Case study to determinate the angle-dependence during the risk determination in lightning protection

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Abstract. To know the formation of the atmospheric discharge is one of the main starting point to create an accurate calculation model. In this paper a study will be discussed what kind of modifications are necessary improve PMAS (probability-Modulated Attractive Space) [1, 2] calculation by taking into consideration the geometrical position of downward leader, especially the direction of the last step between the striking point and the point of strike.

The PMAS is a widely used method to calculate the probability of lightning strike for an object. Based on this calculation it is possible to get the expected number of strikes for a given object in a certain time-period. In the standard method, EGM (Electro-Geometry Method) the correlation between the current and the striking distance are proportional. In the paper [3], for the current distance-dependence was made a weighted solution, but it has no angle-dependence, also. This one was calculated by the help of different EGM.

The connection between the striking distance, lightning current and striking distance is not examined in the case of direction. In the work, the main question is this dependence, and the main goal is to define the context.

1. Introduction

First chapter of IEC 62305 is connected to the risk calculation related to lightning protection, which contains simplifications and suggestions during the formation too. However, these simplifications are mostly based on model calculations. These models need to be refined time to time. On the one hand, because of solutions that are specialized in the fields of application, and on the other, because of the emerging challenges. For example, high structures, such as the wind farms, for which this practical application is not true for other high structures.

In this article, it is shown based on previous measurement results, how the angle-dependence can affect the value of the real risk. To do this, the results are presented through the Probability-Modulated Attractive Space (PMAS) method and the consequences of possible neglect through the Electro-Geometry Method (EGM).
2. Single rod without insulating layer [5]

The polarity-dependence of the attractive space is discussed in detail in numerous publications for single rods, e.g. [1]. In this chapter some, previous case studies will be shown, which will help the demonstration of the angle-dependence. The attractive space for the top of a single rod is different for the different polarities in a single rod and earth arrangement. (The 50\% regression surface is depending on $\varepsilon = z/h$ ($z$ is the height of a possible striking point; $h$ is the height of the examined rod). Considering the geometry, $\varepsilon$ is 1, but according to measurements and experiences in the case of positive lightning $\varepsilon > 1$, while in case of negative one $\varepsilon < 1$.

As it is illustrated in Figure 1, the downward leader was modelled by a conductive rod (55 cm high) and the endpoints of the final jump were recorded. This model represents a tower like buildings. In this case it is assumed that not every discharge hit into the tip of the rod or the ground, but some incidents in the side of the rod also occur. Measurements were carried out with positive and negative polarity. The relative position the top of the rod and the rod model was modified according to a predefined grid (Figure 1). At least 50 impulses were applied at each position.

![Figure 1. Schematic drawing about the measurement.](image1)

A few striking points on the edge of the attractive space were tested (Figure 2). The goal was to investigate the difference between the calculated (theoretical) and the real attractive space. From the measuring point number 200, the strikes ending at the side of the rod is surprisingly high (Figure 2).

![Figure 2. Discharge rates at different endpoint positions of the high-voltage rod (number denotes the ID of the point) (positive polarity).](image2)

![Figure 3. The measured striking points and the discharge distribution (negative polarity).](image3)

The second measurement series is similar to the previous ones, the difference is that negative polarity was used with more measuring points (Figure 3). It was noticed that the attractive space belonging to the side of the rod highly decreased, and the space of the ground is also deformed. In the measurement point number 302, at the edge of the attractive space, ground discharge was not
observed, while in the point number 204, the space of the ground was clearly dominant, still several discharges were observed at the side of the rod (Figure 3).

3. Angle-dependence of the lightning strike

One of the goals was in the cited paper [3] to determinate the azimuthal angle-dependence and probability density of a lightning discharge by the help of the EGM and the rolling sphere method. The model was applied for a 3D high voltage tower structure. To show the difference between this and the PMAS results, a simplified rod arrangement (Figure 4.) was used for this purpose, where \( h \) is the high of the rod (structure), \( R_A \) is radius of the sphere used at EGM and \( R_F \) is the similar then \( R_A \) for the ground.

**Figure 4.** The parameters of the examined arrangement, [2].

**Figure 5.** The two examined points with the two propagation.

The probability density will be maximal if 0° is the closed angle with the rod. However, this is not applicable in the case of PMAS method, because the method defines a 50% surface (attractive volume surface), and the value of the probability is 1 inside this, and 0 outside that. This surface depends on the polarity, and it’s a mathematical solution for \( b=0.5 \) (50% probability). In the Fig. 5, in the point 1 and 2, where the \( dP/dr \) should be different, in this case those look like similar. If the \( dP/dr \) is calculated for a \( dV \rightarrow 0, r \rightarrow 0 \) point, it is possible to get the probability density depend on the angle.

The equation of the PMAS with some modification and simplification is the next:

\[
\frac{dP}{dr}(\varphi) = \frac{kp}{\sqrt{2\pi r_i}} e^{-\frac{1}{2} k^2 p^2 \ln^2 \left( \frac{r_i}{r_m} \right)} \bigg|_{r_x=rsin\varphi, r=r_m}
\]  

(1)

where \( P \) is the probability of the strike at the point \( r_i \) (km); \( k \) is a parameter, which depends on the polarity [2] of lightning; \( p \) is usually between 1.2 and 2 (exponent of \( I/I_m=(r/r_m)^p \)), see explanation in [2]; \( r_m \) is the median value of the striking distance; \( r \) (km) is the striking distance.

The distribution of the \( dP/dr \) depend on \( \varphi \) is the following for the ratio between \( \varphi_x \) and \( \varphi=0^\circ \):

\[
\frac{dP}{dr}(\varphi_x)/\frac{dP}{dr}(\varphi) = (sin\varphi_x)^{\frac{1}{2} k^2 p^2 ln sin\varphi x - 1}
\]

(2)

Because the \( k \) value depends on the polarity (negative: 1/1.52; positive: 1/1.36), it was taken in this calculation as 1. It is a good practice when the goal is to get the relative proportion (Figure 7.).
4. Conclusion

In the first measurement, it was noticed that the space of the ground is also deformed at negative polarity. At the edge of the attractive space, ground discharge was not observed, while in the point number 204, the space of the ground was clearly dominant, still several discharges were observed at the side of the rod (Figure 3).

In the second, angle-dependence calculation gives similar results as in the [3], but the PMAS differential equation (Eq. 1) gives a smaller range for the distribution of the $dP/dr$ proportion, which requires further laboratory measurements to find out the reasons.

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