy or gravelly conditions, there is poor (i.e. high) soil resistivity conditions. Consequently, two or more ground rods at least 3 m (10 ft) apart should be driven vertically to a depth of 3 m (10 ft) or more below grade.

**Shallow topsoil**

Where solid rock is near the surface, a lightning protection conductor may be laid in trenches that extend away from the building at each down conductor location. If trenching proves impractical, grounding may need to be achieved through use of a copper ground plate.

**Soil less than 0.3 m (1 ft)**

Grounding in soil less than 0.3 m (1 ft) in depth may require a ground 'loop,' radials, or plate electrodes. A ground loop or ground ring electrode encircles the structure, preferably in direct contact with the earth at a depth of 457 mm (18 in.) or
System Components

Typical commercial lightning protection system components include the following:

**Adhesive base/adhesive cable fastener:** holds air terminal assembly in place, while connecting and fastening the cable conductor to the structure.

**UL Master Label:** signifies the lightning protection system was inspected to comply with Underwriters Laboratories (UL) installation standards.

**Surge arrester:** protective device for limiting surge voltages by discharging or bypassing surge current.

**Cable connector:** fittings used for the bonding or connection of down conductors and/or grounding equipment. (Bimetallic connectors must be used for splicing or bonding of dissimilar metals.)

**Pipe clamp:** used to connect underground metallic piping systems.

**Bolt fitting:** parallel cable connector that ensures continuity.

**Side mount base:** adhesive cable fastener, used to side mount air terminals for placement on a structure's wall.

**Through-roof assembly:** Used to achieve a through-roof connection to the grounded steel framework.

**Bolt fitting and ground termination:** used for steel column grounding connections.

* In 2003, UL automated its inspection services and began issuing certificates via the Internet to replace the metal Master Labels. As of April 2007, UL revised its wording to “UL Lightning Protection Inspection Certificate.”

more. Ground radials, on the other hand, consist of one or more main-sized copper conductors, each in a separate trench extending outward from the location of each down conductor, not less than 3.7 m (12 ft) and not less than 0.5 m (1.5 ft) below grade. Finally, a ground plate electrode is made of solid copper and has a minimum thickness of 0.8 mm (0.03 in.) and a minimum surface area of 0.2 m² (2 sf).
The following definitions come from the Lightning Protection Institute (LPI) 175-2004, Standard of Practice.

**Bonding:** the permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity and the capacity to safely conduct any likely current to be imposed.

**Cable:** a factory assembly combining multiple conductor strands.

**Conductors:** devices defined by LPI 175-2004 as suitable to carry lightning current; they may include strike termination devices, cables, lightning protection fittings, ground terminals, or metallic structural members.

**Fastener:** component(s) used to securely attach materials to the structure (a fastener may also be a mechanical device, such as a rivet, bolt, screw, or pin used to securely hold two or more components together).

**Ground terminal:** the portion of a lightning protection system (e.g., ground rod, ground plate, or ground conductor) installed to provide electrical contact with the earth.

**Labeled:** equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization acceptable to the authority having jurisdiction (AHJ); concerned with product evaluation and/or inspection, it indicates compliance with appropriate standards or performance in a specified manner.

**Lightning protection system:** a complete system of strike termination devices, conductors, ground terminals, interconnecting conductors, surge suppression devices, and other connectors or fittings required to complete the system.

**Listed:** equipment, materials, or services included in a list published by an organization acceptable to the AHJ; it maintains periodic inspection of production of listed equipment/materials and/or confirms service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

**Strike termination device (air terminal):** component of a lightning protection system that intercepts lightning flashes and connects them to a path to ground.

**Surge protective device (SPD):** device composed of any combination of linear or nonlinear circuit elements intended for limiting sure voltages on equipment by diverting or limiting surge current.

**Transient voltage surge suppressor (TVSS):** surge protective device listed for connection on the load side of the main over current protection in circuits not exceeding 600 volts rms.

**Zone of protection:** space adjacent to a lightning protection system that is substantially immune to direct lightning flashes.

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**Concrete-encased electrodes**  
This method is only used in new construction. The encased electrode (i.e., bare copper main-size conductor or steel reinforcing bars or rods) are located near the bottom of a concrete foundation or footing that is in direct contact with the earth. (The electrode is encased by at least 51 mm (2 in.) of concrete.

**Tanks, watercraft, and miscellaneous structures**  
Special grounding techniques may need to be applied, including:
- connections across insulated joints using spark gaps;
- bonding;
- grounding strips;
- ground grids; and/or
- ground plates.

**Finding common grounding**  
A final, yet crucial, element of the grounding process involves interconnecting all grounding media to provide a common ground potential, explains Mark Morgan, a member of the NFPA 780 Technical Committee on Lightning Protection and an officer of the Lightning Safety Alliance (LSA). This
interconnection includes lightning protection, electric service, telephone, antenna system grounds, as well as underground metallic piping systems. Without the required bonds, a structure could be at risk.

This is important to ensure an electrically continuous and uninterrupted path to properly dissipate lightning's harmful electricity. Common ground bonding is also imperative for the effectiveness of the lightning protection system. It entails the permanent joining of metallic parts to form an electrically conductive path, thus ensuring electrical continuity and the capacity to conduct any current likely to be imposed.

The environment can pose unique challenges for lightning protection and electrical grounding, which is why research continues to be a priority of organizations like NFPA, UL, electrical utilities, municipalities, and lightning protection equipment manufacturers. Representatives from these groups have participated in the National Electrical Grounding Research Project—an ongoing study to evaluate factors that can impact the performance of earth grounds and whether these electrodes become less effective over time.

Resistance data from embedded electrodes of various types (from the six research sites) have been collected on a periodic basis over several recent years. Electrodes have been exhumed from several of the project's sites and are undergoing corrosion testing. Since a key component of grounding systems involves the use of buried electrodes, a major purpose of this study is to determine whether these electrodes have reduced performance after a period. While the conclusion data from the study has not yet been released, it is expected to impact future revisions of NFPA 70, National Electrical Code (NEC).

Low-impedance grounding is important for both safety and performance reasons, according to Mitchell Guthrie, technical advisor for the U.S. National Committee Advisory Group to the International Electrotechnical Commission (IEC) Committee on Lightning Protection (TC 81).

"Grounding and grounding system equipotential bonding are critical in minimizing fire and surge hazards associated with a lightning threat. Discussions are underway in the international standards community concerning the configuration of earth electrodes," he explains. "It is possible the National Electrical Grounding Research Project could have significant impact on future revisions of the National Electric Code, NFPA 780, and lightning protection standards—if the data is properly shared with these standards writing organizations as requested."

Resolving standard interpretation errors
While reference to the safety standards is crucial for proper installation and application, confusion can arise when these
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The lightning rod is the first thing that comes to mind when one thinks about lightning protection. The purpose of such components is to provide a path for electrical current to be safely dissipated into the earth.

standards are misinterpreted. Lightning protection system, gas line, sprinkler pipe, and water bonding requirements are frequently misinterpreted in the field by inspectors, utility workers, and fire professionals, along with engineers, contractors, and other design/construction professionals.

An unfounded belief exists regarding connections for these bonds. There is an incorrect school of thought these bonds should be removed. However, their elimination eradicates a critical component of the lightning protection system and can result in fire, physical damage, and even death.

To clear up confusion surrounding the required bond, it is necessary to understand its purpose. The bond is not intended as an additional grounding electrode—rather, it is there to provide potential equalization or common potential for all building grounded systems. The lightning protection system offers a better ground path than an isolated water or gas transmission system. Should lightning strike external gas transmission piping, jump the isolation fitting, and approach the building interior, the protection bond defends against infiltration. Removing these bonds eradicates a critical component of the protection system and can create the potential for fire and other damage in the structure.

To clarify the issue for sprinkler and water pipe bonding, members of the NFPA 780 Task Group on Grounding initiated a motion for placement of additional wording
into Clause 10.6.8 of NFPA 24, Standard for the Installation of Private Fire Service Mains and their Appurtenances, at the general session of the annual NFPA World Safety Conference and Expo in Orlando in June 2006. (No dissenting views were expressed and the motion passed by a large majority vote.)

As a result, NFPA 24 and NFPA 13, Standard for the Installation of Sprinkler Systems, will now include a statement clarifying that when a lightning protection system is present, sprinkler and water piping systems must be bonded near grade. Even though NFPA 24's wording did not preclude the NFPA 780 bonding requirement, the critical consequences of such misinterpretation warranted the

Specifying an entire system of lightning protection components for a building involves close consultation with manufacturers and other industry experts.

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When storm clouds gather, the beauty of lightning is only matched by its destructive power. With up to 100 million volts of electricity, bolts can rip through roofs, destroy walls of masonry and concrete, and lead to fires, causing more than one billion dollars in structural damages each year.

addition of text. According to Guthrie, the amendment not only clears up confusion, but it also highlights the requirement for equipotential bonding of the piping system with the lightning protection system.

"It sets the stage for addressing amendments needed in other NFPA documents where the lightning protection industry sees problems with 'authorities having jurisdiction' forcing removal of bonds or not allowing them in the first place," he continues. "Although this is a relatively minor change to the text, the NFPA task group on grounding believes this can help solve a significant safety problem."

Industry resources for quality control
Quality control issues frequently arise on the drawing board and in the field, so technical support is often necessary. Of the national authorities who write and revise the lightning safety standards, LPI is the only one founded specifically to study lightning protection. With a membership made up of manufacturers, contractors, scientists, architects, engineers, and safety directors, the institute collects and reviews statistical information and scientific data on the nature and behavior of lightning on a routine basis. In addition to publishing a standard, it offers certification and education programming.¹

Notes
¹ Visit www.lightning.org.

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### Additional Information

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<td>Every building requires a means of defense from the potential damages caused by lightning. This article examines the components comprising a lightning protection system and explores how the design team can work together to ensure there are safeguards against electrical storms.</td>
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