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There Is No Magic To Lightning Protection: Charge Transfer Systems Do Not Prevent Lightning Strikes

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In its November 2001 issue, *Power Quality* published an article by Donald Zipse, “Prevent Lightning Strikes with Charge Transfer Systems” (referred to as Zipse’s article in this letter), which describes a system which the author claims can prevent lightning strikes. Since the time Benjamin Franklin demonstrated the effectiveness of lightning rods in preventing or greatly reducing the damage from direct lightning strikes, there have been many “magical” lightning protection systems marketed which fail to live up to the fantastic claims of their salesmen. These systems are usually marketed by charismatic salesmen who “verify” their claims with testimonials from satisfied customers, but who have no hard scientific or empirical evidence of the effectiveness of their systems. Such salesmen were vividly portrayed as early as 1856 in Herman Melville’s short story, *The Lightning Rod Man*, and the reputation of these salesmen and their systems often puts lightning protection in the same category as snake oil in the public’s mind.

In recent years there have been two highly marketed “magical” systems — the Charge Transfer System (CTS) described in Zipse’s article, and Early Streamer Emission (ESE) air terminals. CTS’s claim to prevent lightning strikes to a protected area, while ESE systems claim that a single air terminal (another name for a lightning rod) will collect all lightning within an exceptionally large radius (typically 100 meters). When subjected to hard scrutiny, both systems have failed to live up to their claims.

In the early 1970’s NASA was looking for a way to protect the Space Shuttle and other manned vehicles while they were on the launch pad awaiting launch. NASA did an extensive study of CTS’s (then called Dissipation Array Systems, the name of the systems marketed by Lightning Eliminators and Consultants, Inc.). They studied a variety of towers, some equipped with a CTS and others not. The studies found that the frequency of lightning to the towers with CTS’s was not significantly different than to those without CTS’s. In short, the studies demonstrated that a CTS did not prevent or significantly reduce the probability of lightning strikes to a tower. (NASA decided to protect the Space Shuttle with a wire above the Shuttle to act as a preferential strike point for lightning. There are many documented incidences of lightning striking the overhead wire, protecting the Shuttle as designed). Since the NASA studies there have been several other studies done with the same results. Similarly, laboratory and field studies of ESE air terminals, done by several independent research organizations, show that ESE air terminals respond to lightning in the same way, and provide the same zone of protection, as traditional, inexpensive sharp-pointed lightning rods.

The underlying theory of CTS’s described in Zipse’s article is full of scientific nonsense. Most of the descriptions of thunderstorm and lightning phenomenology are wrong (e.g., raindrops carry negligible amounts of charge to ground during a thunderstorm), as is the underlying theory claimed for the basis of CTS’s. The article claims that a CTS will inject several coulombs of positive charge into the air above the protected structure, and that this charge will neutralize an approaching lightning leader. Figure 3 of the article presents the equation for determining the number of points, N , needed to provide this charge:

$$N = \frac{Q}{(I_p)(t)} = \frac{2.5}{(10)17 \times 10^{-5}} = 1.5\text{kpt} \quad (1)$$

where Q is the amount of charge needed to neutralize the leader, I_p is the amount of corona current (often called St. Elmo's fire) emitted by a single point under a thunderstorm, and t is the amount of time needed to accumulate charge Q . The numbers in the formula imply that, in order to provide 2.5 C of charge to neutralize a leader, the system needs 1,500 points which each emit $170 \mu\text{A}$ of current for 10 seconds. This is physically impossible, as the next paragraph demonstrates.

The force which drives the corona current from a point under a thunderstorm is the electrical force from the (commonly) negative charge in the base of a thundercloud. The electric field on the ground from this negative charge is typically 2,000 to 5,000 V/meter. (Fields as strong as 30,000 V/meter have been measured, but fields this strong are rare.) When the electric field under a thunderstorm reaches about 1,000 V/meter, sharp objects start emitting corona current. The charge carriers in corona current are not free electrons which can move rapidly away from the CTS, but are ions, typically ionized oxygen and nitrogen molecules, which drift slowly in atmosphere while colliding with other molecules. The motion of ions in an electric field is well known. These ions move with a speed of about 10 meters/second under the forces induced by the fields near the ground. Thus in 10 seconds the ions can move about 100 meters, so the space charge created by the corona current is confined to a region of about 100 meters above the CTS. Corona current cannot continue after the field is reduced below the 1,000 V/meter needed to initiate it. The maximum amount of space charge which a CTS can emit is the amount needed to reduce the field to 1,000 V/m, the onset field for corona emission. The field from a charge is given by the formula

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^2}. \quad (2)$$

To produce a field of 4,000 V/meter (enough to reduce the 5,000 V/meter field typical under thunderstorms to the corona onset strength of 1,000 V/meter) at a distance of 100 m (the maximum distance the charge could travel in 10 seconds) would require a charge of 4.4×10^{-3} coulombs, almost a thousand times smaller than the charge of 2.5 coulombs claimed to be needed to neutralize a leader.

A CTS cannot produce anywhere near the amount of charge claimed in Zipse's article. However, the simple formula in Equation (1) would indicate that it could. What is wrong with Equation (1)? There are two things wrong — one minor and one major. The minor error is that Eq. (1) indicates that a single point will emit $170 \mu\text{A}$ of current under a thunderstorm. Many measurements have been made on corona currents beneath thunderstorms, and these show typical currents of a few to perhaps $10 \mu\text{A}$. Changing I_p to $10 \mu\text{A}$ in Eq. (1) would change the number of points to 25,000 instead of 1,500, so one would need to build an array with at least 25,000 points, if Eq. (1) were correct. The major problem with Eq. (1) is that it assumes that the current from an array of points is simply the current from a single isolated point multiplied by the number of points in the array. This is simply not the case. As an analogy, consider the water delivered from a system of fire hydrants. During a fire, one or a few hydrants can produce a prodigious flow of water under high pressure. However, if many fire hydrants are open (perhaps opened by kids cooling off on a hot summer day) the flow of water out of a single hydrant is considerably less than the flow when only a few hydrants are active. This is because there are physical constraints (water pressure and size of pipes) which limit the total amount of water which can be delivered through a system of hydrants. Similarly there are physical constraints which limit the amount of current which can be emitted from an array of points. As one point releases positive charge into the air above the array, the field from this positive charge offsets the driving field from the charge in the thundercloud, and reduces the amount of charge emitted by itself and neighboring points. As shown in the calculation in the previous paragraph, in a 10 second time period, an array of points with a dimension of about 100 meters can emit a maximum of 4.4×10^{-3} coulombs of charge, for a total maximum current of 4.4×10^{-4} A. With 1,500 points on an array, this would be a current of $0.3 \mu\text{A}/\text{point}$. With 25,000 points,

the same total current would be emitted, for a per point current of $0.02 \mu\text{A}/\text{point}$.

We have done studies on current emissions from multipoint arrays at the Langmuir Laboratory for Atmospheric Research, New Mexico Tech's mountain-top thunderstorm research laboratory. In our experiments we have found, for example, that an array of 80 points emits a corona current about twice the value of that from a single isolated point. Use of Eq. (1) would indicate the current should be 80 times as large. Eq. (1) is incorrect.

If there are no “magic” lightning protection systems available, is it possible to completely protect a facility from lightning damage? With proper application of traditional lightning protection principles, the answer is an unqualified “Yes”. At Langmuir Laboratory we have been conducting research in a high-lightning environment for the past 35 years. We have a specially-built instrumentation shelter (called Kiva II) which was built to take data during a direct strike to the shelter. Because the probability of natural lightning striking a specific point is low, even in the high lightning density of our mountain-top laboratory, we bring lightning to our instrumentation by triggering it — we shoot a small rocket trailing a grounded wire into an active thunderstorm to do this. On many occasions I, as well as other researchers and observers, have been inside Kiva II when it has been struck by lightning, with the lightning terminating on a current-measuring shunt on the top of Kiva II, about two feet above our heads. Because Kiva II was properly designed to withstand the effects of a direct lightning strike, personnel and instrumentation inside it are perfectly safe during these direct strikes to it.

The principles of traditional lightning protection are basic — 1) provide preferential strikes point for lightning (an array of conductors higher than the objects being protected), a good grounding system, and conductors between the two to conduct the damaging current from a lightning discharge away from the structure to be protected; and 2) provide appropriate transient protection on power and signal wires entering the structure to protect equipment and personnel from the effects of induced lightning currents. What does it take to provide complete protection from lightning? It requires a means to ensure that the currents from a direct strike cannot enter the structure, and electrical transients induced from lightning are prevented from getting into the structure. To prevent the currents from a direct lightning strike from entering Kiva II, it was constructed of 1/4” steel, with only a few openings for signal and power wires to enter. To prevent transients from entering Kiva II, every signal and power wire entering into it are equipped with appropriate transient suppression devices.

It is impractical to build most structures with absolute protection from lightning. The cost to encase a structure in 1/4” steel is usually prohibitive, and a structure without windows is not very pleasant to work in. Also, it is often very difficult to identify and provide adequate transient protection to every conductor entering into a structure. The design of a practical lightning protection system (LPS) usually comes down to a cost-benefit analysis. With higher cost (both monetary costs for providing more preferential strike points and transient protection, and aesthetic costs in the appearance of the building) an LPS can provide greater protection. At some point the incremental cost of the LPS exceeds the incremental benefit received from the added protection.

Traditional lightning protection is based on over 250 years of empirical observations of the effectiveness of the systems (with appropriate modifications to the design of systems from studies of system failures), and over 100 years of scientific research into lightning and lightning protection systems. In the United States, the National Fire Protection Association's *Standard for the Installation of Lightning Protection Systems* (NFPA 780) is the primary standard governing the installation of LPS's. The NFPA issued its first standard on lightning protection, the predecessor to the current NFPA 780, in 1904. Since the issuance of that 1904 standard, there have been numerous updates to NFPA's standard reflecting the developing scien-

tific research into lightning and lightning protection. As stated in Zipse's article, the status of NFPA 780 was up in the air for a while because of series of challenges by manufacturers of ESE air terminals. Because of these challenges, the NFPA Standard's Council had decided to delay publication of a revision to NFPA 780 until it received an adequate substantiation of the scientific basis for traditional lightning protection systems. In response to its request the NFPA received two reports, one from a group of federal government users of LPS's and one from a group of lightning and thunderstorm researchers. After holding a hearing on the matter at its October 2001 meeting, the Council voted to issue the newest revision of NFPA 780, and to continue with its project on lightning protection. The recently released 2001 edition of NFPA 780 contains numerous changes from the 1997 edition reflecting today's rapid pace of research in this area.

While NFPA 780 provides a standard for installation of LPS's to protect a structure from a direct lightning strike, it says little about how to protect sensitive equipment from transients induced by nearby lightning strikes. Information on this topic is readily available from several sources, such as IEEE Standard 1100, *Recommended Practice for Powering and Grounding of Sensitive Electronic Equipment*.

Although CTS's do not prevent lightning they do function as pretty good traditional LPS's. They provide a system of overhead wires which function as preferential strike points (similar to the overhead wire used to protect the Space Shuttle), a good grounding system, and conductors to connect the overhead wires to the grounding system. This probably explains the testimonials from satisfied customers used by CTS manufacturers to market their products. However, LPS's based on NFPA 780 are equally effective in protecting structures, at a fraction of the cost.

In his article, Zipse accuses those of us opposed to CTS's of "relying on obsolete information or refusing to consider a viable technology". No, Mr. Zipse, we are opposed to CTS's because the underlying theory claimed for them is scientific nonsense, and because every independent study of them demonstrates that they do not prevent lightning. Charge Transfer Systems and Early Streamer Emission air terminals are modern incarnations of the "magic" wares peddled by Melville's Lightning Rod Man — ornate devices with no independent evidence that they live up to their fantastic claims, sold by a slick salesman who preys on his customers' fear of lightning and exploits their limited knowledge of lightning protection.