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ARE THERE ADVANTAGES IN USING EARLY STREAMER EMISSION AIR TERMINALS INSTEAD OF A FRANKLIN ROD CONSIDERING THE UPWARD POSITIVE LEADER PROPAGATION SPEED?

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Abstract - This paper presents a review of the standardization of Early Streamer Emission (ESE) devices around the world. Currently, there are no international standards that cover this subject, only national standards that contain some misconceptions, which are discussed in this work. This review highlights the potential consequences of these misconceptions and proposes a way to correct the standards equation to provide effective protection.

1 - INTRODUCTION

As introduced by Uman and Rakov [1], conventional lightning protection systems can be described as ground-based structures that create preferential attachment points and paths for the lightning current to flow towards the ground, without causing damage to the protected structure. This type of protection is defined by the international standard IEC 62305-3 [2], which is widely applied worldwide. Additionally, conventional systems are also described in national standards such as the Brazilian standard ABNT NBR 5419-3 [3] and the American standard NFPA 780 [4].

On the other hand, there are unconventional lightning protection techniques that are available commercially under different trade names, but are generally classified as "Early Streamer Emission" (ESE) or "Lightning Elimination" devices, as classified by Uman and Rakov [1]. The main focus of this work is on ESE devices.

According to Cooray [5], an Early Streamer Emission air terminal (ESEAT) - as shown in Figure 1 - is a triggering device that applies voltage pulses to the tip of the rod during the lightning development process, which increases the electric field nearby the rod. Based on this concept, proponents of ESE claim that there could be an earlier initiation of the upward positive leader compared to a conventional Franklin rod. The conclusion drawn by ESE proponents is that this time advance results in a larger protection zone when compared to a conventional Franklin rod under the same circumstances.

In light of these claimed advantages, there are national standards that cover the ESE subject in their respective countries, such as the French standard NF C 17-102 [6], the Spanish standard UNE 21186 [7], and the Portuguese standard NP 4426 [8]. These standards are quite similar to each other. This work will analyze their equations and principles in the following sections to understand the claimed advantages of using ESE devices instead of conventional solutions when the physical premises are adjusted to realistic values. Furthermore, this work intends to present the real effect and risks associated with using Early Streamer Emission lightning rods following these standards.

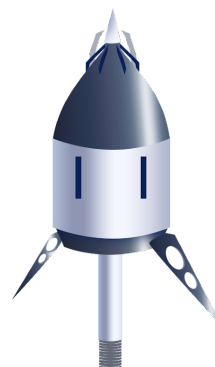


Figure 1 - Early streamer emission air terminal (ESEAT) [9].

The harm caused by using ESE lightning rods according to their standard specifications has been reported in several published works [10,11]. Hartono has reported lightning bypasses occurring in buildings equipped with ESEATs [10]. Figure 2 illustrates multiple bypasses observed right beside the ESE air termination.



Figure 2 - Bypasses observed on a Malaysian building parapet a few meters apart from an ESE air termination [10].

Additionally, a case study was presented in [11] about 5 bypasses that occurred from April 2015 to May 2016 at UNIV360 Place, an approximately 140-meter long building initially protected with a single ESEAT positioned according to Figure 3. One of the bypasses is shown in Figure 4. After the damages, the first ESEAT was reallocated to a higher pole, and two extra ESEATs were installed. However, 4 bypasses were still observed from July 2016 to December 2019. Finally, Franklin rods were installed in a second attempt to avoid the bypasses, but the rod's positioning did not follow IEC 62305-3 standards, which may have contributed to the occurrence of bypasses, albeit in a lower frequency. These events are an example of the failure of ESE standards to provide

proper protection to large areas according to their methods.



Figure 3 - ESEAT location on UNIV360 Place [11].



Figure 4 - Lightning damage on UNIV360 Place [11].

This paper emphasizes the significance of carefully discussing the subject of unconventional lightning protection techniques in light of strong scientific recommendations against their adoption [1, 5, 12-15], past damages experienced [10, 11], and the persistence of manufacturers and national standards in promoting their efficacy. Specifically, this work addresses the misconception about the Upward Positive Leader (UPL) propagation speed, which has led to a misleading conclusion that Early Streamer Emission (ESE) devices provide greater protection compared to conventional techniques. It stresses the need for accurate values in the equations governing lightning protection systems and calls for more stringent testing and evaluation of ESE devices. Furthermore, this paper underscores the importance of updating standards to reflect realistic scenarios and to ensure public safety and structural protection against the adverse effects of lightning.

2 - BASIC CONSIDERATIONS

The French standard NF C 17-102 [6] provides an equation (1) to calculate the protection radius of an ESE device. This protection radius is then used to define a

surface of revolution around the ESE air terminal mast, which encompasses the protected volume. This surface is obtained by combining the protection radii obtained from different heights of the building geometry.

$$R_p(h) = \sqrt{2rh - h^2 + \Delta(2r + \Delta)} \text{ for } h \geq 5m \quad (1)$$

where

R_p (m) is the protection radius at a given height;

h (m) is the relative height between the ESE tip and the protected structure;

r (m) is given according to the protection level;

Δ (m) $\Delta = \Delta T \times 10^6$

Based on Annex C of the standard [6], the effectiveness of an ESE device is determined through testing and expressed in terms of ΔT , measured in seconds. However, the equation (1) in the standard requires a distance measurement in meters. It can be concluded through simple dimensional analysis that the "factor" of 1×10^6 is actually the claimed UPL speed given in meters per second. Interestingly, previous versions of the NF C 17-102 [16] had presented this "factor" as the UPL speed.

The speed at which the upward positive leader propagates, as used in the development of equation (1), is significantly higher than the UPL propagation speeds reported by lightning measurement stations worldwide. This parameter has a direct influence, and increasing the UPL propagation speed to unrealistic and arbitrary values results in an inadequately sized protection system. Therefore, adopting 1×10^6 as a "factor" endangers structures and individuals inside these buildings to the effects of direct lightning strikes.

3 - DEVELOPMENTS

The measured speed of UPL propagation, as reported in various scientific papers [17-24], typically differs from the speed considered by ESE standards.

McEachron [17] presented upward positive leader speeds measured from the Empire State Building between 1936 and 1937 ranging from 5.2×10^4 m/s to 6.4×10^5 m/s. Berger and Vogelsanger [17, 18] reported seven upward positive leader speed measurements from the Monte San Salvatore between 1955 and 1966 ranging from 4×10^4 m/s to 10^6 m/s. According to [18], four out of these seven events reached speeds ranging from 4×10^4 m/s to 7.5×10^4 m/s. Yokoyama et al. [20] reported upward positive leader speeds measured between 1985 and 1987. These speed ranged from 0.8×10^5 m/s to 2.7×10^5 m/s.

There are more recent works that support the order of magnitude of the speed presented in the previous studies. Gao et al. [21], for instance, presented six cases of upward connecting leaders recorded in 2012 by two cameras positioned in form to allow a 3-D reconstruction of the channel. The observed 3-D speeds ranged from 2.1×10^5 m/s to 6.8×10^5 m/s. Although the technological advances allowed for reconstructing the three-dimensionality of the channel, which increased the UPL measured speeds, they did not reach the speed values claimed by the ESE proponents. In 2017, Saba et al. [22] presented three UPL average speed

measurements: case A reached $4.3 \times 10^4 \text{ m/s}$, case B reached $5.7 \times 10^4 \text{ m/s}$ and case C reached $6.2 \times 10^4 \text{ m/s}$. Additionally, there are some measurements from the Morro do Cachimbo Station published by Visacro et al. in 2017 [23] and 2018 [24] ranging from $6 \times 10^4 \text{ m/s}$ to $1.6 \times 10^5 \text{ m/s}$.

It is notable that the majority of the UPL speed measurements fall within the range of 10^4 m/s to 10^5 m/s . Therefore, it is reasonable to assert that the Early Streamer Emission standards overestimate this speed by approximately 10 to 100 times. Since the protection radius is determined by a formula that takes speed into account, it follows that the protection radius is also overestimated when designed according to these standards. Taking these considerations into account, the “factor” in equation (1) was adjusted to more realistic values.

To improve the accuracy of the protection radius, it is necessary to adjust Δ based on the considerations mentioned above. Equation (2) can be used to make this adjustment. Once the equation has been adjusted, the resulting value can be incorporated into equation (1) to calculate the protection radius.

$$\Delta = \Delta L = v \cdot \Delta T \quad (2)$$

4- RESULTS

For illustrative purposes, this work assumes an air termination placed on top of a 6 m mast, with the dimensions of a hypothetical building shown in Figure 5. The estimated protection radius was obtained using the rolling sphere method of IEC 62305-3:2010 [1], considering a class III LPS obtained by the using of the TUPAN2020 [25] risk management software which was developed according to ABNT NBR 5419 requirements, and is shown in Figure 6. It is clear from the figure that a simple Franklin rod placed according to the above description would be insufficient to protect the building, since the sphere touches the roof approximately 23-m far from the mast.

An ESE system was placed on the same mast and building in accordance with the instructions of NF C 17-102 [6]. A $\Delta T = 60 \mu\text{s}$ ESE device was taken into consideration. The conventional protection radii for these boundaries and for each LPS protection class are displayed in the column labeled “standardized ESE protection radii” of Table 1.

Correcting the UPL speed to magnitudes consistent with real measurements [17-24], the ESE protection radii are reduced. Table 1 presents the conventional protection radii for each LPS protection class, along with the corresponding standardized ESE protection radii. The column “a” in the ESE protection radii section of Table 1 shows the results when the UPL speed is 10^4 m/s , while the column “b” shows the results for a UPL speed of 10^5 m/s .

Figure 7 shows the comparison between the standardized ESE protection radius [6] (left); the radius obtained using the “b” UPL propagation speed (center) and the radius obtained using the “a” UPL propagation speed (right). The yellow sphere is the ESE time advance, the red sphere is given according to the LPS class.

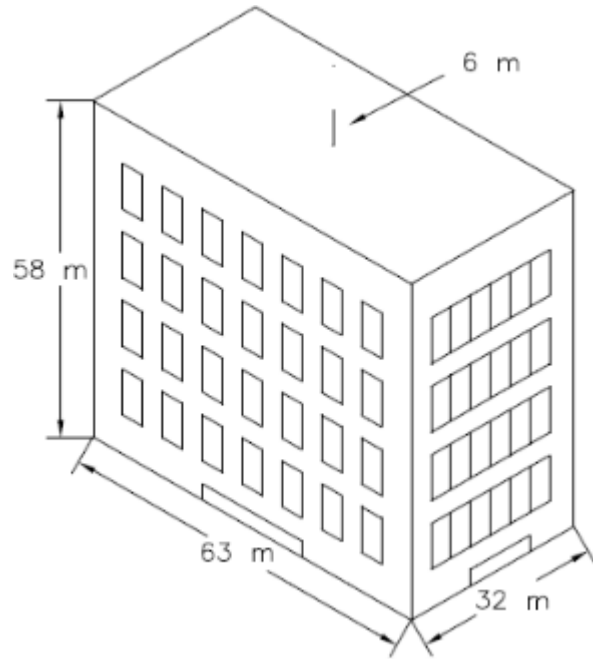


Figure 5 - Hypothetical building dimensions

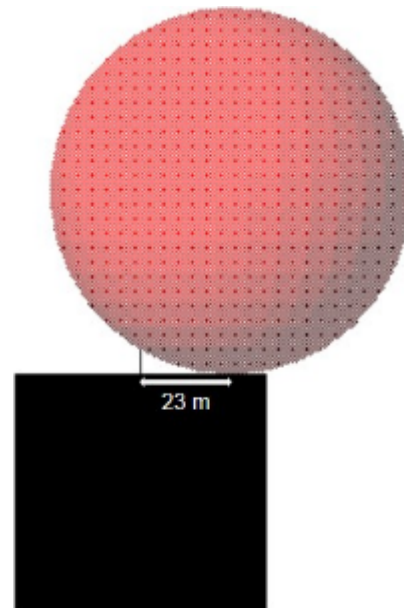


Figure 6 - Rolling sphere method for a class III LPS on the hypothetical building

Class of LPS	Standardized ESE protection radii [6]	ESE protection radii “b”	ESE protection radii “a”
I	79 m	22 m	15 m
II	87 m	27 m	19 m
III	97 m	33 m	24 m
IV	107 m	38 m	27.5 m

Table 1 - Comparison between the standardized ESE protection and the radii obtained by the suggested corrections.

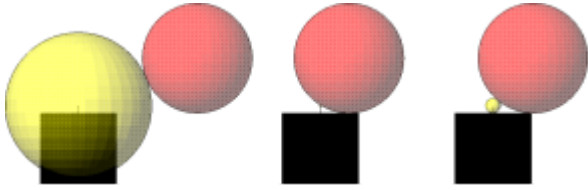


Figure 7 - Comparison of the standardized ESE protection radius and the ones obtained by corrected UPL speeds (distances are presented in Table 1, line III).

The above results suggest that the claimed advantage of ESE systems depends on the assumed UPL speed and the specified time advance. For instance, for a $\Delta T = 60 \mu s$ ESE device, which is one of the largest commercially available time advances, there is no significant increase in protection radii compared to a simple Franklin rod when the UPL speeds are adjusted to match scientific data. The points where the rolling sphere touches the roof in the conventional method (Figure 6) and where the corrected ESE protection radii touch the roof (Figure 8) are quite similar, and more important: smaller than the building dimensions.

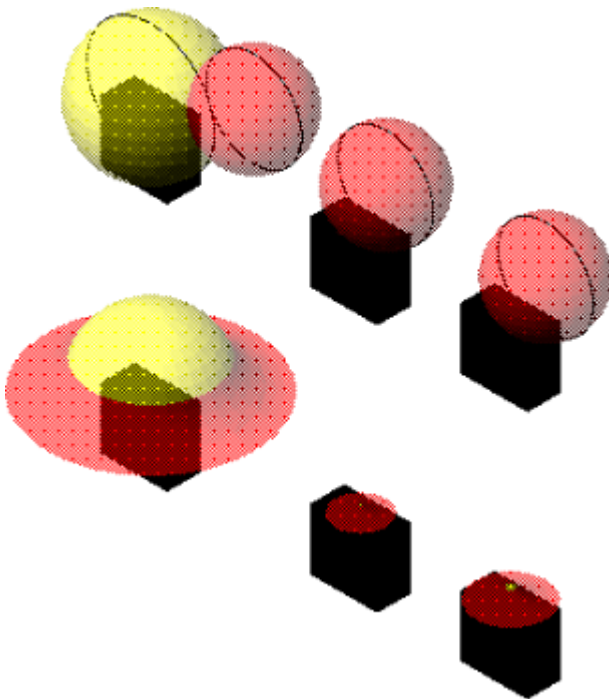


Figure 8 - Building regions outside the protected volume (a) according to the rolling sphere method and (b) according to the corrected UPL speed and the suggested ESE positioning (distances are presented in Table 1, line III).

5- CONCLUSIONS

The UPL speeds presented in this study were obtained from various papers that analyze different aspects of lightning occurrence. These speeds were measured using different methodologies, and the dataset may not be statistically significant for further analysis. However, it is worth noting that the majority of the presented UPL speeds fall within the range of $10^4 m/s$ to $10^5 m/s$. Therefore, this study does not aim to establish

an exact value but rather to discuss the order of magnitude.

For the hypothetical scenario presented in this work, when considering the lower UPL speeds, there is a reduction of 64% to 74% in the protection radii compared to the radii obtained by following the standard instructions [6].

It can be concluded that using ESE devices according to their claimed specifications may result in an undersized and unsafe protection, as demonstrated by Malaysian researchers [10, 11]. Malaysia has one of the highest rates of lightning flashes per year per square kilometer in the world [26]. India is another example of a country located in a high isokeraunic region, its latest version of the National Building Code brings an explicit prohibition of using ESE air-terminations as part of the lightning protection systems [27]. In contrast, western Europe has one of the lowest rates of lightning flashes per year per square kilometer in the world [26], which may contribute to a supposed low incident level. This study was conducted in Brazil, where the lightning rates are more similar to those in Malaysia than in Europe as can be seen in Figure 9. Therefore, it is possible to assume that the described occurrences would be common if this type of system were allowed by national standards and widely used.

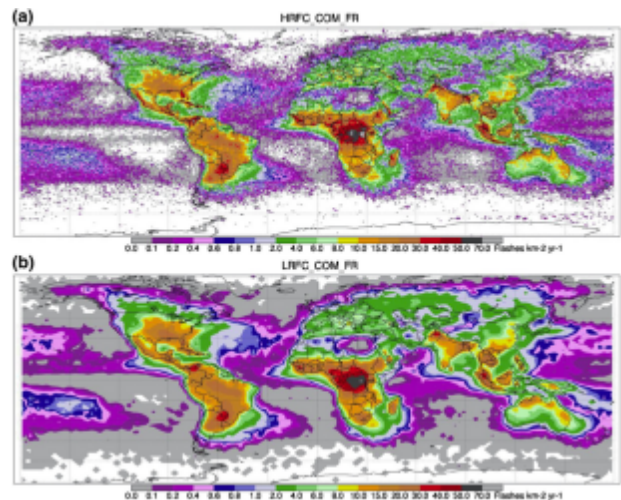


Figure 9 - Map of detected $flashes\ yr^{-1}\ km^{-2}$ obtained between the years 1995 and 2010 [26].

The major conclusion drawn from the results presented in this work is that the use of Early Streamer Emission air terminals does not provide any significant advantages over conventional protection systems. The advantages claimed for these terminals are exaggerated and when corrections are applied, their performance is comparable to that of Franklin rods.

6- ACKNOWLEDGMENTS

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