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Relation Between The Material of Roof and The Risk of Lightning Caused Damage

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***Abstract*—To determine the expected number of accidents caused by a lightning strike has different methods (most popular is PMAS, EGM or SLIM). The aim of the paper to present the case of the further-delvelope of PMAS method throw interesting special case.**

For an air-termination system it is necessary to know the number of the possible lightning strikes for a given area in a given year to design it well. If the methods, which serve that purpose to determinate the risk level, use too much simplification or will be inadequately neglected that could be cause incorrect risk determination.

The aim of this paper is to show one possible case when this could happen.

***Keywords*—PMAS, lightning protection, insulating layer, roof material**

I. Introduction

In this paper, comparison of the well-used models and methods are presented though roof arrangements. In the IEC 62305-ed2 standard, the roof is a discussed part. There are two main case according to the material:

- conductive,
- insulating.

If the material is conductive it has a probability decreasing factor, which is included in the r_f (reduction factor for risk of fire or explosion measures). In this case the roof could be used as an air-termination. But if the material is insulating material (like clay, ferro-concrete etc.) their possible shielding effect is neglected.

In the next chapters, some laboratory measurements will be presented which was made previously in some cases [5]. In this paper there are shown that the insulating coat could not to be neglect in the risk or probability calculation as shown by experience for example for wind power plants, too.

II. The Effect of The Insulation Layer for a Single Rod

First, there will be presented a measurement series are focused on the examination of the effect of insulating layer. Therefore, two types of rod models were created for laboratory tests:

- with insulated coat,
- without insulated coat.

Downward leader was modelled by a conductive rod and the endpoints of final jump were recorded (Fig. 1, Fig. 2) as in further measurements, too. Measurements were carried out by positive and negative polarity. Results were compared to previously published examinations, calculations, measurements and experience of existing wind turbines.

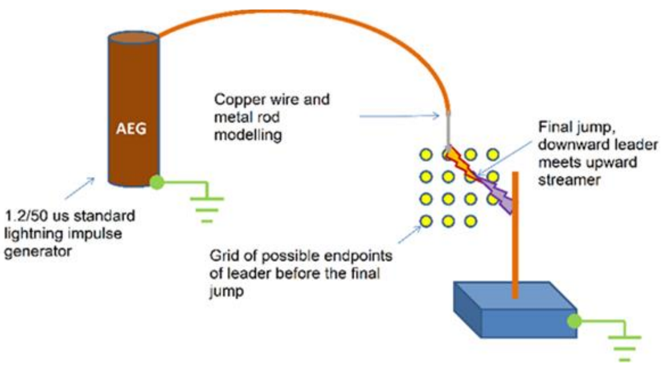

Fig. 1. Schematic drawing about the measurement. [4]

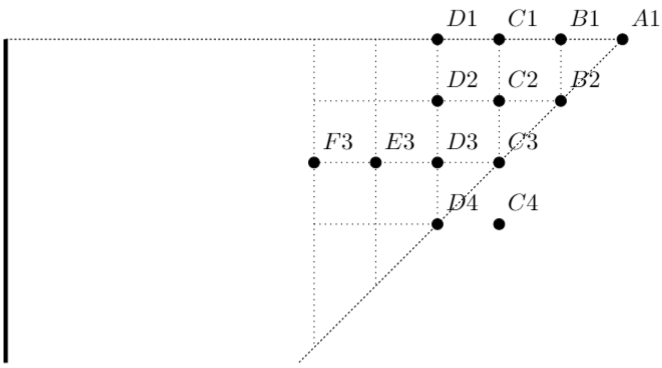

Fig. 2. The coordinates of the measured points.

In the case without the insulating coating, the distribution of the strikes corresponds with the expected ones. From the measuring point C1, the strike ended at the side of the rod is surprisingly high (Fig. 3). In the case with the insulating coating (Fig. 4.), the results were more interesting. The attractive space became very different. The proportion of the discharge, which hit the top of the rod increased, however the measuring points are near to the ground.

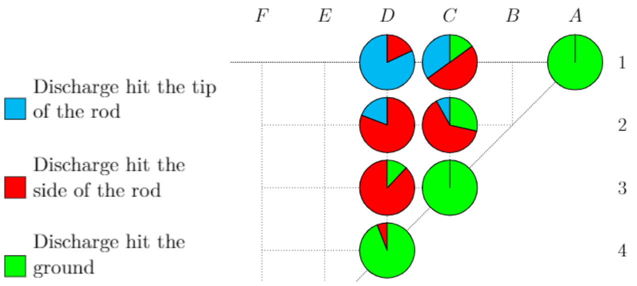

Fig. 3. Discharge rates at different endpoint positions of the high-voltage rod, without the insulating coating (positive polarity) [5]

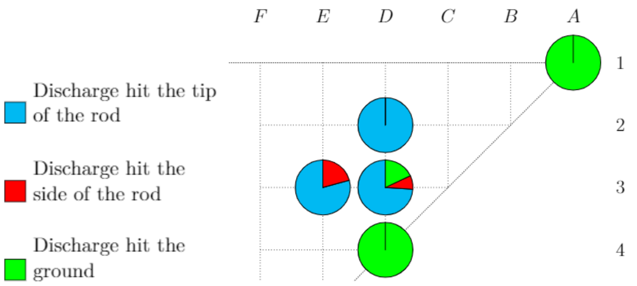

Fig. 4. Discharge rates at different endpoint positions of the high-voltage rod, without the insulating coating (positive polarity) [5]

The third measurement series (Fig. 5) is similar to the previous ones, the difference is that negative polarity was used with more measuring points, and only uninsulated model was applied in this case.

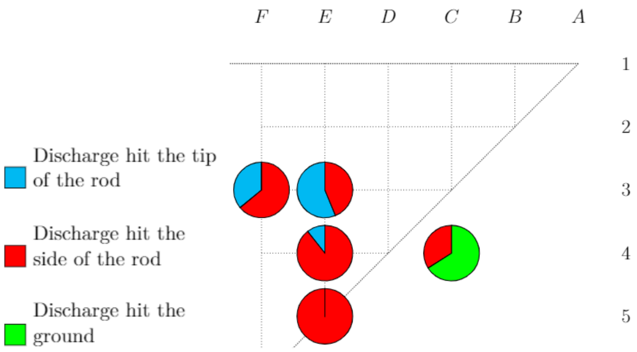

Fig. 5. Discharge rates at different endpoint positions of the high-voltage rod, without the insulating coating (negative polarity). [5]

It was noticed, that the attractive space belonging to the side of the rod highly decreased, and the ground's space is also deformed. In the measurement point *E5*, at the edge of the attractive space ground discharge was not observed, while in the point *C4*, the space of the ground was clearly dominant, however several discharges also were observed at the side of the rod (Fig. 5).

III. About The Use of The Probability-Modulated Attractive Space Method

The Probability Modulated Attractive Space (PMAS) method is a mode to determinate the expected frequency of lightning strokes attached to a certain object. The basis of this method is similar to the Electro-Geometric Model (EGM), [1].

From the point of the application of PMAS it is very important to determinate the boundary (50% regression surface) of the attractive space. According to the experience, this boundary differs from the one generated according to pure geometric method (points that have the same distance from the object and the ground / air termination). In additional to, the boundary surface is polarity dependent.

The striking point is that point, where the endpoint of the downward leader is at the moment, when the return stroke is starting. The distance, between the striking point and the point of strike, is the striking distance, which is dependent on the lightning current. There are different methods to describe this dependence. [2][3]

$$N_F = N_G \int_V b \frac{dP}{dr} dV \tag{1}$$

$$N_{F_a} = N_G \int_{V_a} \frac{dP}{dr} dV \tag{2}$$

In the equation (1) and (2) the P is the probability, the r is the striking distance, V is the volume, N_G is the number of the strikes for a km^2 and a year.

In reality, the attractive space is an abstract term. Although it can be considered, that from a given striking point the lightning attachment will happen to the closest object, it happens only with a given probability. (Let us denote it by b.) So, in the reality, the attractive space of an object gives that points where the probability is higher that the stroke will be attached there than to other point. Therefore, the interface is determined by the points, where the probability of the stroke is $b = 0.5$. (Equation 1. and for the attractive space only the Equation 2.) To each point of the attractive space it is possible to give a dP/dr value:

$$\frac{dP}{dr} = \frac{k\,p}{\sqrt{2\pi r}} exp\left(-\frac{1}{2}k^2\,p^2\,ln^2\frac{r}{r_m}\right) \tag{3}$$

where k is the parameter, which is dependent to polarity of the lightning, p is a value between 1.2 and 2, r_m is the median value of the striking distance and r is the striking distance.

The attractive space for positive and negative polarity is different.

IV. The Probability Dependence for Roof Arrangaments

The result of these investigations is directly not comparable, because they give information in different forms. [6] represents calculations for the highest current Imax that can reach the roof. It is a useful information but does not contain information about the number of lightning strikes where $I \leq I_{max}$.

The paper [2] gives a percentage, what portion of lightning stokes will reach the roof instead of the air termination. However, it is a good tool to compare different versions of air terminations, Ng annual ground flash density must be considered by the evaluation. The same percentage of the efficiency result in different mean time between shielding failures (MTBF) at such places where N_g values are different. (It is obvious that MTBF is 10 times shorter where $N_g = 10$ than in case of $N_g = 1$ at the same percentage of efficiency of the air termination system.)

[2] represents the result of calculation in a form that contains the mean time between the shielding failures. To convert it into %, the following calculation has to be made.

$$N = \frac{1}{MTBF} \tag{1}$$

$$N^* = N_g\, A \tag{2}$$

$$P = 100\,\frac{N}{N^*} \tag{3}$$

where N is the ground flash density (strike/year/km^2); N^* is the ground flash density (strike/year/km^2); N_g is the ground flash density (strike/year/km^2); A is the surface of the roof (m^2) and P is the probability.

Here A denotes the surface of the roof, 40 m×40 m. Results of the calculation can be seen in Fig. 6. Mesh size from the lower curve to the highest one is 5 m×5 m, 10 m×10 m, 20 m×20 m and 40 m×40 m respectively. Horizontal axis represents the height of the mesh in cm, vertical axis gives the probability of interception failures in %. Blue (solid) curves: results according to [7]. Red (dashed) curves: results calculated from [8]. Black (dotted) curves: calculation results according to PMAS using standard parameters.

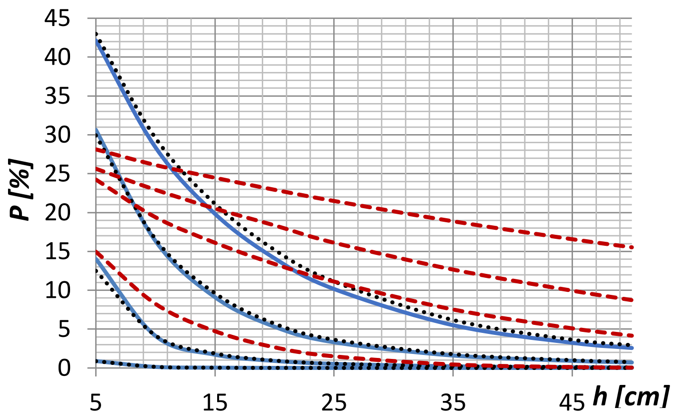

Fig. 6. The results for the 40 m×40 m roof.

It is interesting that there is significant difference between the red and the other curves. There are three main reasons of that., First, in [8] different height of building was taken into account than in [7] (20 m instead of 10 m). Second, different density function was applied in [8] than the standard one. Ad finally, the third: the attractive volume has different border in [8] than in [7]. This difference becomes significant in case of wider mesh, because the overlapping of the real distributions of values b (not the simplified attractive spaces) are not negligible. Detailed analysis can be found in [1]

To illustrate the aforesaid effect, laboratory measurement was made with an air termination model arrangement containing four conductors as a border of a square and four rods at the edges, see Fig. 7.

V. Laboratory Measurements for Special Roof Arrangement

The presented arrangement was placed on a flat metal plate. The high voltage electrode was situated in such a way that its endpoint was above the centre point of the square. The results are represented in Fig. 7. The distance between the plate and the endpoint of the high-voltage (HV) electrode can be seen near the diagrams.

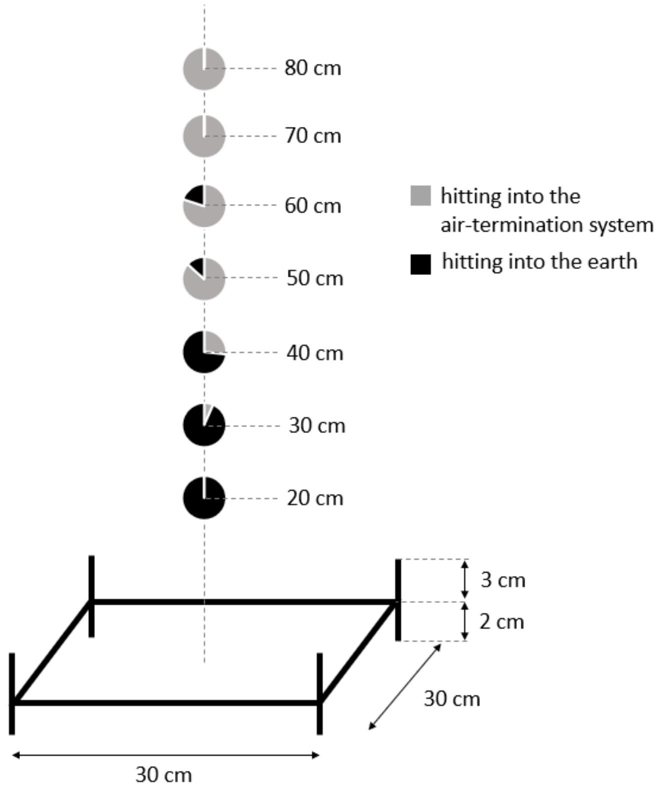

Fig. 7. The results for the 30 cm×30 cm arrangement in the case of pozitive polarity.

In Fig. 8., two pictures about the measurements can be seen. It can be observed, that more upward discharges start, even the downward channel can have branches, but the attachment happens usually to one point of strike.

If we consider which distance is shorter: the plate–HV rod or the air termination–HV rod distance (boundary of the attractive space is a parabola and parameter epsilon equal to 1), the highest point of the b = 0.5 curve is approximately 24,5 cm in the presented arrangement. But even at 40 cm height of the HV rod endpoint the ratio of strokes hitting the roof was higher than 50%, so the attractive space of the air termination was smaller while of the roof is higher. This situation is illustrated in Fig. 10.

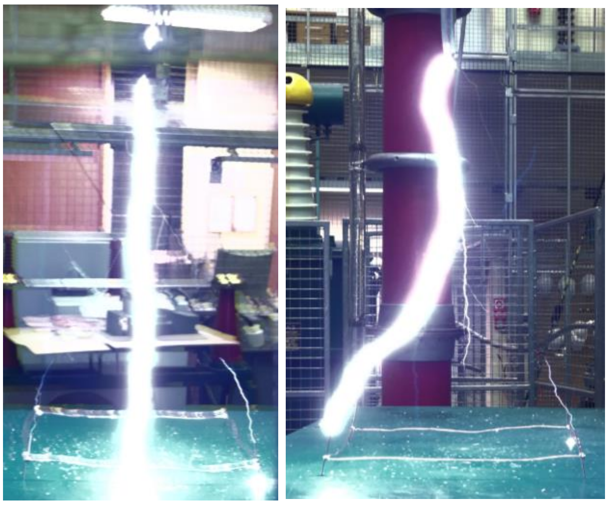

Fig. 8. Some interesting photo about the progression of the downward- and the upward-leader.

Remark that theoretically an ellipse can be closed but its section above the short axis for calculation can be replaced as it is shown in Fig. 9. [1] As a result, the metal plate receives significantly more discharge, and this leads to the significant higher probability values of the red curves in Fig. 6.

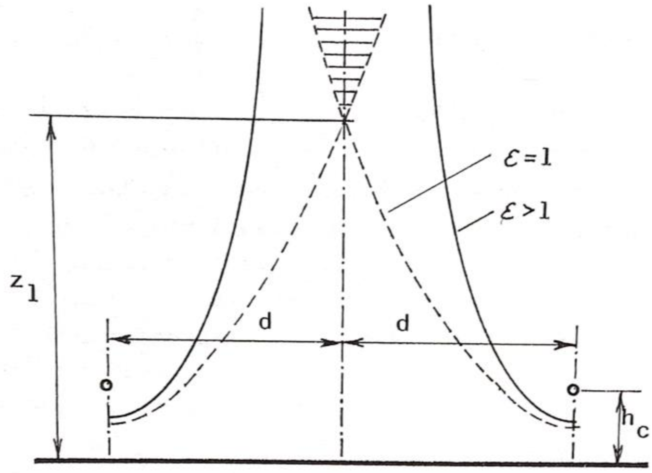

Fig. 9. Overlap of the transition zones when the 50% borders do not interact each other. [1]

Covering the metal plate by a plastic layer increases the number of stokes hitting the air termination drastically. As it was pointed out by Horváth, in such case the endpoint of the HV rod must be much lower to produce discharge that runs along the insulating surface to the foot of the grounded rods. That can be taken into consideration by decreasing the parameter epsilon for the air termination, resulting in less portion of strokes damaging the roof.

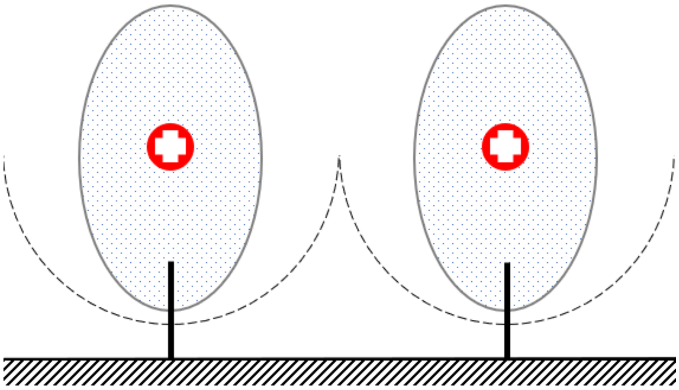

Fig. 10. The attractive volume boundary surface for pozitive polarity based on Horváth (solid curve) and Kern (dashed curve).

VI. Conclusion

The expected number of strokes in different structures depend not only on the geometrical arrangement. It is a useful tool in the designing process, to base the positioning of air termination on geometric data, but for the evaluation of the effectiveness of an air-termination system further properties shall be taken into consideration. One of these properties is the material of the object to be protected. After a theoretical overview of the effect of insulating layer for a single grounded rod, numerical analysis compared to laboratory results were presented in case of flat roofs to obtain better estimation of risk caused by lightning.

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