AN ANALYSIS OF ADVANCED LIGHTNING COLLECTION TECHNOLOGY

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Background

Since the days of Dr. Benjamin Franklin, the mid 1700's, the task of protection against direct strikes has undergone a series of controversies. Dr. Franklin invented the pointed lightning rod collector system. Some of his contemporaries held that collecting rods should be blunt. That controversy has continued to this day. Professor Charles Moore issued a recent paper containing a case for the very blunt rod. The USA NFPA-780 Lightning Protection Committee published its most recent standard based on the use of pointed rods. The arguments seem to center around the fact that a sharp point goes into corona, thus becoming "self protecting". This is to explain why rods with sharp points frequently fail to collect incoming strikes. However, there is sufficient data to justify expecting an equal problem with blunt, pointed or rounded collectors.

The most profound proof of the weakness of collector concepts in general is that illustrated by Figure 1. It illustrates a distribution line where a supporting wood pole was struck directly at a point just under the guard wire; and within a few inches of the grounding wire. Neither guard wire nor grounding wire conductor created an attractive streamer before a sliver of wood on the pole did.

NOTE

> Since there is no current flow in a streamer until strike termination, a non-conductor such as wood, stone and even a body of water (a wave) can initiate a streamer and and collect a strike. Photographic history proves this true.

Many standards and code-making agencies, NFPA-USA included, have not responded to the point versus blunt collector rod. Rather, they switched to different protection premise for the collectors. That is, knowing that the cone of protection concept is suspect and many have switched to the Rolling Sphere concept. They claim that the protected volume is within that created by a rolling sphere against the collector and **declaring** that the protected area is limited to that illustrated by Figure 2. The radius of sphere is assumed to be equal to the height of the collector. Figure 2 compares the Cone of Protection/Rolling Sphere concepts formally in vogue.

Neither of these concepts has any foundation in physics; and cannot be vindicated in a valid test program. Recently the USA NFPA-780 Committee was requested to provide test data to prove that what the standards required could be proven accurate. After much debating and rejecting computer studies as no proof, the Committee agreed that there was no such test data that could provide the requested proof.

Many of the lightning rod manufacturers recognized that the existing collectors were marginal at best, and decided to embark on an R & D program to produce a better "Lightning Trap". This has led to the development of a family of Early Streamer Emitters (ESE).

A Review of ESE Concepts

ESE's or Early Streamer Emitters are a class of devices that were designed to function as a more attractive collector. Their basic premise is: the **faster** a streamer is generated, the greater the chance of collecting the incoming lightning leader. There are at least three different basic ESE concepts; the more common concepts are illustrated by Figure 3.

These are:

1. Radioactive Terminals
2. Geometric Configurations (special shapes)
3. Impressed Voltage Concepts

Many of these ESE suppliers make what appear to be wild claims as to the collection capability or range of influence of the ESE. In doing so, they fail to take into account the competitive nature of strike collection. Their test programs seldom include a fair competitive environment. None of the eight ESE manufacturers reviewed by LEC provide any foundational design data that would justify their claims for collection range beyond 10 to 30 meters, even if the competition factor were not considered.

Some comparative tests were conducted by one or two manufacturers wherein the Voltage Pulsing Terminal did produce a streamer earlier than the conventional pointed rod, estimated to be between 10 and 50 microseconds. According to Uman et al, this is equal to between 10 and 30 meters.

Studies conducted by independent, technically qualified scientist conclude that it is "*…physically unreasonable to expect an upward streamer to continue its progress towards the downward leader tip if it is unable to obtain enough energy from the electric field to do so. The condition for obtaining this energy is directly related to the average field between the downward leader tip and the point launching the upward streamer…All streamers [regardless of the source] once they have progressed into the air beyond the launch point, are subject to the same laws governing their progress. It follows that the striking distance is a direct consequence of these laws and the properties of the air and* ***is independent of the nature of the air terminal launching the streamer."***

Further, they show that "*during the close approach of the downward leader, all prominent conducting earthed objects on the top of a building will be in a high ambient electric field environment and there will be local electric field enhancement [*around all the objects within the leader's influence]. *Consequently, these objects will be emitting ions in corona discharges sufficient to prevent the local field adjacent to the objects from rising above the dielectric breakdown field for air, about 3 MV/m."* This is the forgotten competitive environment factor.

CIGRE (a French working group) states that they cannot support the use of any early streamer emitters based on **the fact** that:

"The theoretical basis for the Early Streamer Emission technology appears technically incorrect for the following reasons:

1. Even if a streamer from a non-conventional terminal can be initiated at an earlier time than a streamer from a conventional air terminal, once initiated it will require the same field strength to propagate as a leader from a conventional terminal

2. The assumed constant velocity of 1,000,000 m/s for the upward leader propagation is in contradiction with the available data for both natural lightning and long laboratory sparks, which show an average velocity of one order of magnitude lower."

Please note that the foregoing data are **based on the physics** of the problem; and therefore stand in opposition to the ESE manufacturer claims.

In conclusion, it can be said that some ESE's could generate a limited early stream; however, it appears to be inconsequential in a competitive environment. Further, the ESE concept that is generating an "early" streamer is of questionable value because of the potential competition factors. Therefore, the question to be addressed is "What can be done to produce an efficient collector, that can be related to the physics of the problem and will permit an empirical derivation of the collective range **in a competitive environment?**

The Physics of Collection

To accomplish the collection of an incoming lightning discharge, there must be some form of attraction between the collector and the incoming lightning leader. In reviewing the physics of the discharge process and termination mechanics, it becomes obvious that there are two forms of attractive forces that will influence the path of the lightning leader. These are:

1. The attractive force of Unlike Charges as defined by Coulombs Law.

2. The difference of potential created by the electrostatic field preceding the lightning leader as it approaches earth.

First, consider Coulombs Law. It is known and easily proven that "unlike Charges Attract." The incoming leader is usually negative and the earth beneath is charge positively; as are all facilities resting on it. Coulomb defines the Attractive Force (F) between two unlike charged bodies as:

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_O d^2}, \ [kfg]$$

where: Q_1 is the leader charge, [c]

Q_2 is the collector charge, [c]

d is the distance between the two charge centers, [m]

$$4\pi\varepsilon_0 = \frac{1}{9 \times 10^9}, \ \left[\frac{F}{m}\right]$$

$$\text{Therefore} \quad F = \frac{Q_1 Q_2}{d^2} \ 9 \times 10^9$$

According to Uman, the average size of the charge contained within a streamer, rising from an earth-bound facility has been found to be about 10^{-4} Coulombs. This is independent of the source of the streamer (from earth); but representative of that produced by any Franklin Rod or ESE.

The charge contained in an incoming lightning leader can be up to 5 Coulombs; however it has been estimated that the effective charge in that portion of the leader will influence an earth-bound charge may be assumed to be approximately 1 Coulomb. The actual value is not relevant when a comparative analysis of potential collectors is made in a competitive situation since all in the potential strike zone are influenced by the same charge.

The key to successful collection in a competitive environment, is to provide a most competitive collector. Since one point produces only 10^{-4} Coulombs, it would seem that 100 points should produce 10^{-2} Coulombs when they are properly integrated into the 100 point collector. The LEC Ion Plasma Generator (IPG) as illustrated to in Figure 4 is just such a collector. The LEC-IPG has been designed to optimize and maximize the collection capability by creating a dense positive "space charge" in the presence of and acting on the incoming negative leader.

Using a 100-point IPG set at 20 meters above the earth, and comparing it with the single point rod as illustrated by Figure 5, the related forces can be calculated and the collection radius for the IPG can be estimated by determining the distance (d_2) from the IPG, toward the single point where the attractive forces on the lightning leader are equal. Since some form of point source is the only potential competitor in any competitive situation, this distance (d_2), where the forces are equal, may be considered as the maximum collection radius of that IPG. That is, at that position F_1 would equal F_2, and $Q_{IPG} = NQ_P$. Where N equals the number of points, 100 for this example and Q_{IPG} is the charge produced by the IPG.

$$F_1 = \frac{Q_L Q_P}{d^2 \ 4\pi\varepsilon_O \left[(H-h)^2 + d_1^2\right]} \quad ; \quad F_2 = \frac{Q_L Q_{IPG}}{4\pi\varepsilon_O \left[(H-h)^2 + d_2^2\right]}$$

Since $F_1 = F_2$ at the IPG limit

$$\frac{1}{\left[(H-h)^2 + d_{12}^2\right]} = \frac{N}{\left[(H-h)^2 + d_2\right]}$$

If $H >> d_1$ $$d_2 = d_1\sqrt{N}$$

From this example, (N = 100), the collective distance d_2 is: $$d_2 = d_1\sqrt{100} = 10\ d_1$$

Now Consider the Electrostatic Fields Influences for a Single Rod

Figure 6 illustrates the theoretical collection zone of a single lightning rod, based on the striking distance estimates, again offered by Uman et al. That is $d_s = 10\ I^{0.65}$.

Where I = peak lightning current (kA), in the resulting return stroke.

The protected radius at ground level (r_1) is therefore equal to:

$$r_1 = \sqrt{d_s^2 - (d_s - h_1)^2} \quad \text{or} \quad \sqrt{h_1(2\ d_s - h_1)}$$

For the Ion Plasma Generator

As shown in Figure 7, considering the situation where the heights (h_1 and h_2) are the same and the electrostatic fields $\left(E_{F_1} \text{ and } E_{F_2}\right)$ are the same. The collection radii can be estimated for both under like conditions at any time during the leader decent. The only difference between the two situations is the significant space charge produced by the IPG and its influence on the local electrostatic field (E_2).

The Electric Field produced by the rod (E_1) is:

$$E_1 = \frac{2q_1 h_1}{4\pi\varepsilon_O\left(h_1^2 + r_1^2\right)^{3/2}}$$

The Electric Field produced by the IPG (E_2) is:

$$E_2 = \frac{2q_2\ h_2}{4\pi\varepsilon_O\left(h_2^2 + r_2^2\right)^{3/2}}$$

where h_1 and h_2 are equal, and $q_2 = N\ q_1$

substituting $h(2d_1 - h)$ for r_1^2

$$r_2 = \sqrt{h\left[\left(2d_1\ N^{2/3}\right) - h\right]}$$

and

$$\frac{r_2}{r_1} = \sqrt{\frac{\left(2d_1 \ N^{2/3}\right) - h}{2d_1 - h}}$$

When $d_1 >> h$ is the ratio of the collective distance can be approximated as:

$$\frac{r_2}{r_1} \cong \sqrt[3]{N}$$

Conclusions

At this point, the conclusions should be obvious:

1. Rods that are sharp, blunt or rounded are of limited effectiveness.

2. An effective collector must be **the most competitive** collector.

3. The most effective collector must produce some form of attractive force that is significantly better than a single streamer.

4. ESE's produce streamers as do rods of various shapes. Only one concept seems to produce a streamer faster than conventional collectors, and that is limited to approximately a few microseconds in advance of a single point; but reaches out to no more than 10-80 meters.

5. All prior art has been offered without scientific rigor. That is, the design cannot be derived empirically from basic physics.

6. The LEC-IPG is the only concept collector that has proven to be effective out to at least 100 meters in a competitive environment; and it is the only one that can be related to the physics of the problem.

The foregoing deals with scientific factors. However, it is recognized that politics will influence the selection for some time to come.

Stroke Physical Damage

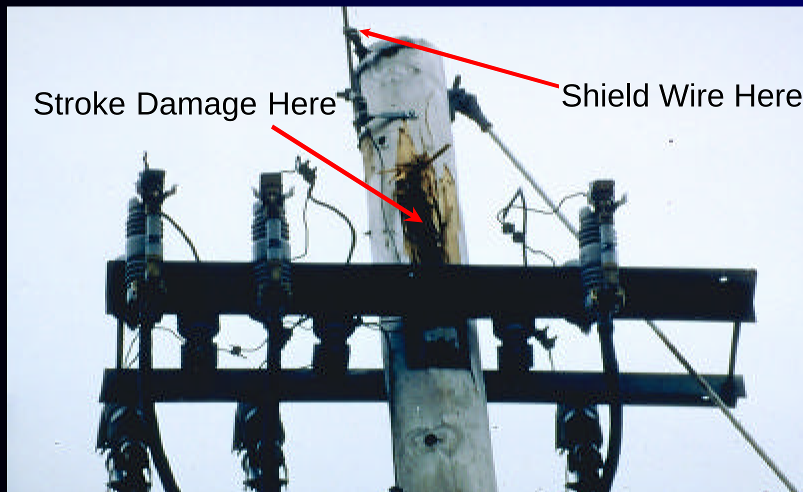
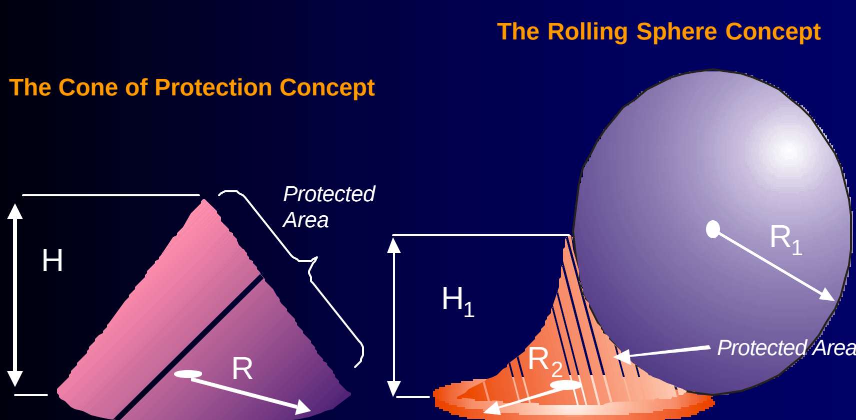


Figure 1

Air Terminal Concepts

(not technology)



Where: R=H; Angle=45 Degrees
Cone of Protection (Collection)
About 90% Effective if H= < 100 M

Where: $H^1=R^2$
About 95% + Collection

Figure 2

ESEs’

Types

- *Sparking*
- *Pulsing*
- *Radioactive*
- *Corona Suppression*

Problems

- *No Test Data*
- *Unreasonable Claims*

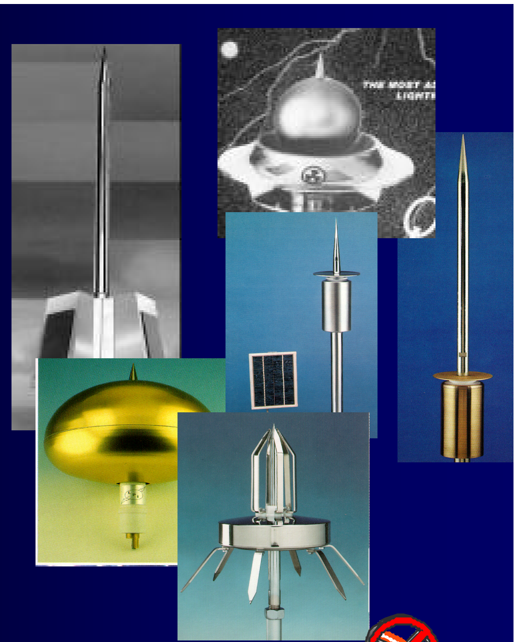
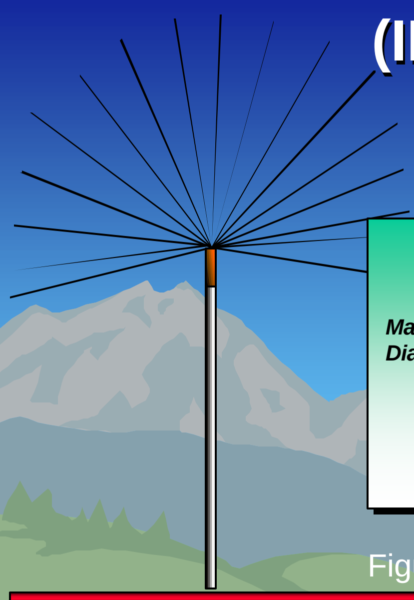


Figure 3

The Ion Plasma Generator (IPG)



IPG DATA

Material	*316 Stainless*
Diameter	*4’ Or As Required*

Collects Most Lightning Current With No significant damage

Shaft Extensions Available

Figure 4

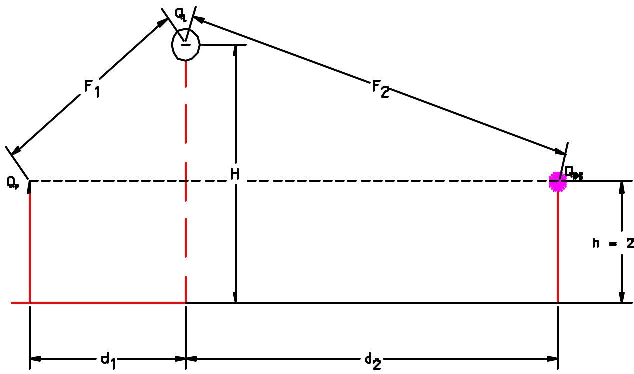


FIGURE 5: THE COMPETITION FACTOR IPG VS SINGLE POINT ROD BASED ON COULOMBS LAW

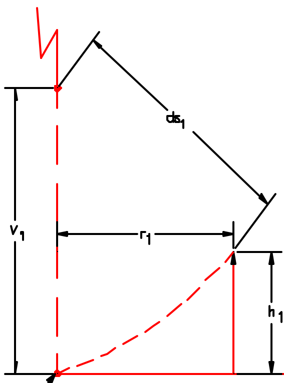


FIGURE 6

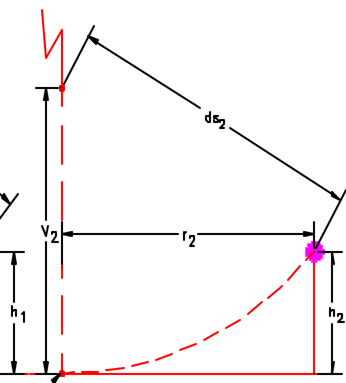


FIGURE 7

NOTES
$E_f = E_{f2}$
$h_1 = h_2$

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DRAWING NO.
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