

A Critical View on the Lightning Protection International Standard

Prof. C. Bouquegneau

Pro-rector of the Faculté Polytechnique de Mons, rue de Houdain, 9, B-7000 Mons (Belgium)
Christian.Bouquegneau@fpms.ac.be

Abstract. The Technical Committee TC81 (Lightning Protection) of the IEC (International Electrotechnical Commission) has finalised the new presentation of its work in five parts (IEC 62305-1 to -5) treating general principles, risk management, physical damage, life hazards, protection against electrical and electronic systems within structures and some services entering the structure. We criticise some options retained.

Keywords. Lightning Protection, Standardization.

1. INTRODUCTION

IEC standards are based on scientifically proven theories and technical experimentation world-wide taking into account the international expertise in the matter. They lay down requirements for the design and installation of LPS (Lightning Protection Systems) for structures and buildings, the protection against lightning of services entering the buildings and the protection of electrical and electronic systems.

TC81 is achieving its first cycle of work when issuing next year a complete standard (IEC 62305) in five parts (IEC 62305-1 to 5, see the list in § 2). The standard provides the general principles to be followed in the protection against lightning of a structure (including its installations and contents as well as persons) and services entering the structure.

The general principles are presented and criticised with the latest contributions from working groups of IEC TC81 (and CLC TC81X, a similar European Committee inside CENELEC), with comments from National Committees concerned with lightning protection.

Direct and nearby cloud-to-ground discharges can be hazardous to people, structures, their contents and installations, as well as to services. Hence the application of lightning protection measures must be considered.

The need for protection, the economic benefits of installing protection measures and the selection of adequate protection measures should be determined in the terms of **risk management**; the risk management method is reported in IEC 62305-2.

There are no devices or methods capable of preventing lightning discharges. Direct and nearby cloud-to-ground discharges can be hazardous to structures, persons, installations and other devices on them. The need for protection and selection of adequate protection measures is determined in items of risk assessment: National Committees have generally interpreted and simplified the international approach, which leads to some discrepancies. Fortunately, a convenient flexible *software* will be offered with the text of the second part of the standard: it is right now on the testing stage.

The criteria for design, installation and maintenance of lightning protection measures are considered in three separate groups:

- protection measures to reduce physical damages and life hazards in a structure is reported in IEC 62305-3 ;
- protection measures to reduce failure of electrical and electronic systems (inside the structure to be protected) is reported in IEC 62305-4 ;
- protection measures to reduce physical damages and failure of services entering the structure (mainly electrical and telecommunication lines) is reported in IEC 62305-5.

In the new edition of the standard there is no limitation of height of the structures and buildings. Nevertheless, railway systems and vehicles, ships, aircraft and offshore installations are still outside its scope.

The classification of the structures depends on the consequential effects of lightning flash which can cause damage to the structure, their contents or their surroundings.

We are going to focus on the basic principles leading to a not so straightforward international consensus and criticise some specific approaches, repelling some other ones emphasised in some countries and essentially based on more commercial than scientific arguments.

2. LIST OF IEC TC81 NEW STANDARDS

The actual list of standards that is already or will be soon issued by IEC TC81 is the following.

IEC 62305-1 Part 1: **Protection of structures against lightning : general principles:**

it introduces terms and definitions, lightning current parameters, damages due to lightning, protection needs and measures, basic criteria for protection of structures and services as well as test parameters simulating the effects of lightning on LPS components;

IEC 62305-2 Part 2 : **Risk management:**

it introduces the risk assessment method, the assessment of risk components for structures and the assessment of risk components for services;

IEC 62305-3 Part 3 : **Physical damage and life hazard:**

it is related to lightning protection systems (LPS), protection measures against injuries of living beings due to touch and step voltages and it offers a guideline for design, installation, maintenance and inspection of LPS ;

IEC 62305-4 : Part 4 : **Electrical and electronic systems within structures:**

it considers the protection against Lightning Electro-magnetic Pulses (LEMP): general principles; earthing and bonding inside structures; magnetic shielding and line routing, requirements of surge protective devices (SPD), protection of equipment in existing structures;

IEC 62305-5 : Part 5 : **Services:**

telecommunication lines (fibre optic lines and metallic conductors lines), power lines, pipelines are concerned.

3. PRINCIPLES AND METHODS

3.1. Interception models

As was stated many times in the past, the conventional lightning protection philosophy, the methods and their practical implementation rest on a well found theoretical and empirical basis with a vast experience for the verification and validation of the the so-called **rolling sphere method** (RSM) associated to an **electrogeometric model** (EGM) and based on a radius **R** equal to the striking distance or final jump distance; so far it is the best model we have to work with in an international standard.

We personally regret that the standard introduces three methods as if they were different ones:

(1) the **RSM** (or **EGM**) method which should be so far the only one to be recommended anywhere and at any time, even if it has not been evaluated yet on tall buildings; it is a crude method which hides our insufficient understanding of the lightning attachment process but appears as the best tool for the design and the positioning of the air terminals; in the future we will improve this model taking into account corners and edges of very tall structures, but we still need more field data about the striking of such tall structures; this model has already been somewhat improved [1] and is now the reference in international standards but it should also be refined taking into account both downward/upward leaders velocities and propagation parameters; in this respect, we strongly support Gérard Berger's last approach as a new candidate to improve the EGM model [2];

(2) the protection angle method (**PAM**) only seems to be maintained for historical reasons; in fact it is simply derived from the previous one (RSM) but is not a different one; we think it should be suppressed or at least it should not appear as a method different from the RSM; moreover it is subject to limits of air terminal height (indicated in Table 2 of IEC 62305-2, § 5.2.2), because the protection angle is not constant any more since it decreases if the height increases ;

(3) the mesh method (**MM**), sometimes (wrongly) called Faraday cage method, can be too approximative if several metallic parts stand as high as and too close to the upper mesh installed on flat planes or roofs; anyway we think that IEC documents should give a little more guidance about the proposed height of the mesh conductors above the flat surface they are supposed to protect.

Other methods have been proposed from time to time to the international commissions, so far without success. For example, the **CVM** method (CVM = Collection Volume Method) recommended by the Australian Committee has received substantial criticism both concerning the method itself and the fact that it was neither accepted nor analysed by the international scientific community; for example, the collection volume does not change when the leaders downward/upward velocity ratio changes, which is not realistic.

3.2. Air termination systems

The designer of a lightning protection system should be more aware of the efficiency of a horizontal conductor with respect to a vertical rod when the tip of this rod is installed at the same height as the horizontal wire. The benefit of vertical rods is generally and wrongly emphasised compared to meshed conductors or catenary wires.

Moreover a lot of funny devices like "aigrettes" let people falsely think that multiple tips improve the effectiveness

of a single rod... though it is exactly the opposite (due to the mixing up of the space charges around the tips).

Side flashes must always be taken into account for buildings and structures higher than 60 m, that is why it seems sufficient to install a regular lateral air termination system (upper parts of down conductors) on the upper part of such tall structures (generally on 20 % of the total height), being careful to the surrounding environment (irregular shape of the structure itself or other separated but neighbouring structures).

Ambitions and potential earnings involved in the design of more effective lightning receptors is an obvious motivation for the invention and presentation of a lot of different lightning protection systems and items, where the claimed advantages have often been advertised, unfortunately without verification of their functions and validation of their effects. So far parallel tests with simple Franklin rods and various ESE (Early Streamer Emission) devices exposed to natural lightning have shown no significant difference in the attraction distance nor in the number of strokes to the different types of rods. Hopefully in the future more effective lightning protection components and systems could be developed but until such systems are proven in a scientific sense their use should not be allowed for objects where protection is required. We have to remain reasonable and to be careful when issuing standards and guides. Of course IEC TC81 following confirmed scientists does not advertise such devices.

Nevertheless is it enough? Is it enough to ignore ESE (French PDA,...), repellers, eliminators,... or just to say that if they are installed they have to be positioned as conventional ones? The international standard looks to me much too shy about the rejection of these devices.

Radioactive air terminals are forbidden nowadays; they had no preferential interception effect but they were only forbidden for their radioactive pollution.

Lightning repellers, dissipation array systems and other eliminators can of course not prevent the initiation of lightning in the thundercloud, nor avert any lightning strike. ESE systems have never shown any superiority over conventional systems and this should be emphasised in all scientific conferences on lightning protection, in particular at this ICLP meeting.

3.3. Earth termination system

The earth termination system is a crucial part of the lightning protection system, since it must disperse the lightning current into the ground without danger to the people nor damages to the installations inside the protected structure. The transient behaviour of earthed electrodes under high peak impulse currents is a crucial point [3].

Soil ionisation is still under consideration, it would decrease the ground surge impedance only for very high peak current values.

In any case a complete integrated earth termination system with ring earth electrode (buried conducting loops or foundation earth electrode) is always to be privileged to decrease both the surge ground impedance and the conventional earth resistance; moreover it is generally better to install short-length vertical or inclined electrodes in multiple ground electrode arrangements (prismatic or pyramid-truncated arrangements) than single deep ground electrodes; of course each arrangement must be connected to a down conductor.

Generally, the ring earth electrode is installed with additional radial, vertical or inclined short-length electrodes. The author showed [3] that the optimal configuration shall stand with multiple earth electrode arrangements with 3 or 4 short-length inclined electrodes separated by about 2 m from each other and making an angle of 30° with respect to the vertical direction.

3.4. Lightning current parameters

Parameters of lightning currents are selected from CIGRE (Conseil International des Grands Réseaux Electriques à Haute Tension); lightning current peak values and waveshapes result from various classifications : short and long duration components, leader polarity and direction,...

Let us notice that the so-called M-components are not considered in the standard [4]; we should say a word on them, at least to mention that the protection is covered when considering the other types of waveshape currents.

We need more and more international data to work with a reliable statistics of lightning peak currents and other parameters on general structures and buildings, because CIGRE data were essentially brought from transmission lines and tall structures.

Besides the peak value of the first stroke current, the important parameters are the maximum rate of rise (induced overvoltages and dangerous sparking), the flash duration and its total charge (thermal effects) and the flash specific energy (selection of metallic conductors for the LPS and earthing system).

A better evaluation of lightning current parameters and particularly their height dependency taking into account downward and upward flashes should be performed by the international scientific community.

3.5. Lightning protection levels

Four **lightning protection levels LPL** (I to IV, with four types of relevant protection measures for the design of LPS) are introduced. For each one, a set of maximum and minimum lightning current parameters is fixed.

The *maximum* values of lightning current parameters relevant to LPL I will not be exceeded with a probability of 99 %; they are reduced to 75 % for LPL II and to 50 % for LPL III and IV. The *minimum* values of lightning current amplitude for the different LPL are used to derive the rolling sphere radius R (RSM or EGM method) in order to define the lightning protection zone which cannot be reached by direct strikes, a minimum peak current of, respectively, 3 kA (LPL I), 5 kA (LPL II), 10 kA (LPL III) and 16 kA (LPL IV) leads to respective values of the rolling sphere radius R equal to 20, 30, 45 and 60 m. They are used for the positioning of air terminations in the external protection and to define the lightning protection zone LPZ 0_B (protected against direct lightning strikes) in the internal protection.

An important question can be raised. Why do we limit level I to a probability of **99 %**, since we are sometimes obliged to take into account complementary measures to come to a level I+ ? Level I should surely be the highest level of protection, why not 100 % even if it looks unrealistic? With 99 %, we are in some uncomfortable position in front of the protection of very dangerous structures (inflammable and explosive environments).

4. RISK MANAGEMENT

The protection measures must be applied taking into account the **risk management method** which is reported in IEC 62305-2, this method provides a procedure for the evaluation of the total risk to be compared with an upper limit of tolerable risk; this procedure allows the selection of appropriate protection measures to be adopted to reduce the risk below a tolerable limit.

In the international standard the definition of **risk R** is peculiar: it is the **probability** of having an annual loss in a structure or its content. For the purposes of this standard, four types of loss (L_1 to L_4) are considered and each one corresponds to a relevant risk :

- R_1 = risk of loss of human life,
- R_2 = risk of loss of service to the public,
- R_3 = risk of loss of cultural heritage,
- R_4 = risk of loss of economical value;

but each typical risk (R_1 to R_4) is also the sum of different components R_X ($X = A, B, C, \dots$, i.e. touch and step voltages, dangerous sparking and thermal effects, over-voltages, ...); each risk component R_X depends on the

point of strike and on the annual number of dangerous events N_X attached to X, the related probability of damage P_X (damage to the structure) and the consequent annual loss L_X due to a single lightning flash (related to the total amount of persons or goods) so that

$$R_X = 1 - \exp(- N_X P_X L_X) \cong N_X P_X L_X.$$

The various risk components are analysed and summed up to end up with a **total risk R** :

$$R = N P L ;$$

This total (level of) risk (frequency of annual loss in a structure due to lightning) is then defined as *the probable annual loss in a structure due to lightning*.

We must insist on some arbitrariness in the evaluation of the different components of this calculation, particularly the assumed values of the probabilities of damages which are most often rounded off to negative powers of 10 or integers (1 to 6, and 9) multiplying them; unfortunately we can never be more precise in this matter but we can be in front of very unprecise values of the total risk! We must suppose that people who consider the final result of the calculation (or the result shown on the screen by applying the proposed software) are clever enough to interpret the faint differences when applying this method!

This total risk R must be compared to the **tolerable** value of the risk R_T and always remain smaller or equal to R_T ; this condition has to be satisfied for each type of damage. R_T is a little arbitrarily defined (under the responsibility of national body concerned!) for the first three types of possible losses (losses of social value), whose suggested typical values are :

- 10^{-5} for the loss of human life,
- 10^{-3} for the loss of service to the public
- 10^{-3} for the loss of cultural heritage.

For the loss of economic value (L_4) a private decision will be taken by the owner or the designer of the structure under their own responsibility.

What is the precise meaning of a suggested 10^{-5} tolerable risk for the loss of human life? Why not 10^{-4} or better 10^{-6} or even better...? Does human life have a price? This is another crucial point. Each choice could be justified by some people and denied by other people... That is why the values of these tolerable risks are under the responsibility of the various National Committees, though the economic tolerable risk is simply left to the owner of the structure or to the designer of the LPS.

We would also like to underline the tremendous work done by Prof. C. Mazzetti and Z. Flisowski in the IEC TC81 WG devoted to the risk management problems and we take this opportunity to warmly congratulate them [5].

In risk assessment, it is crucial to know the average value of the regional lightning flash density (N_g). We have to be careful in the interpretation of different phenomena: the flash density is not the stroke density but people sometimes mix up both concepts. In temperate regions, the stroke density is about 4 times the flash density; moreover there is only one flash to ground for approximately 3 inter/intra-cloud flashes. Fortunately, modern lightning location systems help to discriminate between all types of discharges.

5. BASIC CRITERIA OF PROTECTION

A large consensus showed up in the elaboration of the **basic criteria of protection** :

1) *protection against physical damages* (fire, explosion danger and life hazards; see Part 3 of the standard, i.e. IEC 62305-3) with an efficient LPS both

- external (interception, electric current conducted to earth, dispersion into earth) and
- internal (preventing dangerous sparking within the structure by equipotential bonding and separation distances);

2) *protection against LEMP* based on the principle of (outer and inner) lightning protection zones (characterised by significant changes of the LEMP severities compatible with the immunity level of the internal systems) with protection measures which are essentially earthing, shielding, bonding and line routing (see Part 4 of the standard, i.e. IEC 62305-4); a full LPM system (capable to reduce the risk of permanent failures of electrical and electronic systems which are sensitive to energies as low as some mJ) will protect against conducted surges as well as against radiated magnetic fields; an essential point is the coordination of a set of surge protective devices (SPD system) which must be designed in liaison with the standards issued by other technical committees (TC64, SC37A,...); an important installation problem is the selection of the "protection distance", i.e. the maximum distance along the circuit at which the equipment will still be protected: some proper relations are given in IEC 62305-4, but the user will need to evaluate these protection distances by computer simulation;

3) *protection of services entering the structure* (cables, telecommunication lines,...; see Part 5 of the standard, i.e. IEC 62305-5); unfortunately the work is still in progress in this part of the standard and we are waiting for experts in pipelines and energy lines to work out on the missing measures of protection; the telecommunication lines using metallic conductors or optical fibre cables are already considered.

6. CONCLUSION

IEC TC81 has arrived at a substantial work on the means of lightning protection.

Not surprisingly, Europe adopts most of the IEC TC81 standards inside CENELEC (CLC TC81X); the European and the international commissions followed the same procedures with parallel voting inside the various National committees.

Though the work is surely not perfect yet, we are entering the maintenance period which should be used to improve the standard. Some hints are proposed in this paper.

Anyway all the National committees should adopt this international standard on lightning protection avoiding to promote fancy devices which do not comply with it.

REFERENCES

- [0] See the list of five IEC TC81 parts of the international standard in the text (§ 2): IEC 62305-1 to -5.
- [1] CIGRE Task Force 33.01.03 (Bernardi M., Bondiou-Clergerie A., Cooray V., Dellera L., Pedersen Aa., Rühling F.), "Lightning Exposure of Structures and Interception Efficiency of Air Terminals", CIGRE, 1997.
- [2] S. Ait-Amar and G. Berger, "A 3-D numerical model of negative lightning leader interception. Applications to the collection volume construction", ICLP2004, Avignon, Sept. 2004.
- [3] C. Bouquegneau and B. Jacquet, "How to improve the lightning protection by reducing the ground impedances", ICLP, the Hague (NL), Sept. 1983, paper 2.3, p. 89-96.
- [4] V.I.A. Rakov and M.A. Uman, "Lightning: Physics and Effects", Cambridge University Press, 2003.
- [5] C. Mazzetti, M. Pompili and Z. Flisowski, "Review of application problems of probabilistic approach to the lightning hazard assessment", ICLP, Florence, Sept. 1996, paper 7.1, pp. 707-712.