EFFECTIVENESS OF WORLDWIDE EXISTING ESE LIGHTNING PROTECTION SYSTEMS MANUFACTURED IN EUROPE

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Abstract

Scientific basis of any kind of external lightning protection system (protection against direct lightning strikes to buildings) is empirical. Statistics on existing external lightning protection installations are needed to perform effective empirical studies. For this reason it is unexpected the lack of statistical publications on existing lightning protection installations in relation to the number of installed systems, their location and effectiveness.

This has led the authors to make the present study where the empirical experience of ESE lightning protection systems is analyzed.

The aim of this paper is to evaluate the effectiveness of ESE lightning protection systems for buildings and open areas. This study analyzes the data of the ESE LPS manufactured in Europe and installed worldwide, and demonstrates that, according to the expected strike frequency, the external lightning protection using ESE air terminals has been effective.

1. INTRODUCTION

The objective of the external lightning protection system is to intercept lightning direct impacts on buildings and to conduct and disperse this electrical energy into ground. The scientific basis of any kind of standardized external lightning protection system (meshed conductors, Franklin rods, stretched wires or ESE air terminals) is empirical and therefore their effectiveness should be verified by analyzing the results of the experience accumulated over the years by the installed LPS. Precisely for this reason, it is just surprising the shortage of statistical information, and its scarcity of data and detail on existing lightning protection installations, whether the source is national or international, in relation to the number of installed systems, their location and effectiveness. Many quotes can be found where this fact is highlighted. For instance the so called "Bryan Panel" pointed:

> *"It would appear the ultimate evaluation of any complete lightning protection system would be the performance of the systems as installed on buildings."* [1]

M. Guthrie, NFPA 780 and IEC 81 Chairman, in his 18th September 2000 letter to the Standards Council explained:

> *"Positive feedback on the operation of a lightning protection system is seldom documented and most often not even noticed. Only in some rare cases can it be documented that a lightning protection system has been struck if it works properly and there is no damage"* [1]

In 2001 a group called "Federal Interagency Lightning Protection User Group" addressed a document to NFPA titled "The Basis of Conventional Lightning Protection Technology", where the existing studies and incidents were reviewed. There were mentioned among others the statistics performed by the Iowa Marshal form 1956 to 1966 and another ones from the Underwriters Laboratories form 1923 to 1950. However, Robert W. Rapp from Underwriters Laboratories stated in his 12 June 1995 letter to the NFPA Standards Council that Underwriters Laboratories (UL) cannot provide field data showing the number of lightning-related incidents associated with conventional lightning Master Labelled systems. Considering the small posterior interest in the LPS statistical analysis, this group concludes that the small number of accidents in protected buildings has leaded to a confidence on their reliability thus considering the efficiency of LPS as proven:

> *"Despite a great deal of exposure to lightning, the number of accidents we suffer is quite low… We are convinced these systems are highly effective in preventing lightning damage…. Lightning protection systems as specified by NFPA780 are highly effective in preventing lightning damage"* [2]

In the last decades buildings and the electric equipment inside them have become more complex. Lightning often causes damages to unprotected structures and standards have changed trying to improve protection. Yet there are hardly recent surveys about LPS effectiveness. From a purely statistical point of view only these studies have been found:

- In 2002 the Ministry for Ecology and Durable Development (MEDD) of France commissioned a survey on the lightning protection on a data base of 1581 high-risk industrial facilities in that country. The conclusion of this survey showed that the lightning protection standardized solutions in force in France, both ESE and conventional, are satisfactory. [3]

- The International Lightning Protection Association (ILPA) shows statistics of ESE lightning protection systems from 1986 to 2008: 550,000 units were installed worldwide with an accumulated experience of 4,652,600 years (http://www.intlpa.org)

  The AFBEL/SERCOBE published the updated Spanish manufactured ESE statistics: 232,107 units, worldwide installed, with an accumulated experience of 1,189,930 years of service.

- The Slovakian National Committee, in their document BT134/DG7564/DC/SK April 2009, has stated: *"In Slovakia more than 4000 systems were installed with satisfied customers"*

- "A statistical analysis of strike data from real installations which demonstrates effective protection of structures against lightning", from F. D'Alessandro, reporting the statistics for almost 200 installations in Hong-Kong during the period 1988-1996.[4]

- The company Aplicaciones Tecnológicas, S.A. has recently done a study on 4645 ESE installed in Spain and verified periodically. This work demonstrates, by several means, that the lightning protection by ESE has been fully effective, including at structures where the lightning activity was verified. The results are ready to be published [5].

This situation has led the authors to make the present study where the field worldwide experience of ESE lightning protection system is analyzed.

2. OBJECTIVE

The aim of this paper is to demonstrate the effectiveness of ESE lightning protection systems for buildings and open areas using the available real data. This study analyzes the statistics of the ESE LPS manufactured in Europe and installed worldwide and demonstrates that, according to the expected strike frequency, the external lightning protection using ESE air terminals has been effective.

It is commonly accepted that expected lightning strikes on a structure is calculated by multiplying the lightning density (N_g) by the equivalent collection area of the structure (A_d), taking into account the location factor (C_d).

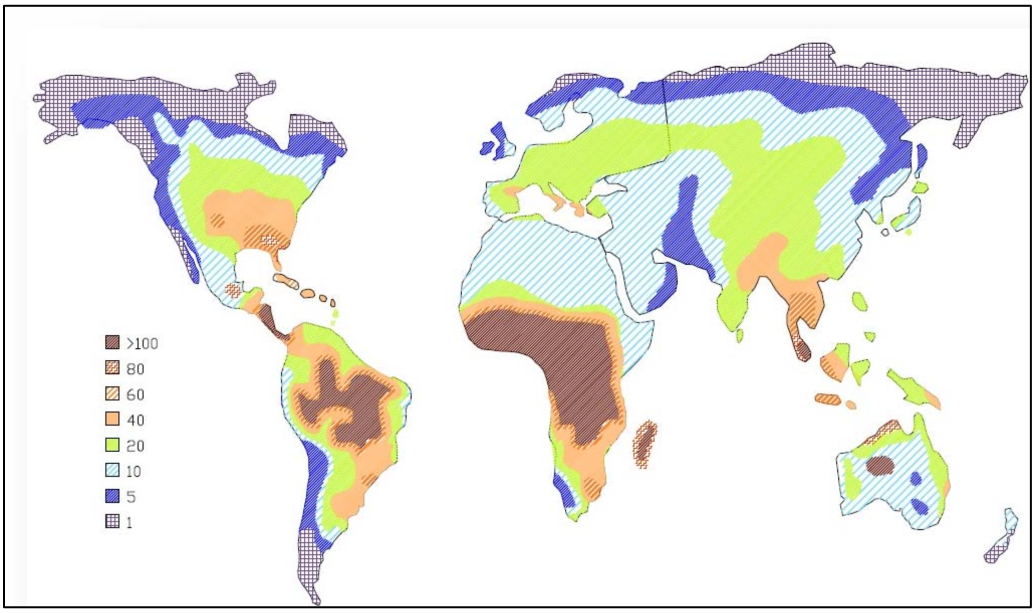
$$N_d = N_g \cdot A_d \cdot C_d$$

Therefore, these parameters have to be estimated for the whole of the ESE LPS installed. Obviously the precision is not strict but the aim is to find out the order of magnitude of the expected lightning strikes to the protected structures.

3. CORROBORATION

a) N_g calculation

The accuracy of the data Ng is actually quite poor when the whole world is considered. Some countries have more precise lightning distribution maps, but the most accepted isokeronic map for the whole world is the one included among other sources in the British Standard BS6651-1999, coming from the World Meteorological Organization. This has been the basis for calculating an average Ng in the present study. A graphic program has been used for estimating the percentage of the areas with each isokeronic level:



N_g has been calculated using the formula $N_g = 0.04 \cdot N_k^{1.25}$ [7]

Days of storm per year	100 or more	80	60	40	20	10	5	1
N_k (y^{-1})	100	80	60	40	20	10	5	1
N_g (strikes/km^2, year)	12.6	9.6	6.7	4.0	1.7	0.7	0.3	0.1
% total area	9%	1%	3%	12%	22%	30%	11%	12%

Taking into account the N_g in the world (the sea has not been considered as we are focused on the protection of structures) and the weight of each of them, it can be considered with a rough approximation that the average Ng in the world is **N_g = 2.5 strikes/km^2, year**. It is also a good average number for France, Portugal and Spain where many ESE LPS are installed.

b) A_d and C_d calculation

For isolated structures on a flat ground, the collection area A_d is the area defined by the intersection between the ground surface and a straight line with 1/3 slope which passes from the upper parts of the structure (touching it there) and rotating around it. For the case of an isolated rectangular structure with length L, width W, and height H on a flat ground, the collection area is then equal to:

$$A_d = LW + 6H (L + W) + 9\pi H^2$$

However, when the structure is surrounded by other objects, this should be compensated by a location factor C_d given in the following table:

Relative location	C_d
Object surrounded by higher objects or trees	0.25
Object surrounded by objects or trees of the same heights or smaller	0.5
Isolated object: no other objects in the vicinity	1
Isolated object on a hilltop or a knoll	2

A typical building to be protected may be:

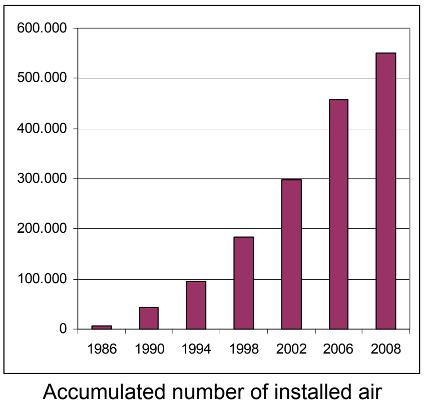
A_e = 30,000m²

C_d = 0.5

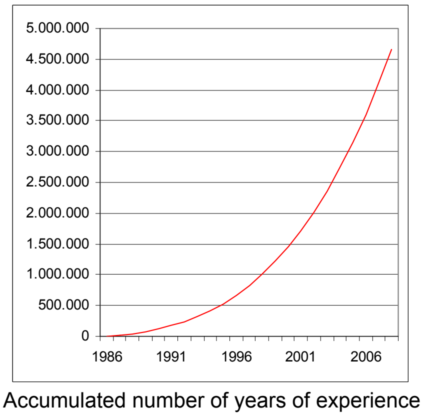
c) Number of installations and years on service

The International Lightning Protection Association (ILPA) gives statistical data about the air terminals of this type that have been manufactured, according to the national standards, in Europe. The data are the following:

"In 1986, which is the first year of available statistics, number of ESE was 4,088 when in 1996 it was already a cumulated number of 112,412 units.
In 2009 the cumulated number of installed units is 550,000.
Total number of ESE units per years is now 4,652,000."



Accumulated number of installed air terminals



Accumulated number of years of experience

Taking these numbers, which cover only a part of the ESE air terminals since the manufacturers of countries outside Europe have not been counted, it is clear that many lightning strikes are expected on the protected areas:

- Total number of air terminals considering the years they have been installed:

$$N_T = 4{,}652{,}602 \text{ units} \times \text{years}$$

- Typical collection area: $A_d = 30{,}000$ m²
- Expected number of lightning strikes on a typical collection area (with $N_g=2.5$; $C_d=0.5$):

$$N_d = 0.0375 \text{ strikes/year}$$

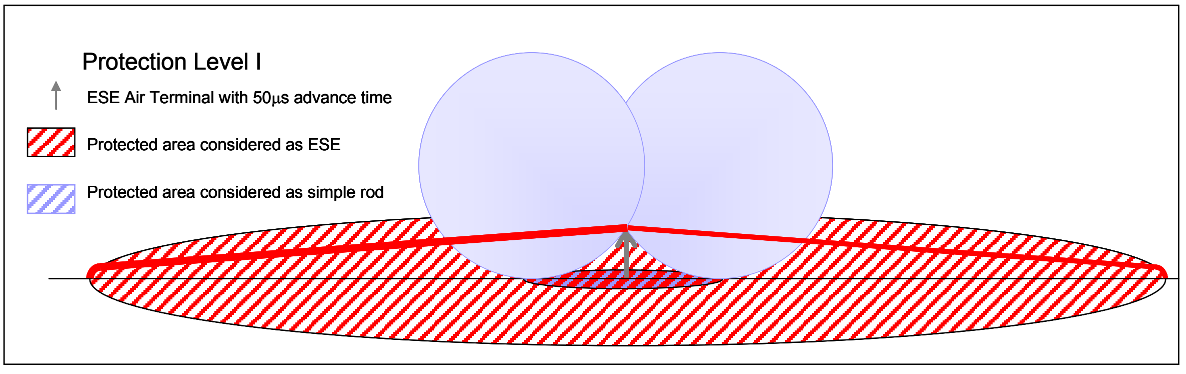
- Expected number of lightning strikes on all the installations during the years they have been installed:

$$\mathbf{N_{dT} = 174{,}473 \text{ strikes}}$$

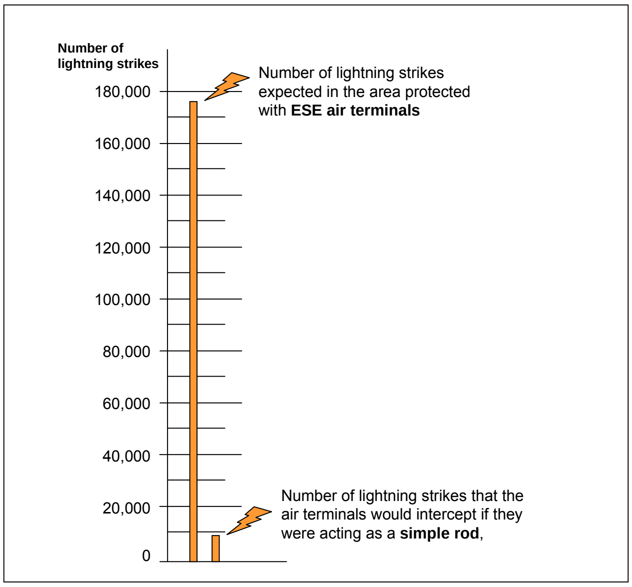
The results are, as explained above, approximated numbers, but they give an idea about the order of magnitude of the protection that the ESE air terminals have been expected to give during the last decades.

4. EXPECTED FLASHES ACCORDING TO IEC 62305

Normally a lightning protection system with ESE air terminals is designed considering that each air terminal protects several 10's meters (typically from 30 to 100m on a 6m mast, depending on the model and on the protection level). Some authors have claimed that the protected area of an ESE would not be greater than the provided by a Franklin rod. Let's consider this point of view: according to the conventional protection described in IEC62305 Series they would protect, on a 6m mast, from 10 to 20m according to the protective angle method, or even less when the shape of the building and the Rolling Sphere is considered. For example, for Protection Level I, if an ESE air terminal with 50µs advance time on a 6m mast is just considered as a simple rod, the protected area is only 5% of the calculated area taking into account the ESE effect. For other protection levels the rate is maximum 9%.



That means that, if ESE air terminals would not be working properly, the vast majority of these 175,000 strikes would have struck the structure and open areas that were supposed to be protected, thus causing thousands of complaints.



5. PROTECTION LEVELS

All lightning protection standards advise that it is not possible to achieve a 100% protection of a structure. Several Lightning Protection Levels (LPL) are defined according to the probability that lightning strikes the protected area. This probability is calculated taking into account the minimum values of the lightning peak current that define the Rolling Sphere radius.

Interception criteria	**LPL**			
	I	**II**	**III**	**IV**
Minimum peak current (kA):	3	5	10	16
Rolling sphere radius (m):	20	30	45	60
Probability of greater lightning parameters:	99%	97%	91%	84%

There are thus a number of expected by-passes. Taken the calculated N_{dT}, the "accepted" failures are 1,744 strikes when the more restrictive level, LPL I, is considered. These are high numbers both for passive and active protection, but all lightning protection systems are designed with these criteria.

The negligible number and especially the minor importance of the incidences in structures protected with ESE air terminals demonstrate that the experience with active lightning protection systems is effective and satisfactory, as equally happens with conventional systems, and therefore the ESE national standards have provided the rules for this good practice, assuring the correct installation of each part of the lightning protection system.

6. CONCLUSION

An empirical study of effectiveness have been done on the European-made ESE lightning protection systems installed worldwide in accordance with the national standards in force at Europe for this type of LPS.

For this aim, the following data have been taken into account:

- European statistics about the number and years of service of ESE manufactured in Europe.
- Medium size building world type and world Ng established.

- Number of lightning discharges that are expected to hit the protected buildings and structures. Calculation has been made in accordance with established risk analysis of IEC/EN 62305-2, as well as ESE national standards
- Number of tolerable bypasses for the different protection levels under the above mentioned regulations.

The study shows that during the 4,652,600 accumulated years of service of these 550,000 ESE LPS, 174,473 lightning discharges were expected on the protected facilities. According to the available data, the assessment of incidents to the referred premises is negligible: very small number, insignificant material damages and no personal injuries. It is very important to highlight that the number of these rare incidents are much smaller than an order of magnitude with respect to the most restrictive level accepted by the rules outlined.

Furthermore, this paper provides an interesting analysis of the lightning protection areas of these ESEs when compared with the protection areas obtained if they were considered just as mere simple Franklin rods. The result of this comparison indicates that in the second case more than 165,000 lightning discharges would not have been intercepted and therefore would have to cause damage to protected structures, and therefore thousands of claims. Obviously this is not the case.

In conclusion the study describes 25 years of safe and effective ESE lightning protection experience, demonstrated by the 4.5 million accumulated years of service of the more than 550,000 units installed worldwide, many of them installed in countries with the highest rate of annual lightning storms. On the other hand ESE European national standards have also shown to be safe, effective, practical and useful.

The authors would also like that this document lessens the shortage of data and statistical studies about existing lightning protection system installations and their effectiveness.

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