Anti CVM/FIM

VALIDITY OF THE COLLECTION VOLUME METHOD/ FIELD INTENSIFICATION METHOD FOR THE PLACEMENT OF LIGHTNING RODS ON BUILDINGS

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Abstract: Because of their much higher unit prices, the commercial viability of Early Streamer Emission (ESE) lightning rods rests on accepting a drastic reduction in the number of air terminals compared to that required by the electrogeometric model (EGM) and its derivative simpler method known as the Rolling Sphere Method (RSM). After collapse of the claim that this can be done on the grounds that an ESE rod has a much larger protective range than a Franklin rod, attempts are being made to accomplish the same objective by advancing a lightning rod placement method known as the Collection Volume Method (CVM)/Field Intensification Method (FIM). The CVM is based on work done by A.J. Eriksson during the 1970's. This paper shows that Eriksson's method is flawed, and that the revision made to it to create the CVM/FIM is also flawed.

Keywords: Lightning Protection of Buildings, Collection Volume Method, Field Intensification Method, Striking Distance, Early Streamer Emission Lightning Rods.

1. INTRODUCTION

Because of their much higher unit prices, the commercial viability of Early Streamer Emission (ESE) lightning rods rests on accepting a drastic reduction in the number of air terminals compared to that required by the electrogeometric model (EGM) and its derivative simpler method known as the Rolling Sphere Method (RSM). As an example of such reduction, an exhibit in [29] by Surtees shows one "Dynasphere" as replacing 15 Franklin rods.

After collapse of the claim that this can be done on the grounds that an ESE rod has a much larger protective range than a Franklin rod, attempts are being made to accomplish the same objective by advancing a lightning rod placement method known as the Collection Volume Method (CVM)/Field Intensification Method (FIM).

The CVM was developed by Eriksson [14], mainly for tall masts, but he also applied it to transmission lines. Eriksson assumes the "final jump" (last step of the downward leader) to occur when the electric field at the tip of the structure "E" reaches 3000kV/m (30 kV/cm). The field E is assumed to be the product of the unperturbed value that would exist in the absence of the structure "E_0" and a factor K_i described as "field enhancement factor", or "field intensification factor", representing the effect of the structure on the electric field [13]. For tall towers, Eriksson took K_i to be a function of the ratio of height to cylindrical radius; the radius being made equal to the "critical corona radius" if less than that value [5]. As an example of Eriksson's estimates, he took K_i to be equal to 60 for his 60-m mast [3]. This means that the final jump would occur when the unperturbed field E_0 reaches just 50 kV/m (0.5 kV/cm).

The use of exaggerated field intensification factors in the CVM, and in any other method derived therefrom, is the trick by which a drastic reduction in the number of air terminals can be made to appear to be justified. For the high values of K_i imply that striking distance conditions would be reached when the downward leader is still far away rom the tip of the air terminal, either vertically or to the side of it. This in turn makes the protective radius appear to be much larger than it really is.

Gumley appears to have been the first to realize the potential benefit of the CVM to the promotion of his Dynashpere, which was then being offered as an ESE device. Hence he worked on applying it to buildings and to 3-D objects. Documentation to that effect existed on the web site of Global Lightning Technologies (GLT) until at least October 1997. After GLT was sold to ERICO, D'Alessandro [8, 9, 10] joined Gumley in that work. The Gumley-ERICO method is referred to as CVM, modified CVM, or FIM.

This paper shows that Eriksson's model is flawed, and that the revision made to it to create the CVM/FIM is also flawed. Comments are also given regarding the data and procedure by which the CVM/FIM is claimed to have been validated [11].

2. THE FLAWS IN ERIKSSON"S CVM

2.1 General

The main flaws in Eriksson's model are:

1. The attainment of a 3000 kV/m gradient at the tip of the structure is not a sufficient condition for the final jump to occur.
2. His estimates of the field intensification factors are invalid.
3. His calculation of the unperturbed field gives exaggerated values as it ignores the masking effect of the pockets of space charge that randomly exist in the space between base of the cloud and surface of the ground.

Each of the above three factors has the effect of inflating the striking distance, especially where effect of height of the structure is concerned. As a result, Eriksson's method grossly exaggerates both the striking distance and the protective radius of an air terminal. This fact manifests itself as follows:

4. Eriksson's estimates of the striking distance far exceed the measured values, and,
5. Eriksson's results are not in agreement with laboratory data regarding flashover of air gaps.

2.2 Conditions for the Final Jump

The inadequacy of Eriksson's criterion was pointed out by the CIGRE Task Force [6] when they stated on p. 68: ".. the criterion of leader inception based on the critical radius concept seems to be insufficient to ensure a stable progression of the upwards leader until the interception with the downward stepped leader."

When Golde [15] did his pioneering work in calculating the striking distance, he adopted the criterion that an average gradient across the gap of 500 kV/m was necessary for the final jump to occur. It is interesting that Rizk [27] similarly took 500 kV/m to be the average gradient needed across the final jump between the tips of the upward and downward leaders. Young et al. [33] were close to the above as they assumed the average gradient across the final jump to be in the range 550-600 kV/m.

Let us now compare the above values to the average gradients across the final jump that are implied in Eriksson's method. Toward that end, we need to estimate the voltage of the downward leader as a function of the current, calculate Eriksson's striking distances for the same currents, then divide these two quantities to arrive at the average gradient.

Equation (1) hereafter gives the relation between voltage of the stroke U (kV) and its velocity v in per unit of the velocity of light. This was developed by Wagner [32] and it was adopted by Young et al. [33]:

$$U = 1.2X10^5\ v/(1 - 2.2\ v^2) \qquad ....(1)$$

Next, we need a correlation between velocity of the return stroke and its current. This requires: a) defining a frequency distribution for stroke velocities. This was available from recent work by an IEEE Task force [22], and it was compiled from measurements from four different sources. b) defining a frequency distribution of stroke amplitudes to ground, and, c) assuming a single-valued relation between the stroke current and the velocity. This way, any two values of I and v that give the same cumulative probability would correspond to one another.

Eriksson et al. [4] suggested that the median stroke amplitude to flat ground should be about 30 kA. The analysis by Mousa et al. [25], on the other hand, indicated that 24 kA was a more appropriate value. Recently, a revised estimate from the statistics of the North American Lightning Detection Network (NALDN) gave a value of 23 kA [31]. This is basically identical to Mousa's estimate, especially when the limitations of the indirect measurement method of NALDN are taken into consideration. It is interesting that Rizk [28], using a different approach, also estimated the median current to flat ground to be about 23 kA.

Using a median current of 24 kA, together with the stroke velocity data of the IEEE [22], a graph correlating current and velocity was developed. From this and Eq. (1), the velocities and stroke voltages for currents in the range 10-80 kA were found to be as shown in columns 2 and 3 of Table I, respectively.

For structure heights in the range 10-100 m, Eriksson's method [13] gives the following equation for the attractive radius:

$$Ra = 0.84\ H^{0.6}\ I^{0.74} \qquad .... (2)$$

Let us take H = 100 m as an example. Eq. (2) then becomes:

$$Ra = 13.31\ I^{0.74} \qquad .... (3)$$

In the general construction of the EGM, the attractive radius is the horizontal component of the striking distance (S), and hence Ra is smaller than S. In the example used by Eriksson et al. [3], they assumed the line between tip of the downward leader and top of the structure to have an inclination of 45°. If we use the same assumption, then:

$$S = Ra\sqrt{2} \qquad .... (4)$$

From (3) and (4), the striking distances for a 100 m mast were found to be as shown in the 4th column of Table I. By dividing the quantities in columns 3 and 4, the average gradients across the final jump were found to be as given in the 5th column.

All the gradients in Table I are significantly less than 500 kV/m. This indicates that Eriksson's striking distance and attractive radii are significantly larger than the actual values.

Table I. The Average Gradients Across the Final Jump Implied in Eriksson's Method (Case of H=100 m)

I KA	v P.U.	U KV	S m	E KV/m
10	0.106	13,042	103.4	126
20	0.156	19,779	172.8	114
30	0.215	28,721	233.2	123
40	0.300	44,888	288.5	155
50	0.435	89,429	340.4	263
60	0.490	124,634	389.5	320
70	0.520	154,028	436.6	353
80	0.532	169,181	481.9	351

2.3 Eriksson's Field Intensification Factors

As noted above, Eriksson took the field intensification factor for his 60 m mast to be equal to 60, i.e. an unperturbed field of only 0.5 kV/cm would be enough to cause breakdown from tip of the downward leader to top of the mast. In connection with the above, the following should be noted:

1. Eriksson's calculation method assumes the structure to be cylindrical, and to be immersed in a uniform electric field along its entire length. That assumption is only valid for the static field produced by very high clouds in the absence of any downward leaders. In assuming this to approximately apply when a downward leader is descending, Eriksson et al. [3] recognized that this applies only when the striking distance is large compared to height of the mast. On the other hand, all shielding designs are usually based on small stroke amplitudes, and hence on small striking distances. For example, the design striking distance in the RSM used in lightning protection standards is usually about 45 m. Under such conditions, Eriksson's intensification factors, even if we assume that they were accurately calculated, would be invalid.
2. In the majority of cases, the structure to be shielded cannot be represented by a simple cylinder. Hence talking about intensification factors in terms of ratio of height of the object to its diameter would be rather meaningless.
3. The critical radii used by Eriksson were based on tests with positive polarity impulses [5]. On the other hand, lightning analysis is assumed to be mainly based on a leader that lowers negative charge. Hence the critical radii used by Eriksson are not necessarily applicable to the phenomena of interest.

2.4 Effect of Pockets of Space Charge

The reason the downward leader takes its well known zigzag shape is that it is mainly influenced over most of its length by random pockets of space charge. These same pockets mask the potential effect of the charge of the leader on the electric field at ground objects. By ignoring this fundamental force, Eriksson's method gives electric fields at ground objects that are higher than the actual values. This in turn exaggerates both the striking distance and the protective radius of an air terminal.

The EGM recognizes the effect of the random pockets of space charge by assuming that the downward leader develops unaffected by the existence of ground objects until within striking distance from a ground object. A higher accuracy cannot be obtained by a better simulation of the development of the leader while ignoring the effects of the pockets space charge. The excuse usually stated has been that it was practically impossible to include the effect of the space charge.

J.G. Anderson [2] recently wrote a comprehensive leader progression computer model to look at shielding failures. He included everything that might influence the process including initial cloud charge, charges on the leader channel as it steps, induced charges on the line wires, image charges in the earth, and differences in velocities of downward leaders and upward leaders. In that model, straight leader channels can be assumed, or channels that bend in the direction of maximum tip field, or "wiggles" can be injected to account for charge pockets. One important finding was that if no "wiggle" is assumed and the channel is permitted to bend, then it will curve toward the line just as Dellera and Garbagnatti assumed [7]. On the other hand, if the leader channel is permitted to wiggle in approximately the same fashion that we see in nature, the chaos of motion of the tip completely overpowers the weak attraction of the line charges. In such a case, it is difficult to find any significant bending of the downward leader channel due to line charges. The above indicates that the approach used in the EGM is indeed reasonable.

2.5 Comparison with Field Observations

Eriksson [12], in attempting to show that his theory can predict the median stroke amplitudes measured on Berger's masts, assigned a 350 m "effective height" to those masts. Eriksson's general equation for the attractive radius is as follows [13]:

$$Ra = 0.84\, H^{0.6}\, I^{a} \quad \ldots (5)$$

Where $a = 0.7\, H^{0.02}$ ...(6)

For H = 350 m, this becomes:

$$Ra = 28.23\, I^{0.787} \quad \ldots (7)$$

Striking distance measurements made on Berger's masts, from rotating-camera photographs, are available for stroke currents of 16 kA and 27 kA.[16]. According to Eriksson's method, the striking distances for these should be **250 m and 378 m**, respectively. On the other hand, Berger's measured values were **27 m and 37 m**, respectively. This huge difference (about a factor of 10) between the predicted and the measured values clearly proves the invalidity of Eriksson's CVM.

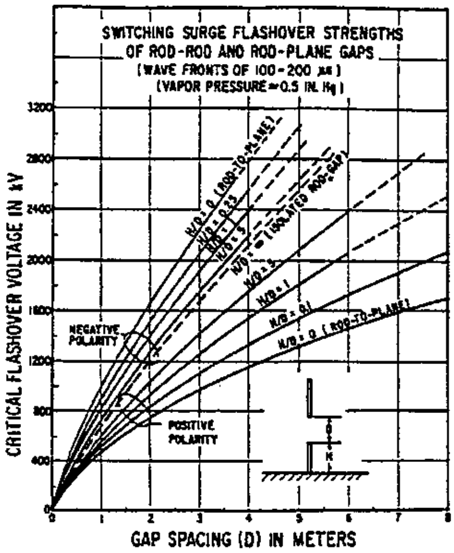

Fig. 1. Switching surge strength of rod-to-rod and rod-to-plane gaps.

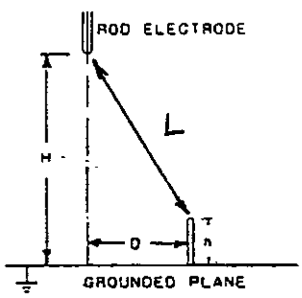

Fig.2. The gap configuration governing the incidence of lightning to masts.

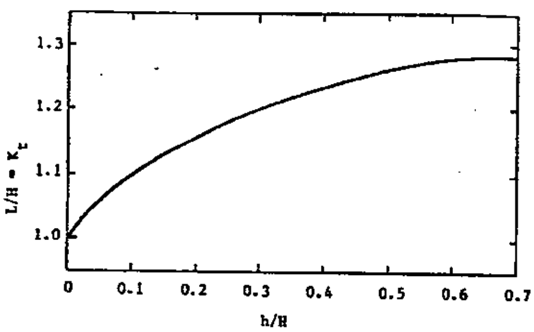

Fig. 3. Suzuki's data regarding ratio between striking distances to masts and to the ground.

In connection with the above, it should be noted that Golde [16] provided a graphical comparison between Eriksson's estimates of the striking distance and those of three other researchers. He then found Eriksson's estimate to be vastly greater than those of all other researchers.

2.6 Comparison with Air Gap Test Data

It is well-accepted that the final jump from a downward leader to the ground plane is comparable to the flashover of a rod-to-plane air gap, and that a strike to a mast is comparable to the flashover of a rod-to-rod gap. Lab data regarding the flashover of air gaps are given in Fig. 1 [1]. In case of the negative polarity impulses of interest herein, the weaker strength of the rod-to-rod gap means that the flashover distance for a given voltage would be larger than that for a rod-to-plane gap. By analogy, it follows that the striking distance to a mast would be larger than that to the ground plane. However, Fig. 1 indicates that the difference is not huge. By examining the curves for (H/D) = 1.0, 5 and ∞, it becomes clear that the striking distance is not sensitive to height of the mast.

For a given negative polarity flashover voltage in the range 800 to 2800 kV, the ratio of the lengths of the corresponding rod-to-rod and rod-to-plane gaps in Fig. 1 is in the range 1.7 to 1.4. This ratio becomes even smaller when the axes of the two rods are offset as shown in Fig. 2, which represents the limiting condition in the EGM. For that case, the existence of the rod increases the striking distance, compared to that of a rod-to-plane gap, by a maximum of less than 30%. Please see Fig. 3 [30].

Grzybowski et al. [17, 18] also did lab flashover tests on the configuration shown in Fig. 2. For rod-to-plane gaps in the range 0.8–1.5 m, the rod-to-rod gap of comparable strengths was larger by only about 7-16%.

In contrast to the above, Eriksson's method implies that the difference between a rod-to-rod and a rod-to-plane gap is rather huge. Consider the following:

For mast heights in the range 10-100 m, Eriksson' Eq. (2) can be written as:

Ra = 0.84 I0.74 f(H) ...(8)

Where,

$f(H) = H^{0.6}$ .... (9)

Fig. 4 gives the value of f(H) in per unit of its value at H = 10 m. This exhibits dramatic sensitivity to height that is not supported by air gap flashover data. This again indicates that Eriksson's method is invalid.

3. THE INVALIDITY OF ERICO'S MODEL

ERICO's model, regardless of the name given to it, is an extension of Eriksson's model. As shown above, Eriksson's model is invalid. Hence ERICO's model and the related software (used to be called NENJI by Gumley) is also invalid.

ERICO's model uses the same erroneous approaches used in Eriksson's CVM: a) it calculates the field intensification factors assuming the building to be immersed in a uniform electric field. b) it adopts the same questionable critical radius concept. Further, in representing the Dynasphere, a 38 cm radius is assumed despite the existence of a sharp rod at its tip. c) In dealing with very tall towers that are known to be sometimes struck by lightning on their sides, ERICO applies arbitrary "de-rating angles" to the collection volume [10].

The Dynasphere is often placed at the end of a mast about 10 m high. As shown in Fig. 5, ERICO [8] estimates that this would make the field intensification factor of the Dynasphere equal to about 50. This claim is even more unreasonable than Eriksson's suggestion that his 60 m mast intensifies the electric field by a factor of 60.

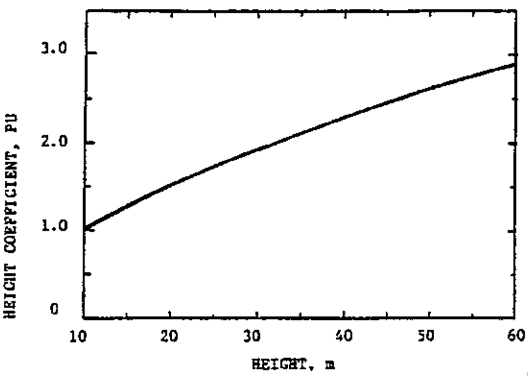

Fig. 4. Effect of height on the protective radius according to Eriksson.

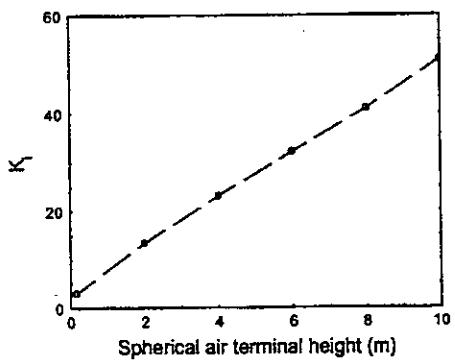

Fig. 5. The field intensification factors used by ERICO for the Dynasphere.

4. DISCUSSION

Eriksson's attempt to develop an alternative to Whitehead's EGM was driven by a perception that its predictions did not match field observations. Part of that perception was based on measurements done by Eriksson on his research mast in South Africa. In this connection, the following should be noted:

1. Melander [23] found, and this was confirmed by Rakov [26], that the stroke amplitude measurements taken by Eriksson at top of his mast were in error.
2. Mousa et al. [24] found Eriksson's measurements of the striking distances from still photographs to be in error. Also, they found that minor rational revisions to the EGM would make its predictions match field observations [25].
3. Eriksson's alternative EGM failed to address the perceived deficiency in Whitehead's EGM which drove Eriksson to develop an alternative model, namely the dependence of the median stroke amplitude on height (and type) of the structure.
4. Eriksson's proposition [4] that the median current to flat ground should be 30 kA has now been established to be in error. For as noted in section 2.2 above, a value of about 24 kA is more appropriate.

ERICO claimed that its CVM/FIM has been validated by field observations [11]. This is also used to imply that the performance of the Dynasphere matches its design targets. On the other hand, this is not possible for any design method that does not have a valid theoretical basis. In this connection, it should be noted that Hartono et al. [20, 21] have exposed serious shortcomings in ERICO's validation exercise. They also showed that the performance of the Dynasphere was lacking [19].

5. CONCLUSIONS

1. Eriksson's CVM is invalid for several reasons; the most serious of which is the use of grossly exaggerated field intensification factors.
2. Eriksson's CVM gives striking distances which are often one order of magnitude larger than the measured values. Further, its predictions are not supported by the established air gap flashover performance. In view of the above, no rebuttal of the arguments presented herein can redeem Eriksson's CVM.
3. ERICO's CVM/FIM, which is based on Eriksson's CVM, is also invalid. Actually, ERICO's estimates of the field intensification factors are rather outrageous.
4. The finding by Hartono et al. of flaws in ERICO's claims of validation of its model should be expected, as the theoretical basis of the CVM/FIM is invalid.
5. The end result of ERICO's method is making the attractive radius of an air terminal appear to be much larger than it really is. This justifies the drastic reduction in the number of air terminals that is needed to make ESE lightning rods commercially viable.
6. The author considers the promotion of the CVM/FIM to be nothing but a coloured attempt to legitimize ESE gadgets following the demise of ESE theory.

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