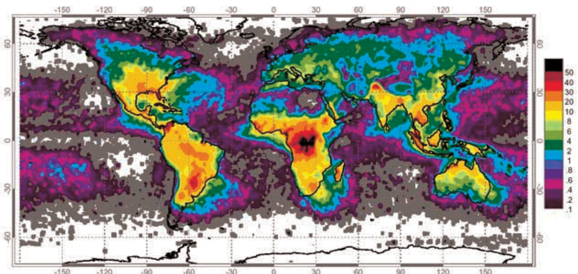
More Than Just Lightning

Part 1 – Protecting Your Plant

by Larry Bloomfield

[FLORENCE, Oregon - January 2004] Lightning is a fact of life! It is more prevalent in some parts of our country than others, but there is no place where it does not occur at one time or another. Like most everything else in life, it is not a case of if, but a case of when. Unfortunately, when that "*when*" happens, most broadcast facilities are ill prepared and lightning often takes out either the most expensive piece of equipment or that device for which you can hardly, if ever, get parts. In fact, installing state-of-the-art equipment in your facility in an environment without proper precautions against damaging transients seems to make little sense.



At any given moment, there are some 1,800 active electrical storms throughout the world, producing 100 lightning flashes per second, or about 8,000,000 lightning flashes per day. Most of us are familiar with the traditional lightning rod that has been around for the past 200 years. Remember Ben Franklin and the kite with the key on it? The lightning rod has come to represent lightning protection. But before we get into lightning and lightning protection, we should review a few fundamentals.

LIGHTNING BASICS

In school we learned there are two kinds of electricity: electrons in motions and electrons (or lack of electrons) at rest. We were taught that approximately 6.24×10^{18} or 6.24 quintillion electrons equals a Coulomb and that one Coulomb per second past a given point is one Ampere of current flow.

We also learned there are certain fundamental things that go into the making of a capacitor – the size of the plates, the distance between the plates and the material filling that space (dielectric). Remember Coulomb's Law? It says: "Like charges repel, unlike charges attract." Following the law of nature which says everything wishes to be electrically balanced, if you try to store too many Coulombs on the plates of the capacitor, irrespective of the kind of dielectric material, you will get an arc.

Furthermore, all electrons have two charges: electromagnetic and electrostatic; so it should not come as any big surprise that when electrons move in the quantities encountered during a lightning strike, those charges are correspondingly large and *very* present. All it takes to generate current flow is a magnetic field, relative motion and material capable of carrying a current.

With the advent of nuclear reactions, it became possible to observe an expanding electric field from a point origin. This field is called the ElectroMotive Pulse (EMP). In electrostatics, the electric intensity is a ratio of the force on a charge at rest to the magnitude of charge. In magnetodynamics the magnetic intensity or induction is the ratio of the force on a moving charge to the product of the charge and the velocity. All lightning is accompanied by an EMP.

CHARGING UP

With respect to lightning itself, as an electrical storm builds, various mechanisms create a stratified charge within the storm cloud, with an electrical charge at the base of the cloud. Since we are concerned primarily with cloud-to-ground lightning, the focus is on the charge on the base of the storm, as that charge induces a "shadow" of opposite charge on the surface of the earth beneath it. Basically, the earth is a giant variable capacitor. If we can reduce any of the parts of the equation that contribute to the buildup of these charges, we can reduce the likelihood of a discharge occurring. Nevertheless, when it does happen, there is a lot going on.

As the storm charge builds, so does the cloud base charge. We know like charges repel and opposite charges attract; the cloud base charge induces an opposite charge on the surface of the earth beneath it, pushing away the same charge and pulling in the opposite charge. The cloud base charge attracts, or pulls, on the ground charge, trying to pull it off the surface of the earth. It is this tendency for the storm base charge and the ground charge to equalize through the intervening air that causes cloud-to-ground lightning.

As the storm cloud travels over the earth's surface, it drags this ground charge along beneath it. When the ground charge reaches your facility, the storm cloud charge pulls it up on, and begins concentrating ground potential on your facility. If, before the storm cloud travels away, it manages to concentrate enough ground potential on your facility so that the difference in potential between the storm cloud base charge and your facility exceeds the dielectric strength, or resistance, of the intervening air, the air breaks down electrically, and a potential equalizing arc occurs – a lightning strike.

Since we are concerned with lightning strikes to objects and structures on the surface of the earth, and some 95% of all ground strikes are negative cloud-to-ground lightning, for the purpose of this discussion we will describe negative cloud-to-ground lightning.

THE STRIKE

When the intervening air breaks down, the strike itself begins with the propagation of stepped leaders. Stepped leaders originate within the cloud charge, and extend in jumps of a hundred and fifty feet or so at a time towards the surface of the earth. These are the wispy, downward reaching branches of light you see in a photograph of a strike.

We actually see a lightning strike in two dimensions as the area of stepped leaders also has depth – so there is a field of stepped leaders working their way down toward the surface. When the stepped leaders reach to within about five hundred feet of the surface, the attraction between the stepped leader charge and the ground charge becomes so strong that objects on the surface of the earth begin to break down, and respond by releasing streamers of ground charge upward toward the stepped leaders. Streamers form off various objects on the surface: utility poles, fence posts, antennas, building edges, etc.

When a streamer and a stepped leader meet, the ionized channel becomes the path for the main lightning discharge. The other stepped leaders and streamers never mature. Occasionally, two or more will meet simultaneously, and forked or branched lightning will occur.

Once the ionized path is completed, the current discharge occurs. Although a lightning strike appears to be a single flash, it is actually a series of flashes. Lightning flashes on for approximately one one-thousandth of a second then shuts off for about two one-hundredths of a second, flashes on for one one-thousandth of a second then shuts off for about two one-hundredths of a second, repeating the process multiple times. When the potential different is no longer sufficient to continue the discharge, the lightning strike ends.

DAMAGE FROM LIGHTNING

There are four basic types of lightning damage: physical damage, secondary effect damage, electromagnetic effect damage and damage caused by changes in ground reference potential.

Physical damage is caused by current flow and heat. For example, a typical lightning strike in the United States conveys between 25,000 and 45,000 amps, with the higher amperage strikes occurring in the South, where the storms build higher. The core temperature of a lightning channel is approximately 50,000° F (27760° C) or about five times the surface temperature of the sun. During a strike, the temperature rises from the ambient temperature very rapidly, expanding in a "shock wave."

This shock wave can damage a structure. Such heat causes the sap in a tree struck by lightning to turn to steam and expand, splitting the tree. Or, when a concrete structure is struck, since concrete never quite dries out (there is always latent moisture), the latent moisture rapidly turns to steam, expands and damages the concrete structure. This is why lightning rods have a minimum length – to lift this shock wave off the roof of the protected structure.

The *secondary effect* of a lightning strike can cause arcing and induced currents. During a lightning strike, the point at which the strike occurs is relatively vacated of ground charge. The area surrounding the point of the strike remains highly charged, causing an almost instantaneous potential gradient across the area. The surrounding area then releases its charge to the point at which the strike occurred, causing a flow of current.

This current flow can arc across any gaps in its path. If that arc takes place within a flammable material, it can cause a fire or explosion. If the arc takes place within a bearing, such as in a pump in a treatment plant, it can scar the bearing and cause premature wear. If it takes place on a circuit board, it can damage the circuit board.

The *electromagnetic field effect* is similar to nuclear blast EMP, and can induce currents in nearby wires or other conductors. The on-off-on-off action of a lightning strike causes the electromagnetic field surrounding the strike to expand and collapse with the series of flashes. This electromagnetic field motion can induce electrical currents in nearby conductors, including wires and electrical equipment.

Finally, when the *ground reference potential* changes across a site, it can cause current flow through grounding systems. Assume the AC power service enters a structure at one location and is grounded there, while telephone service enters the same structure, but is grounded at a different location. Both feed into a computer. The AC power service ground establishes the potential of the motherboard, and the telephone service ground establishes the potential of the modem board. Current divides and takes all paths. The amount of current flowing over any one path is proportionate to the surge impedance of that part vis-à-vis the surge impedance of all paths.

Hence, if lightning strikes near the structure closer to one service ground than the other, a difference in potential occurs between the two grounds. This difference in potential will produce current flow. Most of the current will flow through the ground under the structure (the lower impedance path). However, some current will flow from one service ground, through the modem and computer, to the other service ground. This current flow can damage the computer.

In Part two, we will look at damage caused by lightning from an indirect hit.

Larry Bloomfield has been doing Radio and TV long enough to become the Sagacious Pixel of the Order of the Iron Test Pattern. Check his web site at: www.tech-notes.tv. Larry can be reached at larry@tech-notes.tv

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Protecting Your Plant – Part 2

by Larry Bloomfield

[FLORENCE, Oregon - February 2004] Lightning strikes are considered to be major causes of equipment failure in many broadcast facilities. But, what about damage caused by sources other than a direct lightning strike – in other words, electromagnetic pulses (EMP)?

Recent research has shown that the primary problem associated with lightning current flow over a conductor is not heat. The energy is on the conductor for such a short period of time that heat does not stress the conductor overmuch. The real problem is the electromechanical force of the current flow attempting to straighten a conductor causing physical damage to that conductor.

This is the reason air terminals are constructed of a solid elevation conductor. If an air terminal were to be constructed of multiple wires twisted into a helix, the physical forces associated with lightning current flow along the helix would tend to straighten those wires, possibly compromising the structure of the helix.

Air Terminals

MODERN GEAR, NEW PROBLEMS

The resiliency of today's technology (microprocessors, etc.) to fields and pulses is much different than back in the old days of vacuum tubes and mechanical relays. The move to digital systems and faster components (or transients) of which lightning is the most dramatic, have and will continue to become more of a factor in component reliability and longevity.

Add to this the increase in environmental and man-made transients attacking your equipment, 24-hours a day, and the damage will range from catastrophic failure to minor damage, which eventually accumulates to the point of unreliable or random operation or ultimate failure. There probably are no broadcast facilities today without at least one computer, not to mention all those computer (microprocessor) driven automation systems and other devices.

As our devices operate faster, the problems will become worse. It is not possible to make electricity travel faster. So, in order to make a device operate faster, the distance that the electricity travels must be reduced. As the distances and clearances are reduced, arc-over voltages become lower, exacerbating vulnerability to damage from transients.

SYSTEM DESIGN CONSIDERATIONS

When you or your engineers develop a system, your primary goal is to make it work to further your specific goals. Although the environment in which it will operate is normally addressed, it is usually limited to air conditioning and wire-routing. It is important to optimize the environment to enhance the reliability and longevity of your equipment beyond that.

The folks who deal with lightning abatement approach the situation differently. They are not specifically concerned with what your equipment does; they are specifically concerned with the rest of the environment in which it operates both inside and outside the plant.

Electrical storms and lightning are a year-round phenomenon. The ingredients necessary for the formation of a thunderstorm, irrespective of the time of year, are: moisture, an unstable temperature lapse rate and lifting action. Although electrical storms and lightning are more likely to be present during the traditional thunderstorm season, some of nature's most awesome phenomena are lightning in a snowstorm and lightning during a volcano's eruption.

Lightning prevention system on top of tower.

Lightning rods have been perceived to provide protection from the damage caused by lightning for over 200 years. However, it is important to remember that the purpose of a lightning rod system is to prevent physical damage and to keep the protected structure from burning down, not to protect any equipment inside. Lightning would strike the lightning rod and be conveyed by the conductor system to ground, and the barn would not catch fire. Lightning rod systems are therefore covered by National Fire Protection Association standards.

However, now we have structures with lightning rod systems housing microprocessor-based equipment. Lightning still strikes the lightning rod is conveyed to ground, and the structure still does not burn down, but we cannot say much for what happens to the gear inside – none of the computers work after the strike. That is because, although lightning rod systems are relatively effective at conducting the discharge current and the associated heat away from and around the protected structure to ground, there are other types of damage from a lightning strike: secondary effect damage, damage caused by currents induced by the electromagnetic field effect, and damage caused by changes in ground potential across a site.

While the lightning rod prevents most physical damage, it cannot mitigate these other types of damages.

BEYOND THE LIGHTNING ROD

There are ways of circumventing these kinds of problems: Reduce the potential for any lightning strikes. However, the old Latin saying, "caveat emptor" – let the buyer beware, is very important when it comes to these kinds of approaches and products.

The most successful method of discharging this difference in Coulomb potential is to drain it off. There are three well know ways: (1) the blunt object, (2) the pointed object and (3) multiple fine points or electrodes that resemble a feather duster or chimney sweep brush. This latter approach is called the point radius approach.

1. When the discharge takes place with the blunt object, it is normally quite violent due to the rather large buildup of Coulombs on the surface. This is not acceptable in and around a broadcast environment. It simply directs the lightning to strike a given point.

2. When the discharge takes place with the pointed object, such as a lightning rod, it is normally less violent than the blunt object. Not as many Coulombs can build up on the surface. This is still not usually acceptable in and around a broadcast environment.

3. When the discharge takes place with the multiple fine points (electrodes) resembling a feather duster or chimney sweep brush, a large number of Coulombs cannot built. The potential for an arc is abated while the electrons can steam on or off from a multiplicity of points in their effort to reach electrical equilibrium.

IMPLEMENTATION

Point radius is the property that makes these products work. Electric field intensity is an inverse square relationship to point radius (see white paper on structural lightning protection at www.lightningmaster.com) For example, LightningMaster uses a point size of .008".

Rooftop Installations

The only points which count are those which do useful work. Potential is a function of elevation. It is desired that all the small points break down into a corona around them. This is why the products should be designed so that all of the points, being arranged in a hemisphere, are essentially all at the same elevation and, hence, potential. They all break down into corona at the same time, and therefore, all work together.

Another consideration is point density. Because of inter-point interference, points will not be optimally effective if placed too close to other points. LightningMaster uses the hemisphere approach, which allows the points, being of the same polarity, to repel one another and space themselves optimally. Incidentally, inter-interference is more pronounced with larger radius electrodes.

We first encountered this method of lightning protection that we will be discussing here when we were

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doing the Taste of NAB Road Show last year while in Florida. Florida is quite possibly the lightning capitol of the world. We did see some rather strange appendages on cellular towers, street light-poles, etc, but we really did not give it a second thought.

It was not until we got to WJWB-TV, Jacksonville, FL that we saw the tops of nearly everything at their facility (buildings, towers, Doppler-radar, satellite dishes, etc.) gave rise to porcupines on metal steroids. When questioned, the Chief Engineer told us that he no longer had to put aside large parts of his budget to replace items damaged by lightning hits or near lightning hits.

Lightning Protection on Dishes

Lightning Protection on Dishes: A Closer Look

THE AIR TERMINAL

When LightningMaster, who invented the streamer-delaying air terminal, was issued a patent, manufacturers who wanted to copy these products had to come up with a design they could claim was the same without infringing on the patent. This accounts for the differences in appearance, but these other products are rip-offs and therefore perform differently. It is the difference in performance that is critical to the user. The LightningMaster products are UL Listed as air terminals under UL 96 for the purpose of lightning protection.

As we said earlier, "caveat emptor" – let the buyer beware. The bottle brush products are brushes, manufactured by a brush manufacturer for the purpose of being a brush. The companies offering the bottle brushes in a lightning protection application are marketing companies, not lightning protection component manufacturers. Whose product liability insurance covers these products in the lightning protection application? You might want to check.

LightningMaster uses UL 96A and NFPA 780 as its design standard and as such requires that all of its products be grounded. If these devices are not grounded, you have a very serious and dangerous situation on your hands. It should be noted that if a non-UL approved bottle brush assembly is attached to the top of a UL Listed air terminal; it may void the UL Listing on that air terminal.

In conclusion, lightning protection is not just a lightning rod or other similar device; it is a three-pronged approach: Bonding and Grounding, Transient Voltage Surge Suppression and Structural Lightning Protection. Look at lightning protection as a system whereby you can solve your equipment reliability problems by creating a safe environment in which it may function. Here is a checklist to consider:

1. Have a qualified company perform a survey and analyze your existing environment.

2. Get a written report of findings and recommendations.

3. Design a protection system that includes written specification.

4. Can the supplier manufacture and supply all required parts and equipment?

5. Can the chosen supplier provide a turnkey system installation or supervise the installation by others?

6. Can the chosen supplier provide continuing customer upgrade and warranty support?

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