XIX INTERNATIONAL ELECTRICAL ENGINEERING SYMPOSIUM

Title

Positive experience of external lightning protection in Cuba: empirical validation of Early Streamer Emission air terminals

Eng. Yasser Gálvez Castillo. *STCI specialist from UEB APCI Development and Certification.*
Eng. Alcides Rivera Camejo. *Fire Protection Agency Assistant Director.*

Abstract

Historically, external lightning protection (air terminals or lightning rods) has been a subject of theoretical controversies, from Benjamin Franklin times until now. During all this time, the absence of scientifical validation of any type of Lightning Protection System (LPS) made it not possible to conclude this controversy. Such validation is difficult due to several reasons:

- *In a laboratory, only certain lightning features can be reproduced, since there are scale problems that impede the full reproduction of such a complex and high magnitude phenomenon.*
- *Field tests with natural lightning do not receive a statistically significant number of lightning strikes, nor are they representative of the geographical, architectural and climatological variety, so the statistics obtained cannot be applied to global models.*
- *The performance of an independent scrutinization on the existing facilities implies a dissuasive economic cost, a high complexity and a considerable investment of time.*

In our country, the Republic of Cuba, this singular scrutiny has been possible thanks to the following conditions:

- *One of the highest isoceraunic levels in the orld*
- *The design, installation and use of LPS are controlled and audited exclusively by the Cuban Fire Protection Agency (APCI, in Spanish), so the available data are organized and centralized.*
- *There are thousands of installations and more than 20 years' experience.*

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This paper is the first international, industry-independent document about the empirical validation of external lightning protection systems -in this case, ESE air terminals-, after more than 200 years of lightning protection without a statistically representative survey of any lightning protection system or device. This work is based on data and experience of public institutions and in an environment with very high ceraunic activity, of subtropical climates.

Keywords: Lightning Protection Systems (LPS), empirical validation, Early Streamer Emission (ESE) air terminals, Standardization.

1. Introduction

Lighting protection is based on protection models, which consist of different degrees of simplification of lightning physics. Although many aspects of the physics of discharge are currently known, there are still unknowns due to the complexity and randomness of the phenomenon [1][2].

The first relevant process for lightning protection is the interception process, the attachment of the downward leader and the upward leader, being the second induced by the charge carried by the first one [3][4][5]. Lightning interception air terminals' mission is to be the preferent strike point with a safe path to earth. They achieve it by modifying the electric field, so that the tip of the air terminal emits corona discharges and after then the upward leader, earlier than any other element within its protection area.

In the case of a Franklin rod, this procedure is natural, it occurs in the same way as for any other grounded element (buildings, trees,..). However, an ESE air terminal, besides the field intensification generated by the geometry, there is also a control of such electric field, thus optimizing the upward connecting leader emission process, setting the discharge path and increasing the protection radius when compared with a Franklin rod [6]. This effect is quantified in high voltage laboratories with a test sequence described in UNE 21186:2011 [7], Annex C.

However, the full validation of any air terminal cannot be performed in a laboratory, since high voltage laboratories are not able to completely reproduce the discharge phenomenon since it is highly technical and complex, whilst also requiring to consider other factors, like the

variability of the phenomenon, the atmospheric conditions in which it occurs, the scale factor, etc. Nevertheless, many parameters can be reproduced to study the effects of lightning on materials and devices [8][9][10][11][12][13].

Test fields are not appropriate for these validations, since they do not reflect the diversity of geographical, architectural, climatological, etc. environments. Besides, the amount of obtained lightning strikes is not enough in order to achieve significant statistics [14][15][16].

Therefore, the global working validation of external lightning protection, both with conventional and ESE air terminals, can nowadays only be empirical. In spite of that, there is a lack of structured and reliable documentation for such validation, except for some studies that manufacturers have made in Asia [17][18] and Europe [19][20].

This document mainly highlights the experience of the use in Cuba of lightning protection systems based on ESE air terminals, since they account for around 90% of all LPS installed in the country. The land of the Republic of Cuba, being in the subtropical geographical area, has one of the highest lightning activities in the world. According to the most recent publications of the Center for Atmospheric Physics of the Cuban National Meteorological Institute, the isoceraunic level ranges between a minimum of 30 and a maximum 150 storm days per year, with an average of 80 [21]. Cuba is the 5th country in the world with the highest average of deceases caused by lightning (65 fatalities per year) and the first per number of inhabitants (5,9 fatalities per million inhabitants and year), occurring in open areas and unprotected environments.

This document contains collected information and experience from the competent regulatory bodies, institutions, public project and installation companies and large users, about lightning protection installations from 1997 until now, considering over 9000 structures. These installations are designed, installed and maintained exclusively by professionals accredited by the Fire Protection Agency (APCI), the governmental competent regulatory body, through a very rigorous and supervised process, guaranteeing the objectivity of the entire process since all the entities involved are governmental.

2. *The Cuban fire protection agency (apci)*

The Cuban Fire Protection Agency (APCI) is related with the Republic of Cuba Fire Body (CBRC) and belongs to the Ministry of Interior. This entity has the function of providing integral services of exclusive certification in the field of fire protection, as well as of homologation and approval of projects, means, equipment, substances, materials, systems and facilities. It is also dedicated to the qualification and certification of the human capital linked to these activities.

Regarding its certification activity, it encompasses all the stages of the investment process established in the country, mainly the certification of the executive technical projects, the assembly and maintenance of the fire protection systems. It also handles the certification of both the people who have the responsibility of executing these tasks as well as the entities that perform them. Therefore, there is a strict control of compliance with the regulatory specifications and the quality of the work related to fire protection, through the feedback with the internal certification processes, the verifications of the systems and the communication with the Fire Department, which in Cuba, is the supervisory entity and the authority in the area of fire safety.

All these procedures are applied to lightning protection, since it is one of the specialties related to fire protection in Cuba.

3. *NC 1185 STANDARD*

For many years, there has never been an up to date National standard in Cuba covering all lightning protection technologies and solutions that were actually in use. The standard in force was NC 96-02-09: 1987 "Protection against lightning – Classification and general requirements", that formed part of the fire protection standards. However, that standard was not really being followed by the national experts due to its degree of obsolescence, its limited scope and its incompatibility with several lightning protection principles. Instead, the applied standards were IEC 62305 and IEC 61643 series and the Spanish UNE 21186[7]. It is noted that UNE 21186[7] is applicable both to new and existing structures, while IEC62305 standards are, in practice, related mainly to the design of Lightning Protection Systems for

new constructions where, if lightning protection is considered from the beginning, acceptance levels can be achieved in accordance with regulatory requirements. But, when applied to LPS for existing structures, with limited space and architectural restrictions, it becomes very complex and costly to reach a solution that guarantees that all the requirements indicated in those standards are achieved. Therefore, it was a necessity for designers, installers, inspectors and end users to have an eminently practical standard that unifies all the criteria and technologies that have been used, with positive experience of use, for lightning protection in Cuba.

There were otherwise some sectorial standards, published by several Ministries of the country, regulating the use of technologies and solutions based on positive experiences achieved in their installations and that should be taken into account [22][23][24].

Therefore, a group of experts belonging to APCI, CBRP, specialists from various government entities, public project and installation companies and large users elaborated a draft of the demanded standard after several months of work. The draft was approved by the fire protection group CTN 13.

This standard applies the fundamental criteria of the following documents:

- For the area of lightning protection: NC-IEC 62305 (Parts 1, 2 and 3) [25][26][27], IEC 62305-4:2010 [28] and UNE 21.186: 2011[7].
- For the area of transient overvoltage protection: IEC 61643-11[29], 12[30], 21[31] y 22[32] and IEC 60364-5-53[33].
- For the area of temporary overvoltage protection: UNE-EN 50550[34].
- For the area of storm detection: EN 50536: 2011[35].

The standard also includes other aspects that are no considered in the relevant national standards, such as:

- Personal behavior for safety in case of lightning.
- The mandatory certification processes for executive technical projects and commissioning, as well as the use of approved products.
- check list with the elements to consider for the verification of a lightning protection system at any time of its life.

- Methods for measuring soil resistivity and earthing resistance.

B. Request for revision of the standard and discussion

After a little more than one year in force, the standard NC 1185:2017[36] employed by a great part of the specialist of the country related to this area, its revision was requested by the President of the Standardization Technical Committee 64 to the National Standardization Office. The applicant raised as fundamental elements that justified the review that ESE air terminals are not contemplated in IEC standards, that ESE air terminal increase damages to electronic equipment inside the structures and that there was no theoretical base justifying the performance of ESE air terminals. Therefore, he requested to move the approved part devoted to ESE air terminals to an informative annex, although acknowledging the existence of thousands of facilities in Cuba with positive results.

Upon this request, the National Standardization Office submits these criteria to the consideration of the competent specialists and members of the technical committee for standardization CNT-13. At the end of the established period of allegations and comments initiated by the National Standardization Office (ONN), 26 answers had been received via e-mail corresponding to specialists of 22 national entities and organisms. Most of them were supporting to maintain the standard in its original form, based on positive experience with the use of this type of devices over more than 20 years. Only one comment form one specialist was supporting to move the ESE part to an informative annex, claiming to be in favor because the approved parts of NE IEC 62305 made unnecessary to use another standard.

Annex I of this document shows fragments of the criteria issued in the allegations and comments period.

To conclude the requested review process, the standardization technical committee CTN13 and the ONN convocated a meeting on Monday 29th July 2019. APCI, CBRP, the Ministries of Interior, Army, Tourism, Internal Trade, Health, Energy and Mines and Communication, the Central University of Las Villas; public companies, installers and large end users assisted and participated in that meeting.

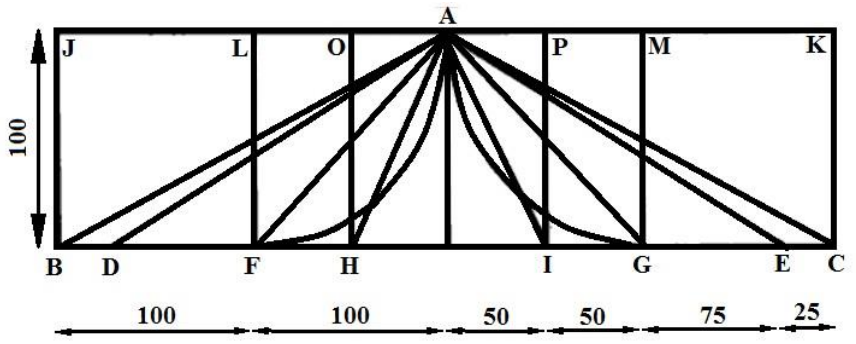
The main conclusion of this meeting was that there was a general agreement in favor of the validity and the maintenance of the standard NC 1185 without modifications, thereby indicating:

- The positive experience of use in Cuba, since there are more than 21 years' experience in lightning protection of all kind of structures using ESE air terminals and without significant failure events.
- There is no technical contradiction with other existing standards in the country
- There is no technical contradiction with IEC 62305 series, since ESE air terminals are not included in their scope. Besides, the part corresponding to conventional systems in NC 1185 are actually based on those standards.

The arguments presented as a base of the requirement for the revision of the standard NC 1185 are in fact within the context of the historical controversy about lightning protection in general and, particularly, between conventional LPS and those based on ESEs. In this regard, it is convenient to make a retrospective, pointing out those controversies generated along the history about the different devices that actuate as interceptors in la LPS and the methods used for their positioning.

4. *FROM FRANKLIN TO OUR DAYS. HISTORICAL CONTROVERSIES AND CURRENT STATUS*

Since the beginning of lightning protection, in times of B. Franklin, it was assumed that the zone protected by a metallic rod had a conical shape with the vertex at the point. The first of the controversies originated when determining the angle that should be considered to establish the area protected by the air terminal. This first controversy started with the definition of the angle to be considered in order to define the area protected by the air terminal. Throughout history, this controversy led to the modification of the value of the angle to be considered. Figure 1 shows the evolution, already during the XIX century, of the protected area related to a passive rod.



JBCK: cylinder, Gay Lussac 1823; **BAC**: cone, DeFonville 1874; **DAE**: cone, Paris Commission 1875; **LFGM**: cylinder, Chapman 1875; **FAG**: cone, Adams 1881; **OHIP**: cylinder, hipótesis; **FAG**: special cone, Preece 1881; **HAI**: cone, Melsens.

Fig. 1. Different protection areas of a rod along the history [37].

Later J.C. Maxwell developed a protection method base on the arrangement of conductors on the structure to be protected, with a pre-defined internal space and connected to earth. There is also a wide controversy about the scientific base of this procedure [38][39] and about the convenience of employing horizontal conductors as interception elements because, unless the conductors are elevated above the structure, they do not generate any protection volume, causing incompatibilities with some protection models.

This controversy about the protection area arose also when ESE technology started, more than 40 years ago. At that moment, a reasonable polemic was established against the new technology due to the lack, until then, of experience supporting it. One of the main arguments has been the absence of physical substantiation of these devices. This argument, usually given against ESEs, is also applicable to passive systems [40], which validation is accepted due to the use experience and good results through the years. Various studies reveal the lack of substantiation in the determination of protected areas, as reflected in the following quotes [39][40][41][42][43][44]:

"Neither the ESE air terminals nor the conventional Franklin rod appear to be cientifically or technically sound when evaluated in field tests under natural lightning conditions" [40].

"Hence the effectiveness of the meshwork protection (the percentage of air termination attachments versus buildings attachment) is not statistically quantified" [39].

"It is regrettable that the efficiency of an ESE air terminal cannot be demonstrated in terms of protection radius; but it is also not possible, with the knowledge nowadays available, to demonstrate the efficiency of a simple rod or any other protection element" [41].

The air terminals positioning methods (ATPM) that are described in the standards in force have not been free of controversy either. Currently, there are 4 air terminal positioning methods that appear in standards: the protection angle method (PAM), the rolling sphere method (RSM), the mesh method (MM) and the method for ESE air terminal positioning. Each of them has been questioned for lack of substantiation, as indicated in [40][41][39].

"Mesh Method is based on long-term experience but does not involve any theoretical background" [39].

"… the protection radius of a simple rod is admitted but not demonstrated" [41].

"The reproach made to ESE air terminals is overconfidence in terms of protection volume but not unsuitability from the physics point of view" [41].

"It appears to the panel the NFPA 780 document does not meet the NFPA criteria for a standard since the recommended lightning protection system has never been scientifically or technically validated and the Franklin rod air terminals have not been validated in field tests under thunderstorm conditions" [40].

There is currently no theoretical explanation supporting the protected volumes for any interception system (based on ESEs or passive). Yet, there are hundreds of thousands of installations of both types all over the world without significant incidents. However, although in practice the protection methods obtain good results without significant failures, in fact there is no statistically relevant data published by independent organisms about it [20][39][45].

For standardization experience, there is indeed a broad prescriptive standardization in this regard. For conventional or passive systems, IEC standards apply, as well as national standards with several particularities. About ESE air terminals, countries as diverse as Spain, France, Angola, Turkey, Portugal or Argentina among others, after a period of positive experience with these air terminals, have developed their own national standards, some of them with mor than 20 years of validity, and they use these devices preferentially due to their lower cost for end customers. Near 100 countries all over the world use the Spanish or French standard for ESEs for the design and execution of their lightning protection installations.

However, the controversy has remained active in recent years due to the monopolistic and protectionist claim of the industry of conventional systems, which unsuccessfully tried to put up standardization barriers to ESEs in international environments as IEC and CENELEC.

As explained above, in fact there is no consistent physical substantiation for any external lightning protection device or system. Therefore, nowadays the evaluation of its efficiency can only be based in comparing the statistical expected results according to the employed method and protection level, as described in its relevant standards, and the results obtained

in a real environment with a statistically significant number of installations, during a period of study long enough for being considered as representative.

"The lightning protection technique has proven its effectiveness as evidenced by the comparative statistics of lightning damage to protected and unprotected structures without mentioning the lightning terminal arrangement." [39].

Achieving an empirical validation, rigorously and formally documented, needs a methodology where projects, installations and actors (companies, designers, installers and auditors), are certified by an independent organism that centralize and control all the process. In this way, there have been some relevant standardization initiatives to cover all or part of this continuous assessment process:

CENELEC: In 2011, the Technical Office (BT) of CENELEC asked the lightning protection European Technical Committee (TC81X) to create a working group of experts to write a standard called "Lightning protection system performance", with the aim of being able to evaluate the efficiency of any existing or future technologies.

The group of experts claimed there was a complexity and the high economic and temporal cost of this project. Nevertheless, a standard draft was written, prEN50522 [46], which proposed the realization of statistical studies on real lightning protection installations. Lately, TC81X Secretary disbanded the working group in the absence of interest from several countries

- **IEC**: Separately, in 2017 started within IEC an Ad Hoc Group (AHG 19), formed by experts from different countries, with the aim of studying possible actions to be taken by TC81 related to Conformity Assessment in the field of lightning protection. Then group is still active and working with the aim of standardizing the certification of people, products, companies and experts involved in lightning protection.

In line with these initiatives, Cuba already has a methodology that has been in place for more than 20 years, in which all elements and actors are certified by an independent government body (APCI), which guarantees the rigor and impartiality in the empirical evaluation of the performance, based on data collection and analysis.

5. *APCI ROLE IN LPS EVALUATION*

In the Republic of Cuba, the installation of any lightning protection system is regulated by APCI with a very methodical and meticulous procedure:

- Products used for facilities must pass a prior approval process
- The design and installation companies, as well as the technicians who carry out the projects, installation and maintenance, must be accredited by APCI.
- Installation and maintenance of the LPS must also be audited by APCI.

That means that there is a control and record of all the steps required for the implementation of the LPS, including design, evaluation, products used, commissioning, monitoring, etc.

APCI is responsible for certifying products related to fire safety and, within them, those for lightning protection that are marketed in the country. This process constitutes a necessary step for the authorization of its use in the country and has therefore been also applied to ESE air terminals. That certification has been carried out since 1997, after several years of positive experience using them, and is based on the verification of the reports of the tests made by the manufacturer at accredited and independent laboratories. Therefore, APCI employs the evaluation procedures given by the relevant standard, such as the Spanish standard UNE 21.186:

2011[7], the French standard NF C17-102: 2011 [47] and now also NC 1185: 2017 [36].

This certification is valid for 5 years. However, it can be withdrawn by APCI at any time if, based on their feedback with other regulatory entities, installers and customers, the user experience has not been satisfactory. As a representative case of this, APCI removed the certification to a model of ESE air terminal due to the detection of several repeated failures in quality, since those air terminals got out of service after intercepting and deriving lightning to earth.

The climatological and organizational singularities of our country in lightning protection make it an ideal setting to obtain, rigorously, the necessary data for ending the historical controversy between different LPS types.

Thanks to APCI's work, Cuba has been a pioneer in methodical LPS conformity assessment and the certification of the elements and actors involved. APCI has been caring the evaluation and monitoring of the LPS facilities for more than 20 years, and today it owns the data of more than 9000 installations. The statistical relevance of these data is indeed high.

6. *DATA AND ANALYSIS*

The data considered for this study come from the certification records of LPS technical executive projects and commissioning from the different APCI territorial divisions, from maintenance and installation audits, as well as from the information required to the main installation companies of the country [48].

This data has been filtered to exclusively identify that related to the interception system and, of these, those cases attributable to the air terminal. Based on the that, first LPS have been classified according to the type (passive or based on ESE). This data is shown in the following table:

Total nr. of installations	Installations with ESE	Passive installations	Incidents in Facilities with ESE	Incidents in passive installations	Cumulative years of service of total
9271	**8433**	**838**	**19**	**5**	**101981**

LPS installations in Cuba

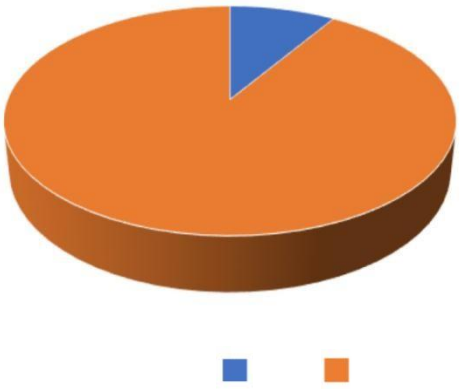


Fig. 2. LPS installations in Cuba. 9% of LPS are based on conventional sensors. The rest are based on ESEs.

Records give an account of 24 incidents, which means approximately 0.26% of all the installations. 19 of these incidents occurred in LPS based on ESE, which is 0.23% of all ESE based installations, while 5 occurred in conventional installations, that is, 0.6% of all conventional LPS installations.

Two types on incidents have been considered during the incident's analysis:

- Damage to the structures: The damages identified were small cracks and minor flaws in the roofs and corners.
- Damage to the air terminals: No damages to the structure, although the air terminal got out of service or broken after intercepting the lightning strike and driving it to the earthing.

Those values have been compared with the expected failure range according to the protection models described in the relevant standards. Those standards consider that an LPS should be designed to be able to intercept a certain percentage of lightning strikes, taking into account the lowest values of the expected current. LPS should also be able to withstand lightning current, considering for that the highest values of the expected current. These percentages are defined by the Lightning Protection Levels (LPL), being 1% for LPL I, which is the most restrictive.

Table 5 – Probabilities for the limits of the lightning current parameters

Probability that lightning current	LPL			
	I	II	III	IV
– are smaller than the maximum values defined in	0,99	0,98	0,95	0,95
– are greater than the minimum values defined in	0,99	0,97	0,91	0,84

Fig. 3. Table 5 of IEC 62305-1[25], with the probabilities related to the occurrence of maximum and minimum values of lightning current for each LPS

Clearly, the results obtained are well below the failure rate expected by the standards.

When considering the 24 incidents, 10 (41.6%) of them caused minor damages to the structure and 14 (58.3%) a damage to the air terminal.

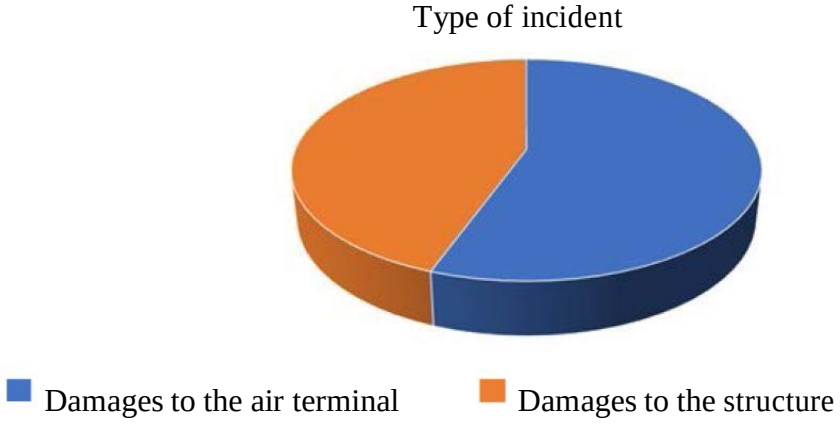


Fig. 4. Identified types of damage: Damages to the structure, attributable to low current lightning, and damages to the air terminals, attributable to high current lightning.

The number of expected lightning impacts to a structure (Nd) depends on the collection area (Ad), the flash density in the area (Ng) and the surrounding location factor (Cd), with the following formula:

$$Nd = Ad \cdot Ng \cdot Cd \quad (1)$$

In the case of Cuba, the average flash density is 9.6 lightning per km2 and year. If we consider an average structure collection area of 10,000 m2 and a location factor of 0,5 (structure surrounded by elements of similar or lower high), then the average expected lightning strikes to a structure is Nd=0.048. When all the registered installations are counted, then the expected lightning strikes to them is 445 every year. If we consider also that the average service time of the lightning protection installations is around 11 years, then the estimated number of flashes that should have stroke the protected structures during this period is 4895.

When this total amount of lightning, then 0.2% of them has caused a damage to the structure, while 0.29% has damaged the air terminal. It is significant to notice that, in the procedure for risk evaluation described in the standards, the probability of damage to the structure (PB) is indicated to be 2% when protected with the most restrictive lightning protection level.

Characteristics of structure	**Class of**	***P***
Structure not protected by LPS	-	1
Structure protected by LPS	IV	0,
	III	0,
	II	0,0
	I	0,0

Fig.5. PB values depending on the protection measures to reduce physical damage in IEC 62305-2 [26].

7. Conclusions

In Cuba, lightning protection is regulated and audited by a single governmental organism, the Cuban Fire Protection Agency (APCI). After several years of documented lightning protection experience in the country, a standard was published, NC 1185, collecting all

technologies for lightning protection that were used successfully for years. After a period with a good usage experience, a review of such document was required.

After a period of allegations and comments, the vast majority of specialists – belonging to governmental organizations, public companies of designers and installers and large institutional users – who summited criteria, asking for maintaining NC 1185 as in the original edition approved in July 2017.

This debate is framed in the historical controversy between conventional LPS and those based on ESEs, and in the lack of available documented validation for both. As explained above, the validation of the different devices or methods applied for lightning protection cannot be based on laboratory studies, where this phenomenon cannot be fully replicated, nor in real lightning fields where the obtained statistics cannot be applied to global models. Therefore, up to now, the only possibility of validation is through the revision of a statistically significant number of real installations, which should be in accordance with standardized criteria, in various geographical, architectural and climatic conditions and for a significant number of years.

This document presents the results of the evaluation of LPS all over a country, considering data coming from more than 9000 existing installations, from which more than 90.9% are using ESEs and 9.1% conventional systems, all them installed according to their corresponding standards. Being a countrywide study, the buildings and facilities considered present dissimilar geographical, architectural and climatological conditions, which indicates that the protection systems work correctly in any type of conditions. These results cover an experience of use of more than 20 years and around 101981cummulative years without significant incidents, which constitutes the most important empirical evaluation of LPS efficiency in real installations made to date in the world.

Data, both of passive (838) and ESE (8433) installations indicates a very low failure rate in both cases, since there is only report of damages in less than 0.3% of the protected structures and, furthermore, with insignificant consequences. This value is below the probability, indicated in the risk assessment of the standards IEC 62305-2 [26] and UNE 21186:2011 [7], that a lightning strike causes physical damages (PB), which is set as 2% for the most severe lightning protection level (LPL I).

The absence of significant damages or claims of the users with ESE installations evidences the effectiveness of the protection model and the air terminals, thus proving the efficiency of external lightning protection systems with ESE air terminals.

To the same extent, although with a less statistically significant number of facilities, conventional LPS do also exhibit a very low failure rate, which demonstrates the validity of the components and positioning methods given today in the standards both for passive and ESE systems.

These results constitute the empirical validation of the efficacy of LPS based on ESE air terminals, giving likewise the answer to the historical controversy between conventional LPS and ESE air terminals.

Last but not least, it is worthy to note that the cost difference and easier installation of lightning protection systems based on ESE air terminals have allowed to design and install lightning protection in environments and structures that, either by cost or by complexity, would have otherwise not been protected.

ANNEX I

Extracts from the emails of users and specialists participating in the established period of allegations and comments:

RADIOCUBA Artemisa-Mayabeque - Territorial Director

"... ESE air terminals, which we use in many of our facilities... a technology that is widely used in our country, with proven effectiveness and also being the most economical option...

The above-mentioned effectiveness has been verified during years of use in our facilities throughout the national territory, through the use of techniques total protection against lightning, following the relevant national and international standards..."

Fire Protection Agency - Development and Certification Director

"... the document was the result of a team work of CTN 13 Fire Safety with the support of the main specialists in the country related to lightning protection... availability of a guide for designers, installers, maintenance staff and competent authorities than have been devoted for years to guarantee in a practical way the safety against lightning in the country..."

APCI UEB Central West - Main Expert

"...ESE air terminals, or active air terminals, based on sustained efficiency practices, have been proved along the country for more than twenty (20) years, with no notice of UNWISHED

events in terms of their protection area, such as strikes to nearby structures within their protection area, and it is the most efficient, economical and commonly used option in Cuba, helping the protection of thousands of installations and saving hundreds thousands dollars in the protection of large and complex areas..."

"...Demonstration of ESE effectiveness in Cuba

The study shows that during the 58 990 year of cumulative service of these 6 940 ESE air terminals, 5 988 strikes were expected to the protected installations. According to the available data, the evaluation if the incidents in the referred places is negligible: very low number, insignificant damages and no personal harm. It is very important to highlight that the number of these rare incidents is by far lower than one order of magnitude with respect to the most restrictive level accepted by the described standards…"

Service Company for Defense Bodies West Division - Senior Expert

"...Our company… has more than 10 years' experience in the design and installation of these types of air terminal in the country …

Along all this time we had no negative incidents of any type caused by the use of ESE..."

"...SERTOD (Company for Telecommunication Services to Defense Bodies) has as one of its main customers the Cuban Revolutionary Armed Forces (FAR) and the national logistics company Almacenes Universales (AUSA) among other national companies. They have been satisfied with any of the designed and installed technologies, and to date they have not reported dissatisfactions or complaints, or claims, nor suffered negative incidents in their installations which are protected with one or other system, although most of them are protected with ESE air terminals.

We have got statistics during more than 10 years (2007-2018) using this type of interception system, with more than 290 ESE systems designed and certified by APCI and 155 installed air terminals, approximately. We do not discard conventional systems or Franklin rods, with 111 designed systems and 31 installed ones along the whole country…"

APCI Mariel - Expert

"...In my modest work experience in the use of ESE air terminals in the Cuban Revolutionary Armed Forces (FAR) and now as APCI expert at Mariel Special Development Area (ZEDM), I can attest that we have come a long way in lightning protection during the last 20 years.

The FAR protected with ESE large antenna fields, open fields with high concentration of people, military air bases, all type of large logistic storage areas, military hospitals, educational institutions of middle and high levels all over the country, among others…"

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"…In the Mariel Special Development Area (ZEDM), its users have assumed as general rule to use ESE, since they do not only protect their installations but also the open areas with freight traffic and people …"

"…Apart from the economical, installation and maintenance advantages of using ESE air terminals, the country as a wide experience in their use and the number of users of these systems is increasing. Therefore, I consider that they should be settled in the Cuban mandatory compliance standards and the use of ESE air terminals cannot be out of than mandatory compliance …"

Copextel Corporation, Province of Holguín.

"…Who writes you is an Engineer with more than 30 years' experience in the works of design and installation of lightning protection systems both passive and based on ESE... In all facilities where I have installed ESEs o use them for the design, and later I have control the installation and made the maintenance, nobody has ever told me that the installation or the structure were damaged, or any human being was harmed …"

Havana Club International, San José Rum Company - Industrial Equipment and Facilities Maintenance manager

"…I work for a company of rum production, Ronera San José, Havana Club International SA. Inaugurated in January 2007.

… we have, as a part of the complete lightning protection system, 24 installed ESE air terminals... those are areas with a high risk of fire provided the characteristics of the materials that are stored or handled…

The readings of the lightning event counters indicate a high incidence of strikes to those air terminals. We had during 11 years of operation no damages in the structures due to direct lightning strikes. This proves the effectiveness of the installed air terminals... We are audited by foreign insurance companies and by APCI with favorable results…"

Central University "Marta Abreu", Las Villas

"… During 33 years I was Professor of subjects related to lightning protection and earthing systems in the studies of Electrical Engineer in the Las Villas Central University. Now I am Master and Doctorate Assistant Professor in this University…

… When I was consulted, I proposed the inclusion of ESE air terminals as protection method in the same conditions as other methods, since their effectiveness is empirically demonstrated as for other methods. The tropics is the area with the highest thunderstorm activity in the world and Cuba is one of the countries with the highest cloud-to-ground flash density in that area. In our country, the use of lightning protection systems indispensable, and more than 90% of the installed lightning protection systems in our country are ESEs, with satisfactory performance recognized

by the Cuban Fire Protection Agency (APCI), who very rigorously regulates and controls this activity in Cuba…"

Service Company for Defense Bodies – Technology Director

"…From our experiences as design and installation company during more than 10 years, we have no negative evidence about the use of ESE air terminals…"

Central University "Marta Abreu", Las Villas

"…Since 1984 I am part of the faculty senate of the studies of Electrical Engineer in the Las Villas Central University "Marta Abreu". Now I am the Director of the Center for Electroenergetic Studies in this University and President of the National Court of Scientific Degree of the mentioned specialty...

... Annex H of the Cuban Standard NC 1185: 2017 accepts that both Franklin rods and ESE air terminals "... have obtained their empirical validation". ... "Cuba has 22 years' experience in the protection of structures all over the country using ESE air terminals with good results, since there are no significant incidents in the reported failures. The data obtained from the studies indicate that a proportion of more than 80% installations protected with ESE. It is estimated that, since the introduction of this technology in the country to date, there are more than 9000 structures protected with ESE air terminals..."

Cuban Telecommunication Company Global Protection Systems (ETECSA) - Team leader

"…ETECSA is provided with ESE and passive air terminals, installed in strategic placements and designed for LPL I. We usually install ESE air terminals to keep inside the protected volume large fields of antennas and warehouses with good results and considerable cost savings …"

APCI Central West - Director

"…as a whole with APCI, Fire Brigades, high level lightning experts, designers and installers of specialized companies, as well as clients and experts, kept frequent consultations and constant feedback for several years on what was proposed and approved about NC 1185: 2017…"

References

[1] Tobias, J. et al, "The basis of Lightning Protection Technology", Report of the Federal Interagency Lightning Protection User Group, June 2001.
[2] Ruiz, D; Polo, S; Pomar, V; Pomar, C. "Lightning Protection: Basis & Praxis", ILPS 2011.
[3] I.Gallimberti et. al. "Fundamental processes in long air gap discharges". C. R. Physique 3 (2002) 1335–1359.
[4] J. R. Roth, Industrial Plasma Engineering, Volume 2. Applications to Non-thermal Plasma Processing, (IOP Institute of Physics Publishing, Bristol) 2001.
[5] J.J. Lowke, "On the Physics of lightning". IEEE Trans. Plasma Science, Vol.32, Nº.1, Feb 2004. Invited Paper.
[6] Berger, G. "New progress in the process of lightning attachment to grounded structures". ILPS 2016.

[7] Comité Técnico AEN/CTN 207. "UNE 21186/2011: Protección contra el rayo: Pararrayos con dispositivo de cebado". Diciembre 2011.

[8] Ruiz, D. Gironella, J.L. "La intercepción del rayo y los ensayos de laboratorio". IV Taller Nacional de Tecnologías de Protección contra Rayos. 2018.
[9] D.Ruiz, et Al. "Analysis of breakdown process at U50 voltage for plane rod discharges by means of neural networks". Journal of Electrostatics 71 (2013) 336-340.
[10] Les Renardières Group, "Research on long air gap discharges at Les Renardière", Electra (23) (1972) 53e157.
[11] Les Renardières Group, "Research on long air gap discharges at Les Renardières", Electra (35) (1973) 49e156.
[12] Les Renardières Group, "Positive discharges in long air gap at Les Renardières -1975 results and conclusions", Electra (53) (1975) 31e153.
[13] Les Renardières Group, "Negative discharge in long air gaps at LesRenardières", Electra (74) (1981) 67e216.
[14] Diendorfer G. "Lightning parameters".OVE-ALDIS. Cost P18. 2007
[15] J.Takami,S.Okabe,Observational results of lightning current on transmission towers, IEEE Transactions on Power Delivery 22(1) (2007) 549–553.
[16] Ruiz, D et. Al "A new concept in lightning parameters measurement". Journal of Electrostatics. Vol. 67 Issues 2-3, 2009.
[17] F.D'Alessandro; N.I Petrov " Field study on the interception efficiency of lightning protection systems and comparison with models". Proc. R. Soc. A 2006 462.
[18] N.I Petrov "Assessment of protection system positioning and models using observations of lightning strikes to structures". Proc. R. Soc. M 2002.
[19] Polo, S; Pomar, V. Llovera, P. "Effectiveness empirical study on Early Streamer Emission lightning protection installations in Spain", ILPS 2011.
[20] Pomar, V; Polo, S; Fauveaux, S. "Effectiveness of worldwide existing ESE lightning protection systems manufactured in Europe", ILPS 2011.
[21] L.Alvarez, T.Gutierrez, et. Al. "Informe certificado meteorológico 23/2011 DIM(023)". Instituto de Meteorología de la República de Cuba. 2011.
[22] NC 775-10:2012: Bases para el diseño y la construcción de inversiones turísticas. Requisitos de electroenergética. MINTUR, Ministerio de Turismo de Cuba.
[23] NRFA 07-06:2005: Protección contra descargas eléctricas atmosféricas. MINFAR, Ministerio de las Fuerzas Armadas de Cuba.
[24] Libro Azul 2012: Guía para el diseño, instalación y mantenimiento de los sistemas de protección integral. ETECSA, Ministerio de Comunicaciones.
[25] International Electrotechnical Committee, "IEC 62305-1: Protection against lightning – Part 1, 2006.
[26] International Electrotechnical Committee, "IEC 62305-2: Protection against lightning – Part 2, 2006.
[27] International Electrotechnical Committee, "IEC 62305-3: Protection against lightning – Part 3, 2006.
[28] International Electrotechnical Committee, "IEC 62305-4: Protection against lightning – Part 4, 2010.

[29] Technical Committee TC37/SC37A. "IEC-61643-11:2011: Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods.
[30] Technical Committee TC37/SC37A. "IEC-61643-12:2011: Low-voltage surge protective devices - Part 12: Surge protective devices connected to low-voltage power systems - Selection and application principles.
[31] Technical Committee TC37/SC37A. "IEC-61643-21:2011: Low voltage surge protective devices - Part 21: Surge protective devices connected to telecommunications and signaling networks - Performance requirements and testing methods.
[32] Technical Committee TC37/SC37A. "IEC-61643-22:2011: Low-voltage surge protective devices - Part 22: Surge protective devices connected to telecommunications and signaling networks - Selection and application principles.
[33] Technical Committee TC64. "IEC-60364-5-53: Low-Voltage electrical installations - Part 5-53: Selection and erection of electrical equipment - Devices for protection for safety, isolation, switching, control and monitoring.
[34] Technical Committee AEN/CTN 201. UNE-EN 50550:2012: Dispositivos de protección contra sobretensiones a frecuencia industrial para usos domésticos y análogos (POP).
[35] Technical Committee CTN 207. "UNE-EN 50536: Protección contra el rayo. Sistemas deaviso de tormentas". 2011
[36] Oficina técnica de normalización, NC 1185:2017 Protección contra rayos – Seguridad integral frente al rayo. 2017
[37] Golde, R.H. (ed.), "Lightning. Vol II: Lightning Protection", Academic Press, N.Y, 1977
[38] Szczerbinski, M. "Attachment process models for the meshwork external protection." 25th International Conference on Lightning protection, Rhodos, Greece., 2000.
[39] Szczerbinski, M. "Lightning protection with the mesh method: some models for the effectiveness analysis". Journal of Electroestatics 64 pp. 283-288, 2006.
[40] Bryan, J.L., Biermann, R.G. & Erickson, G.A., "Report of the Third-Party Independent Evaluation Panel on the Early Streamer Emission Lightning Protection Technology", National Fire Protection Association, Quincy, MA, 1999.
[41] Gruet, P., 2001, "Study of Early Streamer Emission Lightning Conductors – ESE", INERIS Report, October 2001.
[42] Viemeister, P.E., "The Lightning Book, MIT Press, Cambridge, MA, 1972.
[43] McEachron, K.B., "Lightning Protection since Franklin's Day", J. Frankl. Inst., 253, pp. 441-470, 1952.
[44] IPSOS: Satisfaction survey «Lightning protection» Questionnaire GIMELEC/INERIS/ MEDD 2002.
[45] R.H.Lee, Lightning protection of buildings, IEEE Transactions on Industry Applications 1A-15(3) (1979) 236–240.
[46] Technical Committee CLC/TC81. Draft prEN-50622:2014: Lightning protection systems pure performance standard. CENELEC 2014.
[47] AFNOR. NFC17-102: 2011. Protection des structures et des zones ouvertes contre la foudre par paratonnerre à dispositif d'amorçage. 2011.

[48] Amores, F. "Experiencia cubana sobre el comportamiento de los pararrayos de tipo ESE. Homologación por APCI. Normalización". Journal of Electroestatics 64 pp. 283-288, 2011.