

STUDY OF A LARGE-SCALE EXPERIMENT TO PROVE OR DISPROVE THE ALLEGED SUPERIOR PERFORMANCE OF ESE AIR TERMINALS

José Claudio de Oliveira e Silva
EMC Consultant (freelancer)

Abstract – In this study, a large-scale, long-term experiment that can generate statistically significant data is considered for a definite proof or disproof that early streamer emission (ESE) air terminals work as advertised by their proponents. The idea is very simple, as it consists of a large site (or many spread small sites) where poles with and without ESE air terminals compete to intercept lightning. The interceptions are simulated by means of the electrogeometric model (EGM) with randomly generated lightning point of impact and intensity, to provide at least a perception of data behavior, stabilization and therefore an expectation of the necessary time for such experiment to result in an irrefutable evidence.

1 - INTRODUCTION

The debate on the performance of non-radioactive early streamer emission (ESE) air terminals has dragged on for decades. According to the historical introduction in [1], such lightning rod featuring an active ionization device was born in France in 1985, as an alternative to the radioactive rod that was about to be prohibited.

To the scientific community there is neither experimental nor theoretical convincing evidences that support the claimed superior attractive radius of ESE in comparison with a conventional lightning rod (Franklin) [2],[3]. Some of most prestigious scientific, technical and standardization organizations, such as ICLP, CIGRE, IEC, NFPA, have not accepted the claims from ESE proponents. One of the main reasons for the rejection is the arbitrary extrapolation that ESE manufacturers do from laboratory tests to the case of upward leaders initiated under natural lightning conditions [4]. Another question relates to the upward leader propagation speed, briefly discussed in Section 2.2.

Despite the long lasting situation, ESE manufacturers have not dedicated enough effort to perform a long-term (statistically significant) field experiment under real lightning condition, based on an acceptable methodology that could end this debate once for all, for better or for worse. If the results were favourable to their products, they would naturally be accepted by scientific and technical communities, standards and the market. Instead, ESE manufacturers present empirical validations based on surveys about the satisfaction of users, laboratory validation and field experiments [1] (natural and rocket-triggered lightning), all refutable for the following main reasons.

The first (surveys) is obviously incapable of addressing the actual performance of ESE, especially in comparison with what would be the performance of conventional well-designed lightning protection systems (LPS) if they were installed on the same structures. The whole concept of lightning protection is much more involved than just interception, but is affected by the

design of down-conductor and earthing systems, spatial shielding, cable shielding & routing, surge protection, insulation etc., so that it is a technically vague approach.

Validation based on laboratory is readily discarded by the simple fact that laboratory test conditions cannot be extrapolated to the large-scale conditions of natural lightning [2],[3],[4] and [5]. It includes the determination of the time advancement of ESE with respect to a Franklin rod made in laboratory as per the French standard NF C 17-102 [6], which is also considered a form of validation by ESE manufacturers [1].

The few field test campaigns in which ESE devices were put in competition with ordinary rods under natural or rocket-triggered lightning, have not only failed to prove the alleged higher performance of the ESE, but also showed unfavorable performance in some cases. The rocket-triggered lightning tests carried out in Camp Blanding, Florida (1993-1995), and in St. Privat d'Allier, France (1996) [7], did not produce any evidence to validate ESE [2],[3]. The 7-year field experiment in New Mexico [8], to compare the performance of various rod tip configurations: a blunt rod, a sharp (Franklin) rod and an ESE device, also gave unfavorable results to ESE. To complete the picture, a recent review (not published yet) of the tests carried out in Cachoeira Paulista (Brazil, 2000-2005) [9], showed that only two altitude-mode triggered lightning hit the rocket launching & test platform (the altitude-mode is a more representative of natural lightning for the purpose of this test). The platform comprised four masts having two ESE devices, a Franklin rod and an E-field antenna, all at the same height. The two lightning flashes to the platform hit the Franklin rod and the antenna and none hit the ESE devices.

NOTE: There is some confusion in the data presented in [9] and therefore this subject is being considered for future work by the author and colleagues.

This paper presents a preliminary study on a procedure to field test the performance of ESE in comparison with that of ordinary (Franklin) rods under natural lightning. The idea is simple: a number of rods are installed in similar conditions to receive lightning, the number of which are counted for each type of rod. The number of test sites (N_s) and the average ground flash density (N_g) on these sites will determine the time required to arrive at a definite conclusion about what is becoming an almost 40-year dilemma.

2 – BASIC CONSIDERATIONS

The methodology consists of computer simulations of lightning strikes to poles, based on the electrogeometric model (EGM). The positions of the lightning flashes are randomly generated in a given area following a uniform distribution, in quantity according to N_g . The peak current (kA) of each lightning is also randomly generated, following a log-normal distribution with parameters $\mu; \sigma = \ln(35); \ln(1.9)$, which approximates to the probability values given in Table A.3 in IEC 62305-1 [10].

The lightning channels are vertical and ground is flat.

Each lightning flash corresponds to a vector in the numerical calculation program (Mathcad), carrying position x, y and current amplitude I (kA). To each lightning, a radius r (meters) is assigned to the rolling sphere according to Eq. (1):

$$r = 10 I^{0.65} \quad (1)$$

2.1 – FRANKLIN ROD VOLUME AND RADIUS OF PROTECTION

The protected volume of a single and isolated vertical rod of height h , is given by the revolution of the grey area around the rod axis, as indicated in Fig. 1, according to the rolling sphere method that generates an imaginary sphere of radius r (Eq. 1). The radius of protection in meters at ground level R is given by Eq. (2).

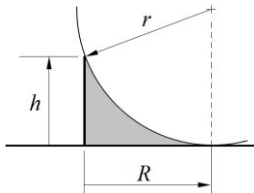


Figure 1 – Rolling sphere around a vertical rod and radius of protection at ground level (R).

$$R = (2rh - h^2)^{1/2} \quad (2)$$

2.2 – ESE AIR TERMINAL VOLUME AND RADIUS OF PROTECTION

The volume of protection of a single and isolated vertical rod equipped with an ESE device is given by the revolution of the grey area around the rod axis as shown in Fig. 2, according to definitions in [6], see Eq. (3). In Fig. 2, R_{ESE} is the radius of protection at ground level.

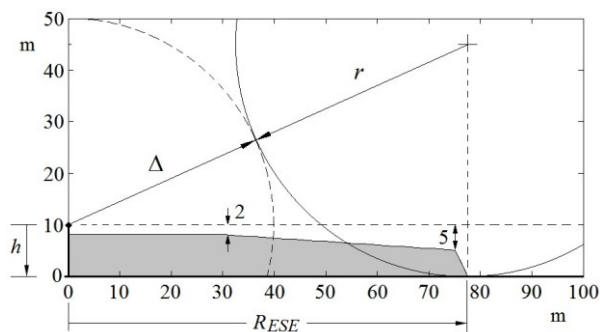


Figure 2 – The volume of protection (grey area) around an ESE air terminal and the radius of protection at ground level (R_{ESE}). Example where rod height $h = 10$ m, radii $\Delta = 40$ m and $r = 45$ m.

The geometry in Fig. 2 can be deduced from Eq. (3) (in meters), which for $h \geq 5$ m combines two spheres of radii Δ and r :

$$R_{ESE} = [2rh - h^2 + \Delta(2r + \Delta)]^{1/2} \quad h \geq 5 \text{ m} \quad (3.a)$$

$$R_{ESE} = R_{ESE}(h) \times h / 5 \quad 2 \text{ m} \leq h \leq 5 \text{ m} \quad (3.b)$$

$$R_{ESE} = 0 \quad h < 2 \text{ m} \quad (3.c)$$

Where h is the vertical distance between the tip of the ESE device and the horizontal plane below taken as reference. For calculation of R_{ESE} at ground level (Fig. 2), h is the height of the ESE air terminal;

and r is the radius of the rolling sphere varying from 20 to 60 m depending on the protection level (I to IV), according to [6], but in this work it follows Eq. (1), for each randomly generated lightning.

$\Delta = \Delta t \times 10^6$ (meters) is the claimed distance advantage of the ESE. Δt is the time advantage of ESE with respect to an ordinary Franklin rod, measured in laboratory as per the test method in [6]. The parameter Δ is in meters, as it has to be in order to fit in Eq. (3), therefore the 10^6 factor must be a speed. The meaning of this factor is controversial because ESE manufacturers use to refer to it as the upward leader propagation speed (1 m/ μ s) [1]. Despite it appears as the leader propagation speed in the older version of the Spanish standard (1996) equivalent to [6], the present version of these standards give a vague definition to it: "Field experience has proved that Δ is equal to the efficiency obtained during the ESEAT evaluation tests". Several 2D speed measurements with high-speed cameras have revealed much lower values during most part of the traveling path of the upward leader, something around 1 to 2 orders of magnitude lower [11]. If the 10^6 factor is tenfold reduced, the ESE claimed advantage is practically lost.

NOTE: Eq. (3.c) is not defined in [6] but is herein assumed as such with basis on Figure 2 therein.

3 – THE PROPOSED EXPERIMENT SETUP

The proposed numerical experiment is based on a simple idea: the larger the radius of protection of a certain rod, the higher the number of intercepted lightning. If a high quantity of test sites, each one comprising ESE rods competing with ordinary Franklin rods, properly monitored, are installed in a place or spread in various places where N_g is preferably high, the difference will show up with time. The question is, how long time? That is the purpose of such numerical exercise: to provide a perception of data behavior, data stabilization and therefore an expectation of the required time for an experiment of this kind to result in a solid evidence in favor or against ESE air terminals.

In the field tests under natural lightning in the past [7],[8],[9], competing conditions between ESE and Franklin rods were created. It is indeed a good way to do, since the Franklin rod can be considered a known reference. In one of the tests [8], there were three 6 m high poles separated by 6 m. In [9], there were four poles, the tips of which at 11.5 m from ground level, installed at the corners of an 8 x 8 m launching platform. In fact, this study began with a similar setup: two ordinary Franklin rods and two ESE devices on top of 10-m high poles at the corners of a 10 x 10 m square. However, the protection volume of an ESE air terminal that in most part looks arbitrary (Fig. 2), discourage any attempt to make an interception simulation model to

handle the competition between the two types of rods when they are close to each other.

The 4-rod arrangement was then simplified into a 2-rod arrangement with the rods far from each other, so that there is no interference between them. The radius of attraction at ground level replaced the complicated protection volume as variable to determine their lightning interception. Assuming that the two poles are sufficiently far from each other and from other objects, on flat terrain, the lightning interceptions are determined by R and R_{ESE} only. By eliminating the difficulty to analyze and interpret the results involving the complex (unclear) working of an ESE air terminal and its interaction with a nearby Franklin rod, the proposed arrangement frees the test setup from high-speed video, current and E-field measurement, discharge physics analysis etc. The only important requirement to produce useful results is to ensure a reliable counting of lightning strikes (flashes) to the rods under test.

The proposed test site is formed by 2 x 10-m poles on flat ground as shown in Fig. 3. One pole (P1) is terminated with an ordinary Franklin rod and the other (P2) with an ESE device featuring $\Delta = 40$ m. An 80-m clearance around P1 is required to avoid interference with its interception performance for lightning currents up to 200 kA. Likewise, a 180-m clearance is required around P2. The minimum distance between P1 and P2 should be 260 m.

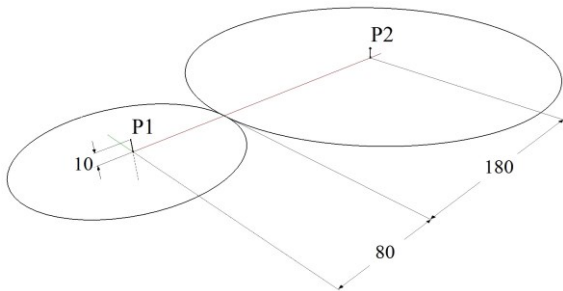


Figure 3 – Test site formed by a pair of 10-m poles; P1 is a Franklin rod and P2 is an ESE with $\Delta = 40$ m; The circles denote clearances to other objects.

4 – SIMULATION RESULTS

In the simulations, the number of flashes on P1 (N_{P1}) and P2 (N_{P2}) are counted and compared to address the relative interception efficiency of the rods. Plotting the intercepted flashes by the rods year by year does not give a clear information, while plotting the accumulated numbers of flashes per rod along the years provide a good visualization of the difference between them. Note that the accumulated number of flashes is proportional to the average value, a naturally filtered information. The problem, as expected, is the random nature of lightning that requires a certain amount of data for them to stabilize, i.e. to bear a sufficiently constant mean value and small deviations.

Taking the basic configuration of Fig. 3 and the conditions in Section 2, the simulations of lightning interceptions are shown in Fig. 4 in terms of the N_{P2}/N_{P1} ratio, which is an evident factor to evaluate the relative interception efficiency of the rods. Please, note that the presented results are valid for the simulated conditions only and further studies are needed for extrapolations or generalizations. At the abscissa, the parameter is $N = N_g N_s N_y$, which are the annual ground flash density, the number of test sites and number of years,

respectively. Each point results from 50 simulation runs to produce mean values and deviations.

In Fig. 4, the difference between the solid (blue) curve and the dashed (black) curve is that the former is the average of 50 N_{P2}/N_{P1} ratios while the latter is the ratio between the sum of all 50 values of N_{P2} and N_{P1} (50 simulation runs). For $N = 100\,000$, $N_{P2}/N_{P1} = 6.0 \pm 0.2$ (mean \pm std. deviation) and $\sum N_{P2}/\sum N_{P1} = 6.0 +0.4/-0.6$ (maximum/minimum). ($N = 100\,000$ per simulation run).

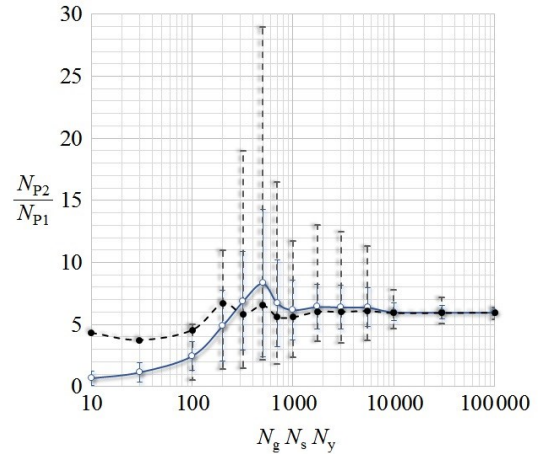


Figure 4 – N_{P2}/N_{P1} ratio as function of $N = N_g N_s N_y$. The solid (blue) line is the average of N_{P2}/N_{P1} ratios from 50 simulation runs; the dashed (black) line is the ratio between the accumulated values of flashes on P1 and P2. The solid (blue) and dashed (black) deviation bars correspond to std. deviation and maximum and minimum values, respectively.

Referring the variations of Fig. 4 to mean value 6.0 (the expected correct value within 10%), results in the percent variations shown in Fig. 5. Note that the $\pm\sigma$ and $\pm 2\sigma$ curves are not symmetrical around 0% because the reference was displaced to a different value from the ones the mean values and standard deviations (σ) were taken.

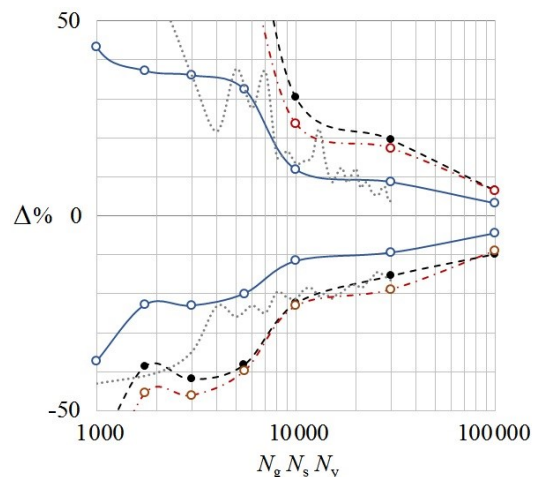


Figure 5 – Percent variation of N_{P2}/N_{P1} ratio referred to 6.0, in accordance with data shown in Fig. 4. Solid (blue) line: $\pm\sigma$ (\pm std. dev.); dash-dot (red) line: $\pm 2\sigma$; dashed (black) line: maxima/minima; dotted (gray) line: see simulations for $N_g = 10$ and $N_s = 100$, subsection 4.3.

The graphic of Fig. 5 provides criteria to determine the necessary time span (N_y) to obtain a reasonable

result as function of the number of sites (N_s) and the ground flash density (N_g), within an assumed margin ($\Delta\%$) of error. For example, if one wants a N_{P2}/N_{P1} ratio within 20% margin taking the $\pm 2\sigma$ curve, for $N_g = 10$ and $N_s = 100$, he/she should consider some 20 years. If the $\pm 2\sigma$ curve is seen as a too pessimist choice and the $\pm\sigma$ curve is chosen, the time falls to 7 or 8 years. For fewer sites, e.g. $N_s = 10$, the experimenter should consider places with higher N_g and/or accept larger error margins.

Even with the application of Fig. 5 as criterion to determine the key test conditions (place, amount of sites, time span and associated errors), the test data may be hard to assimilate in the beginning of real field tests. The results may induce the experimenters to wrong conclusions, if they do not give sufficient time for data to accumulate and gain statistical relevancy. Look, for example, what happened to the N_{P2}/N_{P1} ratio in the simulations presented in the next subsection (4.1).

4.1 – SIMULATIONS FOR $N_g = N_s = 10$

In this case, $N_g = 10$ and $N_s = 10$, the lightning interceptions were simulated year by year along 30 years, as shown in Figures 6 and 7. The simulations were repeated 10 times (10 simulation runs) to give at least a small perception of data dispersion. Every year the number of flashes on P1 and P2 are recorded and accumulated into new N_{P1} and N_{P2} values, and N_{P2}/N_{P1} ratio is updated.

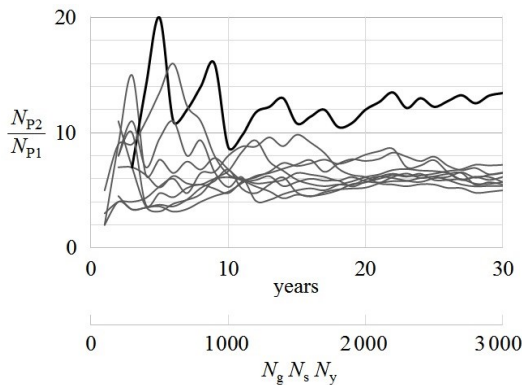


Figure 6 – N_{P2}/N_{P1} ratios as function of time (years), also $N = N_g N_s N_y$, for $N_g = N_s = 10$. The curves represent each of the 10 simulation runs. The thick black line highlights an outlier run.

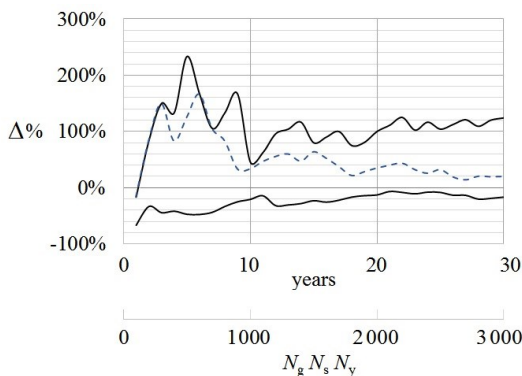


Figure 7 – Percent variation of N_{P2}/N_{P1} ratio referred to 6.0, based on data shown in Fig. 6. The solid (black) lines indicate $\Delta\%$ of all simulation runs, including the outlier run highlighted in Fig. 6. The dashed (blue) line indicates $\Delta\%$ excluding the outlier run.

There is a remarkable N_{P2}/N_{P1} outlier curve in the data set. Imagine the contentment of those in favor of ESE products if an experiment by chance behaves as the outlier simulation run indicated in Fig. 6. After the two very high peaks ($N_{P2}/N_{P1} = 20$ and 16) in the first 9 years, with an average ratio of 13.4 in the same period, the results could look conclusive and the experiment be terminated with a wrong impression about the product efficiency. Remember that the correct ratio here is 6, but the experiment is still far from that value. Consider, also, the difficulty of experimenters who do not know the correct N_{P2}/N_{P1} value neither when to stop.

Note that the high $\Delta\%$ values due to the outlier curve in Fig. 7, particularly at the end of the 30-year period, is possibly in agreement with the “ $+2\sigma$ ” and “maximum” curves in Fig. 5 for such low N value ($N_g N_s N_y = 3000$), as these curves rapidly grow for $N < 10000$.

NOTE: The “ $+2\sigma$ ” and “maximum” values are 72% and 108%, respectively, for $N = 3000$.

4.2 – SIMULATIONS FOR $N_g = 10$ AND $N_s = 1$

Fig. 8 shows the same type of information of Fig. 6, but for $N_g = 10$ and $N_s = 1$. With such extremely low quantity of lightning ($N_g N_s N_y = 0$ to 300), the data is rather chaotic along the first 30-year period.

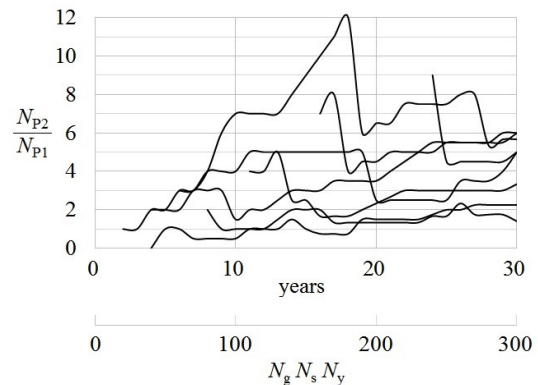


Figure 8 – N_{P2}/N_{P1} ratios as function of time (years), also $N = N_g N_s N_y$, for $N_g = 10$ and $N_s = 1$. The curves represent each one of the 10 simulation runs.

Note that several curves of the bunch of curves in Fig. 8 start late in the 30-year simulation period because the N_{P2}/N_{P1} ratio cannot be calculated until lightning hits the Franklin rod at least once (N_{P1} must be > 0). In reality, there are only 8 curves out of 10 simulation runs in Fig. 8, since no lightning hit P1 in 2 runs in the entire period of 30 years. For a better appreciation of the situation, it is worth to report the equivalent collection area, A_D [12], of the two isolated structures P1 and P2, obtained from the simulations taking a very high number of lightning flashes: 0.00659 km² and 0.0393 km², respectively. For $N_g = 10$, P1 is expected to receive one lightning every 15 years period in average.

NOTE: $N_{P2}/N_{P1} = A_{D2}/A_{D1} = (R_{ESE}/R)^2$.

4.3 – SIMULATIONS FOR $N_g = 10$ AND $N_s = 100$

Fig. 9 shows the same type of information of Fig. 6 and Fig. 8, this time for $N_g = 10$ and $N_s = 100$. The $\Delta\%$ (maxima/minima) curves of this case are plotted in Fig. 5 for comparison. Note that the gray dotted line in Fig. 5 fits reasonably well in between the $\pm\sigma$ and $\pm 2\sigma$ curves. The data become well behaved after some 15 years.

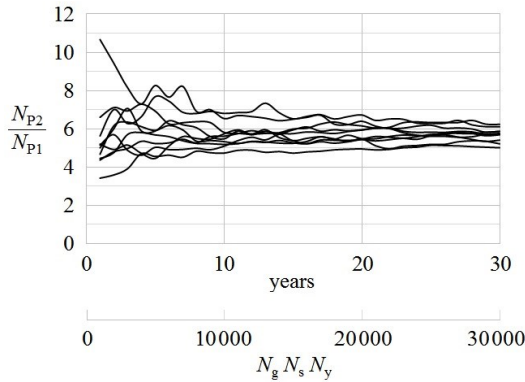


Figure 9 – N_{P2}/N_{P1} ratios as function of time (years), also $N = N_g N_s N_y$, for $N_g = 10$ and $N_s = 100$. The curves represent each one of the 10 simulation runs.

4.4 – SUMMARY FRANKLIN X ESE

To summarize the simulated cases, Fig. 10 presents the required number of years N_y as function of the product $N_g N_s$ for deviations within 30%, 20% and 10% from the expected $N_{P2}/N_{P1} = 6.0$, for std. dev. curves $\pm\sigma$ and $\pm 2\sigma$, according to the curves in Fig. 5.

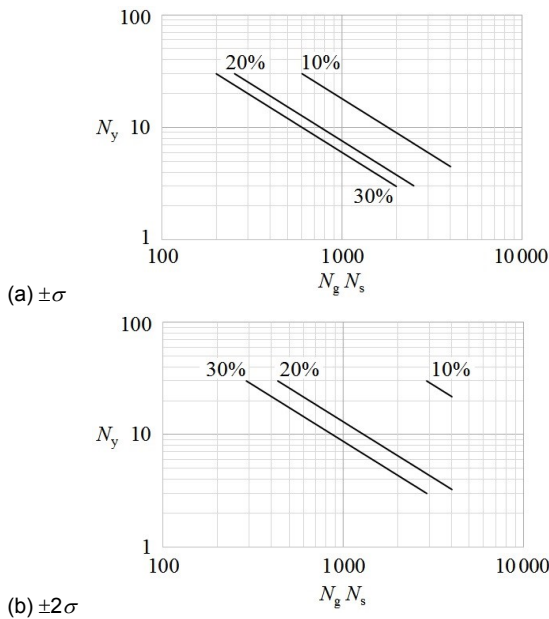


Figure 10 – Required number of years N_y as function of the product $N_g N_s$ for deviations within 30%, 20% and 10% from the expected 6.0 value, considering (a): std. dev. curves $\pm\sigma$, and (b): std. dev. curves $\pm 2\sigma$. Extracted from curves in Fig. 5.

The curves in Fig. 10 are limited to reasonable ranges of N_y and $N_g N_s$. The values can be calculated through the relations given in Table 1.

| Deviation curve | $\Delta\%$ from $N_{P2}/N_{P1} = 6.0$ | Relation ^a |
|-----------------|---------------------------------------|--------------------------------|
| $\pm\sigma$ | 30% | $N_y = 6\,000 (N_g N_s)^{-1}$ |
| | 20% | $N_y = 7\,600 (N_g N_s)^{-1}$ |
| | 10% | $N_y = 18\,000 (N_g N_s)^{-1}$ |
| $\pm 2\sigma$ | 30% | $N_y = 8\,700 (N_g N_s)^{-1}$ |
| | 20% | $N_y = 13\,000 (N_g N_s)^{-1}$ |
| | 10% | $N_y = 87\,000 (N_g N_s)^{-1}$ |

Table 1 – Relations involving N_y and $N_g N_s$ according to Fig. 10.
^a) Being N_g a per-year parameter, round-up N_y to the next integer.

As general information, for P1 to intercept the same number of flashes intercepted by P2, its height should be 100 m. The value was obtained from simulations with very high number of lightning flashes. The equivalence is not valid in terms of the median peak current of the intercepted flashes, which increases with the rod height.

4.5 –FRANKLIN X FRANKLIN

It is interesting to check the simulation results for two identical 10-m Franklin rods disposed as in Fig. 3, which ideally should perform equally. The simulations indicate that the random character of lightning occurrence and amplitude, may not make it evident in the beginning of a real experiment. The number of sites is 10 in this case.

Fig. 11 shows the accumulated number of flashes on both rods. Although the mean values follow closely side by side, the large data dispersion (see error bars) means large dispersion of N_{P2}/N_{P1} ratios, for various simulation runs. In this simulation, the ground flash density varied year by year according to real ground flash variations in two certain places selected from [13]. The average, long-term N_g of these places are very close to 10.

The yearly variation of the average values of N_{P2}/N_{P1} with respect to unity (expected value for this case) as well as the standard deviation, maxima and minima (10 simulation runs) are shown in Fig. 12. Up to 30 years, the variations of N_{P2}/N_{P1} ratio can be wide enough so as not to allow one to affirm that the two rods are identical. More time, more sites and/or higher N_g are required. This situation can be read from Fig. 10, however it was not verified if Fig. 10 can be generalized to conditions other than those used to build the graphic.

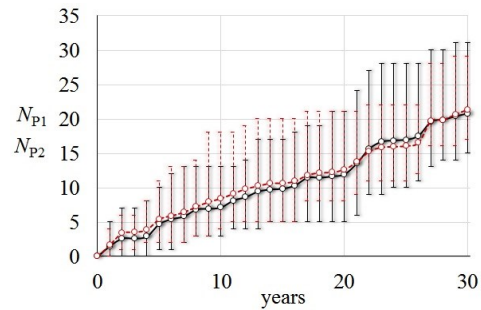


Figure 11 – Accumulated number of flashes on P1 (black solid line) and P2 (red dashed line) along the time. P1 and P2 are identical Franklin rods with $h = 10$ m; the circles are the mean values and the deviation bars indicate maxima and minima from 10 simulation runs. $N_g = 10$ but variable with time and $N_s = 10$.

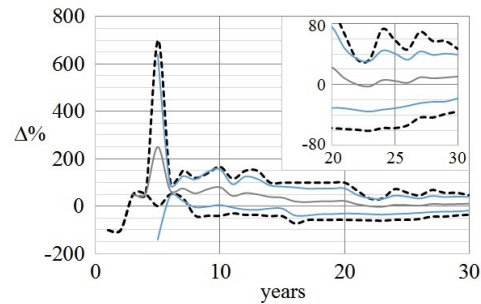


Figure 12 – Percent variation of N_{P2}/N_{P1} ratio from unity, according to data in Fig. 11; central grey solid line: mean value of N_{P2}/N_{P1} ratios (10 simulation runs); blue solid lines: mean $+\sigma$ and mean $-\sigma$; black dashed lines: maxima and minima.

5 – RECOMMENDATIONS FOR IMPLEMENTATION

If real field experiments are planned based on this preliminary study, a more refined study is indicated, as it involves cost, time and the success of the test. The performance of the test setup should be verified through more sophisticated lightning interception models.

The number of sites has to be large for reasonable test duration, in the order of tens or even one hundred. They can be positioned in a very large area or spread in many individual sites all around the world, run by universities, research centers, industrial plants etc., in collaboration.

Places with high N_g (say, $N_g \geq 10$) are advantageous, of course. For large areas (many test sites) care shall be taken with N_g homogeneity throughout the area.

Rod height affects the test requirements: from rod separation and test area to number of test sites and test time. For this reason, other rod heights should be evaluated. It also involves difficulty and safety issues to access their tips for installation and maintenance. High rods require towers instead of poles, as they have to be mechanically stable. To be considered if very high rods could not affect the relative performance between them, producing a result different from that in usual structures where ESE are most commonly installed.

The tip of the Franklin rod (sharp or blunt) is something to be considered if it can influence the result. To be decided whether the most efficient shape [8] or the most usual in the market is to be used. Such parameter is not handled by EGM.

The terrain shall be as flat as possible not to create asymmetries on the radius of protection. It shall be clean, free of objects (observe clearances in Fig. 3), including vegetation, as much as possible.

Lightning flash (not stroke) counting has to be very reliable. No current amplitude, number of strokes etc. are necessary. Lightning counters on poles can neither miss nor overcount lightning. They have to be calibrated (desensitized) to discard upward unconnected leaders.

Proper site monitoring and maintenance are essential. Surveillance cameras can be useful.

5 - CONCLUSIONS

A long-term, natural-lightning field test method was proposed to compare the efficiency of ESE air terminals (on pole P2) with ordinary Franklin rods of same height (on pole P1). If properly executed, it can prove or disprove the claimed superior performance of ESE over its humble competitor.

The method is simple and obvious: the two types of lightning rods are disposed in a certain area and the number of intercepted flashes by each one is counted along the time. To measure their relative performance, the ratio between the number of lightning strikes to one and to the other rod (N_{P2}/N_{P1}) was chosen.

To taste how the test method would work, computer simulations were made to generate lightning flashes at random and make the interceptions by the competing rods based on the radius of protection according to EGM and on ESE standards. The simulations showed how many lightning flashes each rod would intercept with time and, more importantly, how the N_{P2}/N_{P1} ratio would behave.

The random nature of lightning and the limited capacity of a small pole to attract lightning can be deceiving because the number of intercepted lightning is low year by year. The data is poor and erratic in the beginning, until sufficient time is given for it to accumulate and stabilize within a definable error margin or range of dispersion around the final N_{P2}/N_{P1} value.

The test duration depends on the number of test sites N_s (gathered in a very large area or spread in many individual test sites, run in collaboration), the ground flash density N_g and an acceptable error margin. From the simulations, curves were plotted relating the test duration in years N_y with the product $N_g N_s$ for different error margins (± 10 to $\pm 30\%$). Such information can be very useful for planning a test campaign of this kind.

6 - REFERENCES

- [1] FAUVEAUX, S. et al., "Sobre o para-raios com dispositivo de ionização – A tecnologia que vem crescendo no Brasil", E-book (in Portuguese), ISBN 978-65-991853-0-4, 1st. Edition, July 2020.
- [2] UMAN, M.A., RAKOV V.A., "A critical review of nonconventional approaches to lightning protection", Bulletin of the American Meteorological Society, DOI: 10.1175/BAMS-83-12-1809, December 2002.
- [3] COORAY, V., Non Conventional Lightning Protection systems, *Electra* No. 258, pp. 36-41, October 2011.
- [4] BECERRA, M., COORAY, V., Laboratory experiments cannot be utilized to justify the action of early streamer emission terminals, *J. Phys. D: Appl. Phys.*, 41, DOI: 10.1088/0022-3727/41/8/085204, March 2008.
- [5] CHRZAN, K.L., Early streamer emission terminals from the high voltage engineering perspective, 21st International Symposium on High Voltage Engineering, Budapest, Hungary, August 2019.
- [6] NF C 17-102 STANDARD, Protection against lightning – Early streamer emission lightning protection systems (version in English translated by Union Technique de l'Electricité (UTE)), September 2011.
- [7] EYBERT-BÉRARD, A., LEFORT, A., THIRION, B., On-site tests, 24th International Conference on Lightning Protection (ICLP), 1998.
- [8] MOORE, C.B, AULICH, G.D, RISON, W., Measurements of Lightning Rod Responses to Nearby Strikes, *Geophys. Res. Lett.*, 27, p. 1487-1490, May 2000.
- [9] EYBERT-BÉRARD, A., THIRION, B., BOILLOZ, P., Experimental study of leaders initiated by classical and advanced direct lightning protection systems – 2004/2005 Results – Cachoeira Paulista (SP) Brazil, VIII International Symposium on Lightning Protection (VIII SIPDA), 2005.
- [10] IEC 62305-1:2010 STANDARD, "Protection against lightning – Part 1: General principles", International Electrotechnical Commission (IEC), Ed. 2.0, December 2010.
- [11] SABA, M.M.F. et al., Lightning attachment process to common buildings, *Geophys. Res. Lett.*, 44, DOI: 10.1002/2017GL072796, 2017.
- [12] IEC 62305-2:2010 STANDARD, "Protection against lightning – Part 2: Risk management", International Electrotechnical Commission (IEC), Ed. 2.0, December 2010.
- [13] SILVA, J.C.O., "Ground flash density dispersion from N_g – An observation based on 14 years of LIS data collected over Brazil"; XV International Symposium on Lightning Protection (XV SIPDA); September – October 2019.

Main author

Name: José Claudio de Oliveira e Silva
Address: São José dos Campos – SP, Brazil
Phone: +55 12 9 9101 9314
E-mail: claudio.silva@aptemc.com.br