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Field Testing Review

Background

This document follows on from the previous one which provided a detailed description of the calculations underlying the Collection Volume Method (CVM) for positioning air terminals on structures and around sites and facilities for protection against cloud-to-ground lightning discharges. The aim of the previous document was to provide a traceable procedure for numerical calculations of the collection volume and attractive radius of a specified point.

The present document provides a different perspective on the matter in the sense that it synthesises the results of unprecedented "real-world" studies on the interception characteristics and performance a lightning protection system (LPS) in the field (on real buildings under real lightning conditions). It is shown that the CVM yields interception efficiencies at least equal to the protection provided by traditional air terminal positioning methods and hence air termination systems.

Hence, this second document attempts to demonstrate the Collection Volume Method (CVM) is an improved electrogeometric model (EGM) when compared to more traditional, simple EGM-based methods such as the rolling sphere method (RSM) prescribed in the IEC 62305 standard. The improvement is achieved by considering different points of electric field intensification and hence introducing efficiencies by not needing to protect low-probability (flat) surfaces to the same extent as the sharper features.

Overview of the Field Studies

The two real-world field studies referenced in this report, namely Petrov & D'Alessandro (2002) carried out in Hong Kong and D'Alessandro & Petrov (2006) carried out in Malaysia, have been published in the prestigious "Proceedings of the Royal Society of London A". It is a high-quality, international-class journal with very stringent peer-review, for the publication of novel, interdisciplinary research findings. Full citation details can be found in the reference list.

In this section, a very concise overview of the relevant aspects of each paper is provided along with the main result from the research of relevance to this report, namely the features of the improved EGM / CVM, quantification of interception efficiencies and comparisons with the IEC standard.

Petrov & D'Alessandro (2002): Hong Kong

In this study, various models of lightning interception were analysed against real lightning strike data from Hong Kong. The field data spanned a period of 8 years and was taken from 161 structures ranging in height from 10 m to 370 m. These structures were protected with lightning air terminals that had been positioned in the optimum roof location(s) using an improved electrogeometric model, namely the Collection Volume Method (CVM). One of the goals of the paper was to determine the validity of Eriksson's "attractive radius model", which is at the heart of the CVM. In doing so, an assessment was carried out on the effectiveness of the CVM.

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It is important to realise that this study did not involve the gathering of lightning bypass data (how many strikes might miss the lightning protection system) and hence did not evaluate the interception efficiency of the system (percentage of all incident lightning strikes that would normally be captured).

The attractive radius concept of Eriksson, as the basis of the CVM, is described in Section 1(c) of the paper. The most important aspect of this concept is that the attractive radius (or range of capture of lightning by any point on the structure or the air terminal on the structure) is a function of its height above the ground. So, all attractive radius models include a height term in the equation. The CVM includes this dependence, as do many other modern models of lightning interception. The RSM, being based on the simple EGM, does not include any height dependence. This height-dependence constitutes a fundamental difference between the RSM and newer methods like the CVM.

In summary, the aspect of the Hong Kong study of relevance to the CVM was the comparison, using rigorous statistical methods, of the total number of expected, incident strikes to the buildings in the study with the actual number of strikes captured by the LPS's.

D'Alessandro & Petrov (2006): Malaysia

This paper analysed 13 years of lightning strike and bypass data for buildings in a high-lightning region of the world (Klang Valley, Kuala Lumpur). The data sample was comprised of 86 structures with a mean height of 57 m and mean exposure time of 6.9 years. These structures were subjected to 384 flashes over a total observation time of 592 years. Each building was equipped with a lightning protection system (LPS). Since a practical and economical LPS with 100% efficiency does not exist, the major aim of this study was to determine the proportion of strikes captured by the LPS out of the total number of incident strikes. This quantitative study was remarkable in the sense that such an analysis had not been carried out since the discovery of lightning protection by Benjamin Franklin more than 250 years ago. After the application of a wide range of statistical tests on the data, it was found that the percentage of strikes captured was about 87%, in excellent agreement with three leading theoretical models of lightning interception.

Apart from the unprecedented nature of this landmark paper, it should be noted that all of the lightning capture terminals in this study were placed in the optimum locations on the structures using the CVM. By "optimum" is meant that the CVM was used to produce the most efficient positioning of the air terminals for the stated interception efficiency or protection level. For air terminals positioned with the CVM, the typical interception efficiency is between about 84% and 99%, i.e, in accordance with the IEC standard for lightning protection (see IEC 62305-1).

These percentage values are derived from a standard cumulative frequency distribution of peak lightning stroke current, e.g., as given by Anderson & Eriksson (1980) or Berger et al (1975) and are common to the RSM and the CVM. For example, approximately 91% of all strikes result in a peak current greater than 10 kA. On average, at least this portion of the strikes expected to be intercepted by the LPS. Up to, but not necessarily all of the remaining 9% of low-intensity strikes may by-pass the LPS. This concept forms the most fundamental risk-management principle in lightning protection and also provides a relatively straightforward quantitative indicator for assessing the effectiveness of a LPS in the field.

Analysis

(a) Introduction

A crucial point to note about both field studies is the importance of having sufficient statistics to carry out a valid study with solid conclusions. In general, a valid statistical analysis requires > 20 data points. Therefore, to work with strike data from an individual site or structure may require decades of field observations, i.e., it is impractical. Even sub-groupings, such as those shown in Table 2 of the Malaysian study paper, show that analysing only small sections of the data is not appropriate. Hence, to make a comparison of the observed interception efficiency with the desired or estimated value, we need to use the entire data set.

In addition to statistical requirements, the temporal and spatial variability seen in a stochastic process such as lightning strike incidence means that averaging is absolutely necessary in field experiments. A study involving a single structure may require an exposure period of 30 years, while a study on a sample size of 100 structures might only require a few years of exposure.

So, in both studies, all of the strike data were combined to allow the analyses to be made with statistical validity. The inherent statistical assumption in this approach is that all the data from the buildings belong to the same "population" and that no buildings have features which differentiate them significantly from the rest of the buildings. It was shown in the paper that these uncertainties are less than the fluctuations observed in normal lightning processes.

(b) Hong Kong study

The air terminals comprising the LPS's in this study were placed in the optimum locations on the structures using the CVM. In practice, the IEC protection levels in the range 84 – 99% are desired, with designs at higher percentages (97% and 99%) typically required for sensitive and explosive assets and designs at the lower end being carried out for "ordinary" buildings (either at 84% or 91%). So, in the Hong Kong study, a protection level between 84% and 91% would be expected.

As noted earlier, this particular study did not produce data for measuring interception efficiency directly. Instead, it was focused on validating the attractive radius models of Petrov, Eriksson and Rizk, i.e., showing that strike incidence has a dependence on structure height and also quantifying the relationship. The numerous analyses described in the paper showed that there was indeed the structure height dependence predicted by the models.

It is possible to obtain some indirect indication of the interception efficiency of the LPS's by comparing the observed number of captured strikes with the total strike incidence predicted by the models. The main difficulty in providing a definitive value lies in the fact that the ground flash density (GFD) in Hong Kong is not known (or, at least, it is not publically available). The Hong Kong Observatory (HKO) only established a lightning location network in mid-2005, and since it takes 5-10 years to obtain a reliable value of the average GFD, there is no HKO lightning density data available as yet.

The analysis of the Hong Kong field data indicated that a GFD between 1.8 and 2.8 flashes.km−2.yr−1 is the most appropriate value. Indeed, the well-known equation of Anderson & Eriksson (1980) gives a value of 2.8 flashes.km−2.yr−1 for a keraunic level in Hong Kong of ~ 40 thunderdays per year.

From Table 1 in Petrov & D'Alessandro (2003), the mean value of ne_h (total expected number of strikes, allowing for height-dependence effects) for the attractive radius models considered is 111. As shown in the paper, the total observed number of flashes was 103. Therefore, 103/111 or approximately 92% of all flashes are estimated to have been intercepted by the LPS's. Such a value is consistent with the typical design interception efficiency expected from traditional LPS's based on the RSM or similar methods.

In summary, the Hong Kong study demonstrated the validity of the attractive radius models, upon which the CVM is based, in showing the striking distance is a function of the height of the structure. Also, using the overall statistics, an interception probability of around 90% was estimated.

(c) Malaysian study

From the data presented in Table 2 of D'Alessandro & Petrov (2006), it can be seen that the total number of lightning flashes captured was 338 and the number of by-passes was 48 over the equivalent observation period of 592 years. Using these values, the observed interception efficiency was found to be 87.5%.

Also from Table 2, a mean value of 80% was calculated for the expected interception efficiency across the whole sample from the location and number of air terminals located on the buildings. It is important to understand the background to this value. It can be summarized as follows:

- Air terminals comprising the LPS's were placed in the optimum locations on the structures using the CVM.
- Rather than relying on the assumed protection level which had been documented at the time the LPS was installed, a CVM analysis was carried out for each building in order to obtain a reliable estimate of the interception efficiency of each LPS at each site.

- This analysis gave a mean interception efficiency of 80% rather than a value of 90% or more, as would be expected or desired for normal structures.
- Investigation of the difference revealed a number of "human factors" that sometimes creep into the installation practices of LPS's and which are out of control of the LPS system designer. Two classic examples are:
  - Post-installation of antennas, dishes, UHF radio equipment, advertising signs, structural alterations, etc. often occur. These will alter the protection level of the LPS that was installed beforehand, especially if the items are of similar or greater height than the air terminals.
  - Sometimes, a LPS would be installed in the "shielding zone" of taller, adjacent buildings which were not divulged in the plan sent with the design request.

The interception efficiency of 80% that was calculated took all of these factors into account and hence can be treated as a conservative estimate of the level of protection to be expected.

Comparing the actual or observed interception efficiency of 87.5% with the theoretical or expected design interception efficiency of 80%, it can be seen that the observations agree very well with and in fact exceed the expectations of the CVM design process.

The paper by D'Alessandro & Petrov (2006) also presented a theoretical estimate of the interception efficiency expected from the attractive radius models of Eriksson and Petrov. Using a known median current of 33 kA for Malaysia, the theoretical interception attainable from the Eriksson and Petrov models was 86% and 83% respectively. Hence, both are in excellent agreement with the observed protection level of 87.5%.

Conclusions

The results from both field studies clearly show that the efficient design obtained using the Collection Volume Method (CVM) for placing a Lightning Protection System (LPS) on ordinary structures does not compromise the performance of the system in any way. The interception efficiencies observed for the existing LPS installations in Malaysia and Hong Kong lie between the IEC LPL's III (91%) and IV (84%) as designed using the Rolling Sphere Method (RSM) or similar traditional methods. Hence, it can be concluded that the existing, CVM-placed LPS's in the field studies provided equivalent protection to traditional RSM-based LPS's at IEC LPL III or IV.

Importantly, the two field studies have shown that interception efficiencies of almost 90% can be obtained with a minimum CVM design, i.e., the most cost-effective LPS, and that these measured efficiencies actually exceed the expected values from the design. For example, in Malaysia, given the number and position of air terminals on the buildings surveyed, an efficiency of 80% was expected but, in fact, the field observations showed that the actual value was 87.5%.

When higher protection levels are required, a larger number of air terminals of sufficient height and correct positioning according to CVM computer modelling will result in higher interception efficiencies. For example, if the LPS is designed at 98% (IEC LPL I), then this level will be met and, based on the results of the field studies, will most probably be exceeded.

In terms of a traditional Franklin rod LPS, it is clear that the use of the CVM calculation algorithm will result in the removal of unnecessary rods and the optimum positioning of the remaining rods, yet still achieve the same protection efficiency as the LPS designed using a traditional method such as the RSM.

References

1 Petrov, N.I. & D'Alessandro, F., 2002, "Assessment of protection system positioning and models using observations of lightning strikes to structures", Proc. Roy. Soc. Lond. A, 458, 723-742.

2 D'Alessandro, F. & Petrov, N.I., 2006, "Field study on the interception efficiency of lightning protection systems and comparison with models", Proc. Roy. Soc. Lond. A, 462, 1365-1386.