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Assessment of Early Streamer Emission Technologies

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***Abstract*— This paper is devoted to a presentation of an INERIS report[1] concerning the early streamer emission technologies and aspects involved in the assessment of these technologies in application of the standard NF C 17102 (September 2011) and complementary on-sites tests**

Keywords—Lightning protection, Early Streamer Emission (ESE), Lightning Rod (LR), efficiency, testings

I. Introduction : Context and Methodology

INERIS, a public establishment supervised by the French Ministry of the Environment is assigned with helping to prevent the risks for the health and safety of individuals and the integrity of assets, and clearly, the environment. INERIS carries out research programs aiming to improve the understanding of the phenomena likely to lead to at-risk situations, and to develop its expertise in terms of prevention. Its scientific and technical skills are at the disposal of public authorities, companies and local authorities in order to assist the former in reaching the most appropriate decisions in order to improve environmental safety.

INERIS was entrusted by the French Ministry of the Environment (MEEM) with revising the report "Etude des Paratonnerres à Dispositif d'Amorçage" (Study of Early Streamer Emission], 2001 version (reference: DCE-2000-25265f), in order to incorporate changes to standards and technological developments in relation to early streamer emission (ESE).

This report has been fully redrafted and incorporates changes to standard NF C 17102 (September 2011), and the information provided by manufacturers, standardization bodies and recent scientific publications. This report exclusively covers the performances of ESE and does not attempt to compare this technology with other technologies such as lightning rods (LR), meshed conductors or catenary wires.

A questionnaire was forwarded to manufacturers in order to obtain information on the latest technical developments and incorporate the progress achieved over the last 15 years, to better characterize these terminals. Most of the manufacturers consulted generally replied to this questionnaire by enclosing technical documentation, test reports and scientific publications.

INERIS did not test the performance of this equipment.

9 out of the 12 French and European manufacturers consulted provided information. The ESE manufacturers on the following list provided technical information to INERIS.

Manufacturer	Country of the manufacturer
ABB France	France
ADEE ELECTRONIC	France
DUVAL MESSIEN	France
ERICO (PENTAIR)	USA/France
France PARATONNERRE	France
FRANKLIN France	France
INDELEC	France
ORWELS / PIORTEH	Poland/France
SAP	France

[1] ***Report ref DSC-16-156206-10594A***

Internet link : at https://prestations.ineris.fr/sites/prestation.ineris.fr/files/PrestaWeb/Pages-Solution/DSC/Protection%20foudre%20-%20Qualifoudre/DSC-16-156206-10594A_EVALUATION_REPORT_INERIS_ESE_2016_ENG_version%203%20Mo.pdf

INERIS will not issue opinions on products by ESE manufacturers which failed to respond to the request for information.

II. Early streamer emision : history and operation principles

Early streamer emission (ESE) lighting protection air terminals appeared in 1984, initially in France, and later in Spain, which were also the first countries to adopt specific standards (NF C 17 102 in France, UNE 12 186 in Spain). This type of air terminal is currently sold by foreign manufacturers (European, American, Chinese, Australian, Argentine, Turkish, etc.).

In recent years, various devices designed to improve the efficiency of Franklin-type rod lightning protection terminals have appeared, particularly to replace prohibited radioactive devices. France has been extensively involved in this research, alongside other countries such as Spain. Research results have now been validated with laboratory tests, and even site testing. The industrial products developed based on this research improve the efficiency of capturing an upward connecting leader compared with a lightning rod air terminal.

All discussions on efficiency aim to determine how the upward connecting leader can be activated as early as possible (at the best possible time) with the best possible initial speed. The principle is therefore to adjust and/or drive the corona discharge.

Two physical principles [2] are applied for this concept:

- Using high voltage pulses: repetitive high voltage pulses are applied to the end of the air terminal; the basic principle is to control the initial corona discharge and benefit from the "memory" effect left by previous discharges.
- Using a spark near to the tip: a spark is triggered near to the tip in order to ensure the presence of initial electrons in correlation with the increase in electric field. In practice, an ESE with the same size as a Franklin rod leads to a faster initiation of the upward connecting leader, which may, according to some authors, lead to a larger radius for the protected area or, with an identical radius of the protected area, to significantly higher reliability (probability of capture) compared with a rod terminal. However, the efficiency of such a terminal must be validated with specific tests.

In 2001, INERIS listed ESE-related technologies: technologies with electronic or piezoelectric activation, or with special profiles.

In 2016, only ESE technologies with electric/electronic activation and special profiles exist, and many manufacturers have combined both a profile and an activation mode.
Piezoelectric terminals are no longer sold in France.

In 2001, INERIS listed 100,000 ESE air terminals manufactured after 1985, GIMELEC[2] currently lists 440,000 for French members alone, i.e. ¼ of production occurred over the first half of the 30-year period and ¾ over the second half. This demonstrates the strong growth recorded in the market availability of these products.

How does an ESE air terminal operate?

> If a lightning protection terminal generates an upward connecting leader before a nearby object, it will naturally win any competition with upward connecting leaders. This is the basic principle behind ESE. ESE air terminals must demonstrate early triggering ΔT compared with a lightning rod (LR) air terminal.
> If a terminal benefits from early triggering ΔT, the upward connecting leader or leader generated will cover a distance D, greater than for an LR air terminal, to meet the downward leader. The terminal will capture the lightning at a larger distance, its range is therefore increased. The increase in range is therefore obtained from the propagation speed of the upward connecting leader as $\Delta L = v\ \Delta T$.

The standard NF C 17102 defines the Early Streamer Emission air terminal as a lightning protection terminal with an earlier emission than a lightning rod air terminal in identical conditions. No information on the technology used is given.
An ESE air terminal comprises a capture lightning rod, an attachment device, a fixation and a connection to the downward conductors.

Two main ESE groups can be identified:

1. air terminals with special profiles including passive components (L, R, C: coil, resistor, capacitor),
2. air terminals with electronic activation including one or more active electronic circuits for managing the activation of the upward connecting leader at a specific point in time.

Most of the ESE systems of the manufacturers operate whether the ambient electric field is negative or positive, which is compatible with a downward negative or positive lightning strike.
No early triggering is required for an upward connecting lightning strike (positive or negative), the terminal will emit at the highest point connected to the earth and the ESE air terminal, if installed at the highest point as required by standard, will represent the preferred starting point for this type of lightning strike.

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[2] GIMELEC: A group representing French companies providing electrical and automation solutions and associated services

III. IMPROVEMENTS OVER THE PERIOD 2001-2015

The analysis of improvements and changes is covered to answer the following questions:

1. What has changed in terms of the technical aspects mentioned in the previous report?
2. What works have lightning professionals launched to ensure the credibility of these terminals?
3. How have regulations changed and taken these terminals into account?

Manufacturers of ESE air terminals must ensure that these terminals comply with the NF C 17102 standard [11].
Products have therefore been developed to meet the requirements of the 2011 standard, which has improved credibility in terms of product operation and life.

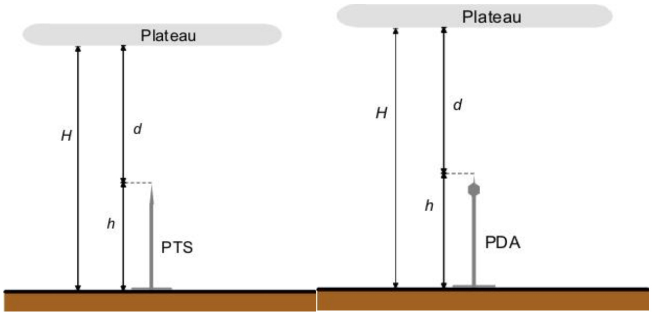
Several specifications have been added in relation to the efficiency of the ESE air terminal (ΔT). The first is in the range of the early triggering, which must be between 10 µs and 60 µs. If ΔT is less than 10 µs, the terminal is not considered as an ESE air terminal.

The criterion adopted to assess the efficiency of an ESE air terminal corresponds to its ability to emit an upward connecting leader before an LR air terminal placed in the same conditions, on a repetitive basis. The value T[3] at the point in time when the upward connecting leader is triggered is measured for each valid strike on the LR air terminal, and subsequently on the ESE air terminal.
Efforts by manufacturers of ESE air terminals have also focused on adding performance tests based on the series of standards, EN 50164-x (maximum current, corrosion, etc.), and on the significant changes to standard NF C 17102, which includes details of the test procedure and introduces by specifying, for example, tests with a lightning strike of 100 kA.
These tests meet the requirements of the international standard IEC 62305-3 in application of the series IEC 62561-x (replace EN 50164-x), which are also mentioned in standard NF C17102.
The amended law of 4/10/2010 [5] [6] [7] specifies the application of the French and European standards in force.

IV. THE IMPORTANCE OF EFFICIENCY TESTS

The efficiency of an ESE air terminal is assessed by comparing the point in time when the upward connecting leader is emitted with that of an LR air terminal in a high voltage laboratory.

In this context, the LR and ESE air terminals are assessed one after the other in identical electrical, geometric and climatic conditions as part of laboratory tests simulating the "natural" conditions activating an emission (upward connecting positive leader).



A recent technical publication [3] highlights the efficiency of an ESE air terminal, compared with LR air terminal. Indeed, experimental tests performed by SIAME laboratory of Pau university in France [3] demonstrated the efficiency of an ESE air terminal compared with a conventional Franklin rod terminal.
To complement standard NF C 17102, some manufacturers of ESE air terminals have mandated efficiency tests in laboratories with vertical clearance of 7 to 10 m and outside (particularly at the WHVRI laboratory).

V. ON SITES TESTS

Two types of on-site tests are defined below:

- natural lightning tests, where it is necessary to await until lightning hits the object undergoing testing (long-term tests),
- triggered lightning tests, where lightning is triggered using rockets (testing over one or two stormy seasons).

A protocol was developed by GIMELEC [1] and UTE at end-2003 in order to obtain preliminary experience of at least 3 years on around a dozen sites.

The aim was to install ESE air terminals at potentially exposed sites in order to confirm the protection model used in NFC 17102 in normal conditions of use, particularly with components competing with the ESE air terminal (antennas, stack, etc.).

Table below summarize on-site tests (by manufacturer A to H)

ESE	Location	Type of test
A	Pic du Midi (France)	GIMELEC protocol
B	Saint-Privat-d'Allier (France), Japan, USA, Brazil, Indonesia	GIMELEC protocol
C	New Mexico	define the best tip shape

[3] Mean emission times *Tmean'LR* and *Tmean'ESE* are calculated based on valid strikes, using the measurements of the points in time when the upward connecting leaders are emitted from an LR air terminal and an ESE air terminal, in compliance with parameters. In the same way, standard errors are calculated for the two distributions (σLR and σESE)

D	Johannesburg (South Africa)	GIMELEC protocol
E	Poland	protocol with IEN Warsaw
F	Super Besse (France) Satu Maru (Romania) Arequipa airport (Peru)	GIMELEC protocol
G	Manilla (Philippines)	GIMELEC protocol
H	Manilla (Philippines)	GIMELEC protocol

Some manufacturers have drafted technical publications to define on-site tests in more details ([12]-[15]-[16]-[17]).

VI. ITEMS TO BE DEMONSTRATED

Standard NF C 17102 from 2011 has changed in terms of how the radius of the protected area, Rp, is calculated, with:

- The addition of the protection rating IV in the formula,
- The value of ΔL in the formula without using the speed, v, of the upward connecting leader (measured value).

The radius of the protected area, Rp, from standard NF C 17102 is determined using the formula:

$$R_p(h) = \sqrt{2rh - h^2 + \Delta(2r + \Delta)}$$ for $h \geq 5$ m

and

Rp = h x Rp(5) / 5 for $2 \text{ m} \leq h \leq 5$ m

With

Rp (h) corresponds to the radius of the protected area at a given height h (in meter);

h corresponds to the height from the end of the ESE in the horizontal plane to the farthest point of the object to protect (in meter);

r 20 m for protection rating I;
30 m for protection rating II;
45 m for protection rating III;
60 m for protection rating IV;

$\Delta = \Delta T \times 10^6$ Field experience has shown that Δ is equal to the efficiency obtained during the ESE assessment tests (in meter).

The value of 10^6 used in the formula is no longer related to a speed of the upward connecting leader, but is based on trials carried out in the field (with a high speed video camera).

The formula used to calculate the radius of the protected area, Rp, is based on the rolling sphere method also known as the electro-geometric model by adding the extent of the early triggering ΔL.

In order to incorporate current scientific developments, the theoretical model for lightning attachment is currently being revised at international level. The following scientific articles could be mentioned in particular ([4]-[8]-[9]-[10]-[13]-[14]).

A scientific article [9] reports on the influence of corona discharge space charges on the interception of a downward lightning strike on high single rods. Using a simulation model known as SLIM (Self consistent Leader Inception and propagation Model), it has been demonstrated that the reduction in the vertical interception distance (ID) when capturing the lightning strike due to corona discharge space charges is approximately 20%, and the reduction in the lateral interception distance (ID) is approximately 10%. It was also demonstrated in the conclusion to this article that the theoretical attachment model must be modified in order to integrate the propagation of upward connecting leaders under the influence of downward leaders.

Various lightning attachment models have been described in recent years [8] (effect of space charges and tip shapes), [13] and [14] (connection model between upward connecting positive leaders and downward negative leaders).

In addition, a recent publication [10] (on the attachment process) proved that existing lightning protection models (Electro Geometric Mode: EGM, Rolling Sphere Model: RSM, Leader Progression Model: LPM) must be upgraded to a new model, in which upward connecting leaders (UCL) are replaced by FLF (Faintly Luminous Formations), which would describe the creation of upward connecting leaders from ESE air terminals more precisely.

Once the new model has been validated at international level for standard NF EN 62305-3, it will be necessary to apply this model for ESE air terminals.

VII. Conclusion

Since 2001, the manufacturing of ESE air terminals has changed to integrate improvements to the electronic components used in these terminals and, above all, to meet the new requirements of standards, and the more-exhaustive performances tests required by NF C 17102.

This study identified several positive points for the actions taken by manufacturers, particularly with the launch of on-site tests (which go beyond the requirements of standards) and the harmonization of operating principles.

The requirements of standard NF C 17102 (2011):

- demonstrate the early triggering of ESE air terminals (measuring efficiency ΔT) by laboratory testing,
- guarantee the long-term operation of products thanks to current tests (100 kA) and environmental tests (corrosion, etc.), which simulate real conditions.

The manufacturers of the ESE air terminals covered by this study all propose terminals which meet the requirements of the applicable standard NF C 17102 (2011), which was harmonized with European standards.

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