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Understanding lightning protection systems

Scientific advances improve lightning protection for mission critical facilities.

Jennifer Morgan, East Coast Lightning Equipment, Inc. and **Michael Chusid**, RA FCSI CCS

Learning objectives

- Know the basics of lightning protection systems and the need for them.
- Understand the factors that electrical engineers should consider when assessing lightning risk.
- Apply standards to specifying lightning protection.

Benjamin Franklin demonstrated that an electrically conductive path can safely channel lightning strikes from the top of a building into the earth. His lightning protection system (LPS) has repeatedly proven its effectiveness and has been gradually refined during the past two centuries. For ordinary facilities, it assures reliable and affordable protection when designed and installed in accordance with NFPA 780: Standard for the Installation of Lightning Protection Systems.

Yet the lightning protection requirements of many structures exceed those provided by ordinary air terminals (formerly called lightning rods) and grounding. Their vulnerabilities have increased as increasingly sensitive electronics now control vital functions including building security, climate control, data storage and processing, lighting, manufacturing and processing equipment, door hardware and access systems, health care systems, and other critical functions. At the same time, the risk appears to be rising due to the occurrence of more frequent extreme weather events associated with climate change, as lightning accompanies tornadoes and hurricanes as well as thunderstorms.

Lightning poses a significant risk to buildings and their occupants and contents. It strikes 40 to 50 times per second worldwide, for a total of nearly 1.4 billion flashes a year, with up to more than 200,000 amperes of virtually unimpeded current surging between ionic charges in the atmosphere and the earth. Every region of North America is vulnerable to lightning. On a national scale, lightning causes about as much damage as tornadoes. The scope of this devastation, however, is frequently unrecognized because individual lightning strikes do not attract the media attention that is given to regional disasters. Yet a single lightning strike can be a disaster for a business or community if it disrupts mission critical operations.

Insurance claims for lightning-damaged buildings in the U.S. total more than $5 billion annually. This figure understates the cost because it primarily measures fire and structural damage and overlooks most of the damage to electronic devices and systems. Lightning damage to electronic devices is frequently misattributed to other causes.

Consider, for example, a Level I trauma center that had installed a new backup generator. The generator repeatedly failed routine, monthly checkups, and the hospital made claims against the manufacturer's warranty. Someone eventually noticed a correlation between equipment failures and thunderstorms in the area, and it was discovered that the generator had not been properly integrated into the building's LPS. Since remediation, the facility manager reports the generator has not failed again.

Even if an insurance policy paid for damaged equipment, would it cover consequential damages, such as loss of revenue or failure to respond in an emergency? You would not want to be the police or fire chief that is unable to respond to storm-related damage because the very storm fried your communication system.

Risk assessment

A good place to begin understanding your building's lightning protection needs is with the lightning risk assessment in Annex L of NFPA 780.

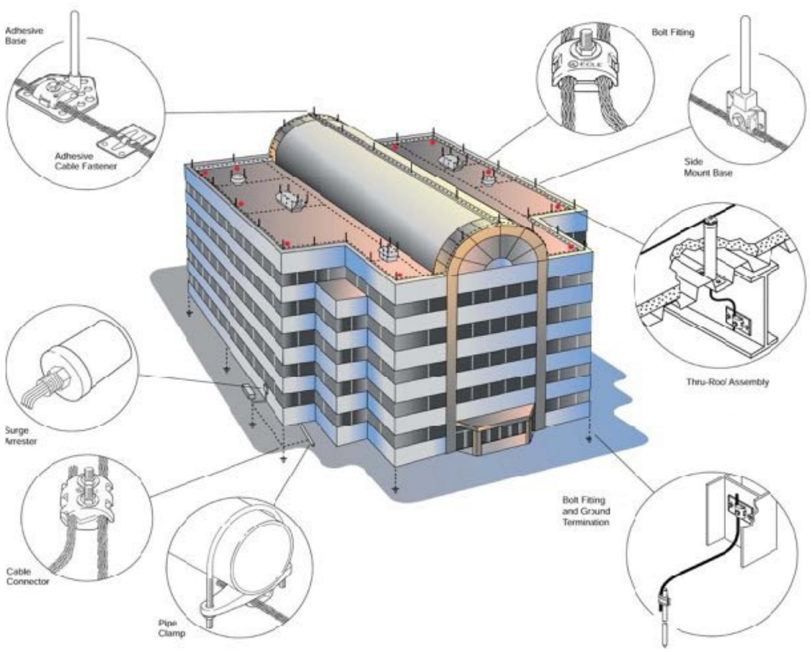

Figure 1: A lightning protection system provides a conductive path that can safely channel lightning into the ground. Air terminals, conductors, ground rods, fittings, and other components must be listed under UL 96—Lightning Protection Components. In most steel-framed buildings, structural members can be used as down conductors between the roof and earth. Surge-protection devices must be installed on all power and signal services penetrating the building envelope. Courtesy: East Coast Lightning Equipment Inc.

The standard recommends lightning protection when a structure's vulnerability to lightning is greater than its tolerable risk:

▪ Vulnerability is determined by lightning-flash density (frequency/area/year based on national weather-service maps) with modifications based on a structure's area, height, topography, and proximity to taller structures or trees.

▪ Risk is affected by the conductivity and combustibility of the roof and structural system, the value and combustibility of the building, the ease with which occupants can be evacuated, an owner's attitude toward continuity of operations, and environmental hazards, such as the release of hazardous materials.

Regardless of the calculations, NFPA recommends serious consideration of lightning protection if any of the following factors are present.

■ Large crowds

■ High lightning-flash frequency

■ Tall, isolated structures

■ Explosive or flammable content

■ Irreplaceable cultural heritage

■ Regulatory or insurance requirements

■ Continuity of critical services.

Lightning monitoring

Many of the recent advancements in lightning safety were developed for military and space-launch applications. This is understandable because launch facilities, such as those at Cape Canaveral, Fla., are located in areas with intense lightning activity. At such launch facilities, the value of the assets is high, the avionic and aeronautical equipment is sensitive, rockets and their launch structures are tall, and the stakes are enormous when astronauts or other high-value payloads are sitting on top of massive, highly volatile rocket-fuel tanks.

This was illustrated in 2011 as Space Shuttle Atlantis sat on Launch Complex 39A (LC-39A) at the Kennedy Space Center. One day before Atlantis was due to make the final voyage of NASA's Shuttle program, lightning struck near the launch complex, twice. The crucial questions for engineers and officials hoping to keep the launch on schedule were: Where exactly did the lightning strikes hit, and were they close enough to damage the shuttle's electrical systems?

Two systems were monitoring lightning activity around Kennedy Space Center at the time: the local Cloud-to-Ground Lightning Surveillance System (CGLSS), operated by the Air Force's 45th Weather Squadron, and the U.S. National Lightning Detection Network (NLDN), a nationwide lightning-detection system owned and operated by Vaisala, a private company.

The systems indicated the lightning events were close to LC-39A where Atlantis was waiting for launch. But prior NASA investigations had determined that both CGLSS and NLDN produced questionable results: They reported only 70% to 80% of lightning strikes and were prone to reporting strikes in locations where they did not actually occur.

In previous cases, lightning strikes in the vicinity of the launch pad would have delayed the launch by up to a week while engineers retested potentially affected systems. This time, however, NASA had the benefit of a new lightning-monitoring system. The system used state-of-the-art, high-speed cameras designed to capture visual evidence of any lightning striking the pad directly or in the nearby vicinity.

Images from the camera showed one strike was outside the LC-39A perimeter and the other struck a water tank. NASA officials had sufficient confidence in the relatively untested system to keep the Atlantis launch a "go."

Commercial availability

Technology similar to the surveillance system relied upon to monitor Atlantis on the launch pad has been refined and is now available commercially. The optical lightning-monitoring system uses high-speed, zero-dead-time cameras to detect and record 100% of strikes within a specified surveillance area. The system uses robust, aerospace-grade components that are easily deployed and solar-powered to provide immediate reports that allow timely responses.

Recently, the innovative optical lightning-surveillance system was crucial to the successful December 2016 launch of the Cyclone Global Navigation Satellite System (CYGNSS), allowing the countdown to continue despite fierce lightning at Cape Canaveral Air Force Station just days before the scheduled deployment. CYGNSS contains eight micro-satellites that will measure wind speeds over Earth's oceans, increasing the ability of scientists to understand and predict hurricanes. CYGNSS was launched Dec. 15, 2016, by Orbital ATK Inc. using their Pegasus XL rocket—an air-launched vehicle mounted under a modified Lockheed L-1011 aircraft.

Two optical lightning-surveillance systems provided unprecedented precision in determining where lightning struck. Engineers immediately reviewed the data collected and provided conclusive evidence that the aircraft and rocket had not been exposed to lightning-related effects that would endanger the mission.

Commenting on a photograph taken by the system, NASA's Sean Potter said, "Though the photo gives the appearance of lightning directly striking Orbital ATK's L-1011 carrier aircraft, the strike occurred approximately 2.5 miles from the aircraft's location beside Cape Canaveral Air Force Station's runway. The aircraft and Pegasus XL rocket were surrounded by an overhead lightning protection system designed to protect them had a strike actually occurred in the immediate vicinity; the three masts of the LPS can be seen near the front and aft of the aircraft."

To augment the LPS, Potter said, "The surveillance system was designed for NASA's Launch Services Program to document and assess potential deleterious effects of lightning strikes. The lightning-surveillance system provided timely and accurate

Figure 2: The physical plant director of this hospital said he can't accept the risk of lightning damage when someone could be on the operating table. The railings around this roof-top equipment acts as a strike termination device and is used in lieu of conventional air terminals (lightning rods). The cable at the base of the railing is UL-listed for lightning protection and assures electrical continuity with the rest of the lightning protection system.
Courtesy: Bonded Lightning Protection Systems, Inc.

Figure 3: Lightning can exceed 3 million V and protecting structures and equipment from lightning is not covered in the electrical codes. Lightning protection system (LPS) should be designed and installed by individuals certified by the Lightning Protection Institute and using equipment specifically listed for lightning protection systems. This copper grounding bar is used to create a common ground point where the LPS and the grounds for other building services can be interconnected.
Courtesy: Mr. Lightning

data that allowed for continuation of the Pegasus XL countdown despite numerous cloud-to-ground lightning strikes recorded that day." He also said that the contractor, "provided outstanding support and was able to quickly provide information that was helpful in mitigating the concern and moving forward with the launch."

The optical lightning-surveillance system is also proving invaluable to other industries. In the wind-energy industry, for example, a lightning-damaged wind-generator blade can throw the turbine out of balance, potentially causing the entire tower to collapse. By monitoring an entire wind farm, an operator can quickly determine if a particular wind turbine has been struck so it can be safely shut down for maintenance—and possibly avert a catastrophic failure.

In the insurance industry, accurate lightning surveillance allows property owners to document claims that damage is due to lightning and not mechanical malfunction. Similarly, insurance companies can protect against fraudulent claims. Both parties benefit by not having to send investigators into the field for costly forensic work.

The horizontal footprint of a facility is a significant factor in determining vulnerability to lightning. This makes the optical surveillance system particularly valuable to organizations providing services across areas with many high-valued assets, such as airport and harbors, military installations, construction sites, power-generation facilities, and complexes with multiple lightning-vulnerable structures.

Triggered lightning

Rockets also are used to guide lightning to earth for research and testing programs, using a modern version of Franklin's famous kite experiment. At the University of Florida's International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, small rockets are launched toward thunderclouds. The rockets trail a thin wire that provides a conductive path for actual lightning currents to follow to the ground where tests can be conducted. Triggered lightning provides much more realistic testing conditions than can be achieved using even the largest laboratory spark generators. Laboratory spark generators mimic either the high voltage or high current present during a lightning discharge, but fail to reproduce both quantities simultaneously, as they occur in real lightning.

These real lightning currents can be injected directly into precise locations on a given test article. Test articles also can be subjected to the indirect electromagnetic effects of lightning, with the distance between the test article and the lightning accurately controlled. The ICLRT is equipped with electric and magnetic field antennas, x-ray and gamma ray detectors, high-frequency and very high-frequency systems, and optical measurement systems to detect and record all aspects of triggered lightning and its interaction with a test article.

Through a research partnership with private industry, the ICLRT is now available for commercial testing. It is being used to test items ranging in size from

Figure 4: Photovoltaic equipment, such as this solar collector array on a municipal building, is typically installed in locations prone to lightning strikes. Courtesy: HLP Systems, Inc.

individual electronic components to full-sized integrated systems and building assemblies that must withstand the worst that nature can send their way. Manufacturers in aviation and aerospace, communications, computers and electronics, military, energy-generation and -transmission, and other critical industries can use the lab to test hardware, control systems, safety protocols, and innovative lightning protection schemes.

Architectural concerns

Many mission critical buildings—police and fire stations, for example—have a public face that requires sensitivity to architectural aesthetics. Conductor cables usually can be installed within a building or its walls; exposed cables can be aligned with the building's lines to minimize any unsightly appearance.

Air terminals installed on the roof of a building are frequently only 10 in. tall and 3/8 to 5/8 in. diameter. They usually have a minor impact on the building's appearance. In situations where appearance is more critical, air terminals can be replaced by structural elements that are at least 3/16-in.-thick electrically continuous metal.

These "strike-termination devices" have proven popular when installed as railings around rooftop terraces where the public may be in close contact with the LPS. In addition to providing increased architectural freedom, strike-termination devices also meet functional demands. For example, the steel framing on an elevated helicopter-landing platform can be connected to the lightning protection system roof network to avoid the need for protruding air terminals.

LPS can also be integrated into rooftop solar arrays and other sustainable design features. At Chicago's O'Hare International Airport, for example, a building housing the Federal Aviation Administration's (FAA) communication and data-processing equipment used an earth-covered green roof to meet the airport's environmental guidelines. Due to the critical nature of the FAA's services, the agency's lightning protection guidelines exceed NFPA standards.

Certifications

LPSs should be designed and installed by specialist firms employing individuals whose qualifications include Lightning Protection Institute certification. Owners of critical structures should also require third-party certification by the Lightning Protection Institute Inspection Program (LPI-IP) or UL Master Label program.

Regardless of the care that goes into designing and installing LPSs, facility managers have to stay alert to anything that could disrupt a system's effectiveness.

For example:

- Air terminals installed on rooftop equipment, such as HVAC units, while equipment is being serviced.
- New equipment installed on the building—such as antennas, light fixtures, cameras, etc.—has to be incorporated into the LPS.
- New signal and power lines penetrating the building envelope will require surge-protection devices.

■ Grounding systems for new equipment require interconnection to the lightning protection ground.

A building's maintenance staff and contractors working on the building should be trained to protect the integrity of the LPS. Industry recommendations call for a visual inspection to be performed annually, with an in-depth inspection and follow-up quality assurance certification or report provided every three to five years. Buildings with critical systems, like hospitals, emergency medical-services facilities, airports, etc., may justify an in-depth inspection every year.

Failure of alternative systems

Recent research has demonstrated that air terminals with blunt tips are more effective than those that are tapered. While tapered points can still be used to match historic styles, the blunt terminals are generally preferred because they also pose less chance of injury to people working on a roof.

Some manufacturers claim their proprietary style of air terminals will prevent lightning or greatly extend the area of protection they provide. These devices are sold under names such as early streamer emission (ESE) air terminals, charge-transfer systems (CTS), or lightning dissipaters.

ESEs have proprietary configurations or contain electrical charging capacitors. These "enhancements" are advertised to provide a larger zone of protection than that of conventional air terminals and permit the use of fewer air terminals, bonds, and grounds. The manufacturers sometimes claim that a single mast-mounted ESE device can protect even large buildings and open areas.

Many peer-reviewed research projects and government studies prove lightning strikes have occurred well within the zone of protection claimed by ESE advocates. In 2005, a U.S. District Court ordered two ESE-device manufacturers to stop making false advertising claims about the radii of protection provided by their products. The court found unrefuted evidence that "the tests on which [ESE manufacturers] base their advertising claims are not sufficiently reliable to establish that [their] air terminal products provide an enhanced zone of protection."

Adding to the confusion, ESE devices are now included in French and Spanish standards that are premised upon evidence that has been repeatedly rejected by the NFPA and other standards-development organizations.

CTSs, also called dissipation systems, are claimed to prevent lightning from occurring in their vicinity. They are fabricated with a large number of small metal points; some look like umbrellas wrapped with barbed wire and others like a dandelion or sea urchin with fine wires radiating from a hub. The metal points are said to leak ions from the earth into the atmosphere, thereby creating a corona that inhibits lightning.

The corona effect can be demonstrated in a lab, but does not protect structures from forces acting under actual meteorological conditions—reinforcing the need to test devices under actual lightning conditions. The FAA, Kennedy Space Center, U.S. Air Force, and other authoritative sources have documented the failure of CTSs.

ESE and CTS devices can function as simple air terminals when used at the same spacings and locations required for conventional air terminals installed pursuant to accepted standards. However, using ESE and CTS devices in this way is impractical because they are sold at many times the cost of conventional air terminals.

Brick-and-mortar buildings

While the need for lightning protection in high-tech manufacturing, research, data processing, telecommunications, and similar fields are obvious candidates for lightning protection, one should not overlook the need for LPSs on buildings in more traditional brick-and-mortar industries.

Distilleries, for example, are at high risk of lightning damage due to the combustibility of spirits. Lightning is considered the cause of a 1996 fire at the Heaven Hill distillery in Kentucky that destroyed almost 5 million gallons of bourbon, 2% of the global inventory. More recently, a 2003 fire at the Jim Beam distillery, also in Kentucky, consumed nearly 1 million gallons and spawned fire tornadoes.

The industry's automated warehouses pose another problem. Their large roof areas provide an exposed target for lightning, and an errant surge from a lightning strike can knock the inventory-management and stock-picking robots offline. ■

Case Study: A Forensic Investigation

A natural gas-fueled power generation plant's cooling unit experienced lightning-related damage more frequently than the other units.

Some buildings and facilities are so complex or have such stringent performance criteria that specialist consultants have to be consulted.

This was the case at a 15-year-old, 1,800-MW, natural gas-fueled power generation plant serving two southern states.

Along with other concerns, one of the plant's cooling units was experiencing significantly more lightning-related damage than the other units. In addition to ordinary risks to buildings and equipment, there was concern about the explosive nature of the tank farm. While damage to-date has been limited to lights, sensors, video monitors in the motor control center, and other individual electronic devices, an investigation was ordered to prevent a major failure.

The investigation included careful inspection and testing of ground resistivity, ground resistance, bonding, stray currents, loop impedances, and motor ground currents and bonding resistance. The consultant found that the cooling units with less damage more closely conformed to lightning protection and grounding standards, evidence that further substantiates best industry practices (see Figure 5).

Figure 5: A forensic analysis of lightning-related problems at a power-generating station found several breaches of accepted lightning protection standards. In addition, the motor ground and lightning protection system (LPS) perimeter conductors on this cooling tower (shown in aerial view) run parallel to each other and are separated by only the wall of a nonconducting fiberglass-cable tray. Cooling units that did not have as many lightning-related problems used a different design. Testing identified stray currents that were likely induced currents resulting from the motor ground and LPS perimeter conductors running parallel to each other in close proximity. Courtesy: Scientific Lightning Solutions LLC

Some of the problems were as obvious as broken connections or lighting poles that had not been connected to the lightning protection system. Other problems required sophisticated analysis of ground loops, electromagnetic shielding, and other phenomena. Many of the problems stemmed from modifications that were made over time, but not properly integrated into the LPS.

The consultant prioritized issues and proposed improvements the plant could make in a gradual manner.

Jennifer Morgan is co-owner of East Coast Lightning Equipment, Inc., a leading producer of lightning protection products. She is also president of Scientific Lightning Solutions LLC, an expert in lightning protection engineering, testing, and surveillance.

Michael Chusid is an architect and authority on building products and systems.

The authors are certified by the Lightning Safety Alliance to provide continuing-education programs.

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EAST COAST LIGHTNING EQUIPMENT INC

info@ecle.biz ■ www.ecle.biz ■ +1 888-680-9462