Lightning Interception
Non Conventional Lightning Protection Systems

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Non conventional lightning protection systems

The external lightning protection systems used by engineers in different countries can be divided into two categories, namely, conventional and non-conventional lightning protection systems. The conventional systems use Franklin rods. Many decades of experience shows that by combining Franklin rods located at critical points on a structure with a proper down conductor and grounding system the damage due to lightning could be reduced significantly [1]. The Early Streamer Emission rods and Dissipation Arrays (sometimes called Charge Transfer Systems) belong to the category of non conventional lightning protection systems. The latter systems have been introduced into several lightning protection standards without testing them over the same long period of time in the field as done for conventional ones to assess and validate their performances. In this note we will summarize the results of studies pertinent to these systems as reported in the scientific literature.

The Early Streamer Emission (ESE) concept

The ESE terminals used in practice are equipped with a discharge triggering device to initiate streamers from the terminal in an attempt to increase the probability of inception of a connecting leader from the terminal during the approach of a downward lightning leader [2 ,3]. According to the proponents of ESE the time advantage realized by the early inception of the connecting leader from a ESE terminal in comparison to a normal Franklin rod would provide a possibility for the connecting leader generated by an ESE terminal to travel a longer distance in comparison to that from a Franklin rod. Consequently, it is claimed that under similar circumstances an ESE terminal will have a larger protection area than a Franklin rod of similar dimensions. However, recent experimental and theoretical investigations find results that are in conflict with the claimed performance of ESE devices [4].

Experimental data that are in conflict with the concept of ESE

Case studies conducted by Hartono et al. [5] in Malaysia, provide clear evidence that lightning do bypass the ESE terminals and strike the protected structures well within the claimed protective region of the ESE devices. The same study showed that no damages were observed at the corners of structures equipped with Franklin rods installed according to the international lightning protection standard to cover the vulnerable points such as edges or corners of the structure. However, in structures where Franklin rods were installed without consideration of these high risk interception points, lightning strikes have been observed at these points.

In another study conducted in New Mexico [6], ESE lightning rods were allowed to compete with symmetrically spaced Franklin rods to validate the enhanced attractive zone of ESE devices claimed by its proponents. If, as claimed, ESE rods can initiate an upward leader before the Franklin rods and if they have a larger attractive zone, one would expect ESE rods to be the preferential point of attachment of the lightning strikes. However, according to the observations all the lightning strikes got attached to Franklin conductors and not a single one terminated on the ESE devices. It is worth mentioning that among Franklin conductors only those with blunt rods were struck by lightning, while those with sharp rods were not struck. This experiment represent an additional indication that the ESE terminals do not have an advantage over the Franklin rods and the claimed enhanced protective range does not exist.

Proponents of ESE sometimes refer to an experiment conducted in France using triggered lightning [7] to support the action of ESE terminals. In this experiment an ESE terminal was put in competition with a Franklin rod to get attached to a down coming leader created in an altitude triggered lightning experiment. The downward moving leader got attached to the ESE terminal and the proponents of ESE claim that this proves the superior action of ESE terminals in comparison to Franklin rods. However, it is important to note that in the experiment the ESE terminal was located closer to the rocket launcher than the conventional one. The reason for the attachment of the lightning flash to the ESE rod could simply be due to the spatial advantage it had with respect to the conventional rod. Unfortunately, the positions of the rods were not interchanged to validate the claimed enhanced attractive range of the ESE terminal. Thus, one has to conclude that this experiment does not provide evidence for the claimed superiority of the ESE terminals against the conventional ones.

Theoretical evidence that are in conflict with the concept of ESE

The whole concept of ESE is based on the observed fact that by artificial triggering of streamers from the tip of a lightning terminal (i.e. ESE rod) stressed by a switching impulse, one can cause the terminal to initiate a leader earlier than from a lightning terminal placed under identical circumstances but without the action of artificial streamers (i.e. Franklin rod) [2]. In the laboratory, it was found that the time advantage (i.e. the time interval between the initiation of leaders from ESE and Franklin rods), Δt of an ESE terminal is about 75 µs. Proponents of ESE terminals have taken this laboratory observation and extended it to natural conditions claiming that a 75 µs advantage will give rise to a length advantage equal to the product $v\,\Delta t$ where v is the speed of the upward moving leader. Assuming a leader speed of 10^6 m/s ESE proponents claim that an ESE terminal would have a length advantage of about 75 m over a conventional rod. Thus, the following two conditions have to be satisfied for the ESE devices to function according to their specifications:

1) The early initiation of leaders from ESE terminals observed in the laboratory takes place also under natural conditions. In other words, an ESE terminal can launch a connecting leader long before a conventional rod under natural conditions.
2) The time advantage observed will translate to a length advantage of $v\,\Delta t$ over a conventional terminal.

Let us first assume that a time advantage exists in ESE devices when exposed to lightning-generated electric fields. This time advantage was converted to a length advantage of about 75 m over a conventional rod by assuming a leader speed of about 10^6 m/s. The majority of speeds of upward connecting leaders reported in the literature is from those in either rocket triggered lightning or from those in upward initiated lightning flashes. In these cases the upward connecting leader moves in a more or less static background electric field created by thunderclouds. These leader speeds are not relevant to the study under consideration. Yokoyama et al. [8] managed to measure the speeds of upward connecting leaders initiated from an 80 m tall tower as a result of the electric field generated by downward moving leaders. In four examples analyzed in the study they found that the connecting leader speeds just before the connection is made between them and the downward moving leaders were 1.3 x 10^6 m/s, 1.4 x 10^6 m/s, 2.9 x 10^6 m/s and 0.5 x 10^6 m/s. These speeds are similar to the one used by ESE manufactures in calculating the striking distance. However, it is not correct to use these speeds in the analysis of ESE terminals because what is required to calculate the length of the connecting leader given the time advantage is the average speed of the •••

connecting leader. The average speed of connecting leaders measured by Yokoyama et al. [8] varied from 0.8 x 10^5 m/s to 2.7x10^5 m/s. This average speed is an order of magnitude less than the one used by ESE manufactures. Moreover, the connecting leaders photographed in the study originated from an 80 m tall structure. In general, the connecting leaders issued from tall structures are relatively longer than the ones issued by short structures during lightning interception. Long leaders have ample time to thermalize their channel and this makes them move faster than short connecting leaders. If this experimentally observed value of average leader speed is used in the conversion of time advantage to distance, the resulting length advantage would be of no use in many practical situations. Second, this conversion of time advantage to a length advantage is not correct because the eventual length advantage depends on the ratio of the speeds of both downward and upward leaders. If this is taken into account the assumed length advantage will be less than the value calculated by just multiplying Δt by the speed of the leader. Third, according to the proponents of ESE the earlier initiation of a connecting leader from an ESE device occurs in a smaller electric field than is required for the initiation of a leader by a conventional rod. However, for a successful propagation of a connecting leader a certain background electric field is needed. If the background electric field is not large enough the initiated leader could be aborted [9]. The proponents of the ESE do not consider the requirements for the propagation of a leader and they do not consider the possibility that the initiated leaders could be aborted if the background electric field requirements are not met.

Now, we come back to the first assumption. Recently, Becerra and Cooray [10] constructed a model incorporating the physics of the attachment process to simulate lightning attachment to structures. This model has been validated using data from altitude triggered lightning [11]. Since the current measured at the base of the trigger wire showed the occurrence of several aborted streamer leader inceptions, in the validation of the model the space charge left behind by these unsuccessful leader inceptions (precursors) were taken into account. It is worth mentioning that the effect of corona generated by the trigger wire on the inception of leaders from its tip – disregarded in a first approximation in [10] – was the subject of a recent investigation [12]. Using their model Becerra and Cooray [9] have simulated the initiation and development of positive leaders under the influence of time varying electric fields used in laboratory as well as the time varying electric fields generated at ground level by the descent of the downward leaders. Their results show that indeed one can obtain a time advantage in the laboratory but also they show that such a time advantage will be practically negligible when the rods are exposed to the background electric fields of leaders. As shown in Figure 1, in order to change the striking distance significantly, ESE rods have to be supplied with Mega-volt strong generators.

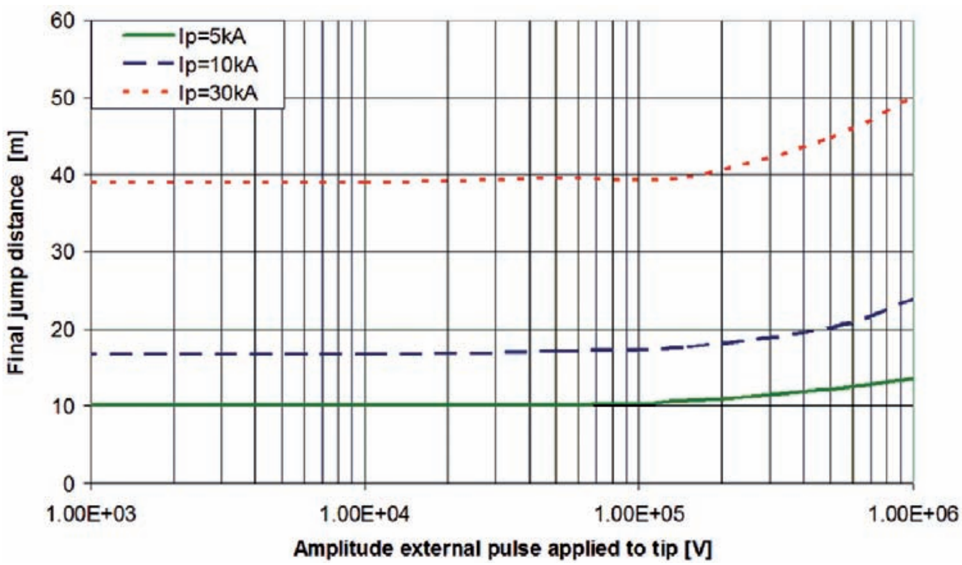

Figure 1: Distance between the downward leader tip and the ESE rod at the moment of connection between the connecting leader and the down-coming stepped leader as a function of the voltage impulse applied to the ESE rod. Calculations are given for three prospective return stroke currents

The concept of dissipation array systems and mounting scientific evidence against their principle of operation

The original idea of lightning eliminators or dissipation arrays is to utilize the space charge generated by one or several grounded arrays of sharp points to "dissipate" (i.e. neutralize) the charge in thunderclouds and thus prevent lightning strikes to a structure to be protected. The proponents of this system claimed that the space charge generated by the array will silently discharge the thundercloud. The following argument shows that this indeed is not the case. The mobility of small ions at ground level is about (1 – 2) x 10^{-4} m^2 V^{-1} s^{-1} [13] and in the background electric fields of 10 – 50 kV/m the drift velocity of these ions may reach 1 to 10 m/s. Even if the array can generate charge of sufficient quantities to neutralise the cloud charge, in the time of regeneration of charge between lightning flashes in the thundercloud of about 10 s the space charge can move only a distance of about 10 to 100 m. Thus, the space charge would not be able to reach the cloud in time to prevent the occurrence of lightning. Facing this challenging and convincing opposition from lightning researchers the proponents of lightning eliminators accepted that the arrays are not capable of neutralizing the cloud charge [14]. In turn they suggested that the function of the dissipation array is to neutralize the charge on the down coming stepped leaders.

Now, a typical stepped leader may bring down about 5 C of charge to ground and the dissipation array has to generate this charge in about 10 s, the time interval between lightning flashes. The proponents of dissipation arrays made the following argument to show the effectiveness of the array in generating sufficient quantity of charge to neutralize the stepped leader [14]. According to Zipse [14] a 12 point array (four sets of three points) located on a 20 m pole can produce about 1 - 2 mA as the storm sets in (no details as to how these measurements were carried out are given in the paper). Thus, a typical array with 4000 points can inject a charge comparable to that of a stepped leader in about 10 s, the time interval between lightning strikes. Firstly, the proponents of dissipation arrays do not explain the physics behind this claimed neutralization process. For example, since the charge generated by the array is distributed in space the stepped leader has to move into this space charge region before it could be neutralized. Recall that the bulk of this space charge is located in the near vicinity of the dissipation array. If the stepped leader channel, which is at a potential of 50 to 100 MV, moves into this space charge region, a critical potential gradient of about 500 kV/m could easily be established between the stepped leader and the dissipation array (which is at ground potential) leading to an imminent lightning strike. Secondly, in making the above claim proponents of dissipation arrays have assumed that the current generated by a multi point array is equal to the current generated by a single point multiplied by the number of points. Cooray and Zitnik [15] conducted experiments to investigate how the corona currents produced by an array of sharp points or needles vary as a function of number of needles in the array. The experimental setup consists of a parallel plate gap of length 0,3 m with 1.0 m diameter, Rogowski profiled electrodes. The bottom electrode of the gap was prepared in such a way that a cluster of needles can be fixed onto it. The needles used in the experiment were pointed, 2 cm long and 1 mm in diameter. The needles were arranged at the corners of 2 x 2 cm adjacent squares. A constant voltage was applied to the electrode gap and the corona current generated by the needles is measured as a function of the background electric field and the number of needles in the cluster using a micro ammeter. The lower limit of the corona current that could be measured in the experiment was about 1 μA. The results obtained are shown in Figure 2. Observe first that the corona current increases with increasing electric field and for a given electric field the corona current increases with increasing number of needles. Note, however, that for a given electric field the corona current does not increase linearly with the number of needles. Even though the conditions under which dissipation arrays are supposed to be working are different to the conditions under which this laboratory experiment was conducted, this experiment clearly demonstrates that the corona current does not increase linearly with increasing number of needles. The reason for this could be the screening of one needle from the other in a multiple needle array.

More recently, proponents of the dissipation arrays claimed that the dissipation arrays work by suppressing the initiation of upward leaders by screening the top of the structure by space charge. This claim was based on the study conducted by Aleksandrov et al. [16]. In that study Aleksandrov et al. showed that the electric field redistribution due to space charge released by corona discharges near the top of a high object hinders the initiation and development of an upward leader ●●●

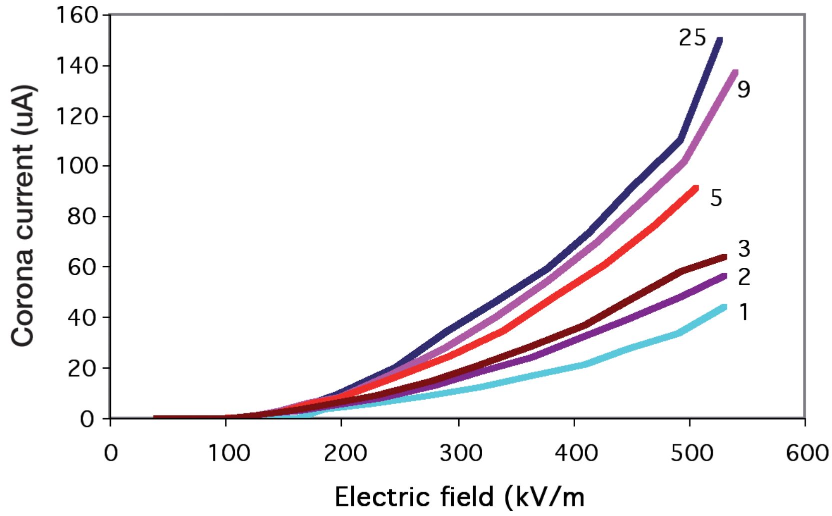

Figure 2: The corona current as a function of the background electric field from clusters of needles. The number of needles in the cluster is shown in the diagram.

from an object in a thunderstorm electric field. It is important to recognize, however, that the corona charge issued from the terminal would not screen the sides of the terminal or the tower. Thus, as the stepped leader approaches the dissipation array a connecting leader could be issued from the sides of the terminal which is not screened by the space charge. The main question is whether the space charge from the needles can counter balance the increase in the electric field caused by the down coming stepped leader at the tip of the structure to such an extent that the formation of a connecting leader is inhibited. Calculations done in [15] show that a tower without the space charge produced by the needles will launch a connecting leader before a tower with similar geometry but with space charge, generated during the descent of the leader, at the tower top. However, the space charge controlled field does not lag far behind the field that would be present in the absence of the space charge. For example, the difference in the stepped leader tip height from the tower top when the electric field at the tower top is large enough to launch a connecting leader in the presence and in the absence of space charge is no more than two meters [16]. This study indicates that the reduction in the striking distance caused by the space charge may not be more than a few meters.

In addition to the above points, there are several well documented cases in which lightning has been observed to strike dissipation arrays. The best procedure to conduct such a study is to compare two similar structures, one with a CTS and the other without. Several such studies have been conducted [17, 18, 19, 20]. All the studies show that CTS systems were struck by lightning as well as the control structure. No reduction in the frequency of lightning strikes to structures has been observed.

The proponents of dissipation arrays claim that according to the anecdotal evidence of the users there is a reduction in the cases of lightning damage after the installation of arrays. However, this does not necessarily mean that the array has prevented any lightning strikes. First, since the array is well grounded, it provides a preferential path for the lightning current to go to ground. This it self will reduce the damage due to lightning strikes even if it does not prevent a lightning strike. Second, as suggested by Golde [21], the connection of an umbrella shaped array at the top of a tower will increase the radius of curvature of its tip and inhibit the upward initiated lightning flashes by reducing the field enhancing effect of the tip. This may lead to a reduction in the number of upward initiated flashes from the tower. But, as noted by Mousa [22], upward initiated flashes are of interest in the case of towers of effective heights larger than about 300 m or more. The dissipation arrays will not have any effect on the number of lightning strikes to smaller structures.

Conclusions

Both theory and experiments show that (i) ESE principle, namely that the ESE rods have longer striking distances than conventional Franklin rods, does not work under natural field conditions and there is no justification at present to assume that the ESE rods perform better than Franklin rods and (ii) the dissipation arrays cannot dissipate an imminent lightning flash either to the protected structure or to the terminal itself.

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