# THE LIGHTNING PROTECTION INTERNATIONAL STANDARD

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**Abstract – The Technical Committee on Lightning Protection of the International Electrotechnical Commission (IEC TC81) has finalised the new presentation of its work in four parts from general principles and risk management, to physical damage, life hazards and protection against electrical and electronic systems within structures. In this invited lecture we summarise their content and criticise the options chosen.**

## 1. INTRODUCTION

Following a world-wide scientific and technical work, IEC standards are based on scientifically proven theories and experimentation 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 has achieved its first cycle of work when issuing a standard (IEC 62305) in four parts (IEC 62305-1 to 4) listed below. The complete standard provides the general principles to be followed in the protection against lightning of structures (including their installations and contents as well as persons).

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 terms of **risk management** ; the risk management method is reported in IEC 62305-2.

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The criteria for design, installation and maintenance of lightning protection measures are considered in 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) is reported in IEC 62305-4.

In this 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.

## 2. LIST OF IEC TC81 STANDARDS

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

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

## 3. GENERAL PRINCIPLES

Since it is impossible to avoid a lightning strike, the application of lightning protection measures must be considered.

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 this method, mainly the so-called **electro-geometric model** (EGM or RSM : rolling sphere method considering a radius R equal to the striking distance or final jump distance).

Other methods are proposed from time to time to the international commissions, without success so far. For example, the CVM method (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.

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 effect. 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 will 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.

Direct cloud-to-ground discharges on or nearby a structure can damage it or strike persons as well as installations and their equipments.

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

These parameters will be illustrated by several pictures at the oral presentation. Let us notice that the so-called M-components are not considered in the standard.

Four **lightning protection levels LPL** (I to IV, with 4 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 in order to define the lightning protection zone which cannot be reached by direct strikes, a minimum peak current of 3 (LPL I), 5 (LPL II), 10 (LPL III) and 16 kA (LPL IV) leads to a rolling sphere radius R equal to 20, 30, 45 and 60 m respectively. 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.

In annex C of IEC 62305-1, the simulation of the lightning current (specific energy, charge, front current steepness…) for test purposes is described.

In annex D of IEC 62305-1, the test parameters simulating the effects (thermal, mechanical, electrical, acoustical…) of lightning on LPS components and on surge protective devices (SPD) are considered.

## 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 the tolerable limit.

Different types of *damages*, i.e.
**$D_1$** = injuries of living beings due to touch and step voltages,
**$D_2$** = physical damages (fire, explosion, chemical release, mechanical destruction,…) due to the lightning current effects, including sparking,

**$D_3$** = failure of electrical and electronic systems due to overvoltages**,**
and *losses* due to lightning, i.e.
**$L_1$** = loss of human life,
**$L_2$** = loss of service to the public,
**$L_3$** = loss of cultural heritage,
**$L_4$** = loss of economical value (including service and loss of activity)**,**
are introduced with the various *sources of damages*, i.e.
**$S_1$** = flashes to the structure,
**$S_2$** = flashes near the structure,
**$S_3$** = flashes to the services entering the structure,
**$S_4$** = flashes near the services entering the structure.

To each *type of loss* corresponds a **risk of probable annual loss**,
**$R_1$** = risk of loss of human life,
**$R_2$** = risk of loss of services to the public,
**$R_3$** = risk of loss of cultural heritage,
**$R_4$** = risk of loss of economical value which is fixed by the owner of the structure or the designer of protection measures according to a criterion of purely economic convenience.

Let us note that the assessment of $R_4$ allows to evaluate the cost of the economic loss with and without the adopted protection measures; the lightning protection is convenient if the sum of the cost $C_{RL}$ of residual loss in presence of protection measures and the cost $C_{PM}$ of protection measures is lower than the cost $C_L$ of total loss without protection measures: $C_{RL} + C_{PM} < C_L$ .

For each type of losss (loss components $L_1$ to $L_4$) the relevant risk (risk components $R_1$ to $R_4$) is the sum of different components **$R_X$** (X = A, B,…); each risk component $R_X$ depends on the point of strike; it also depends on the number of dangerous events **N**, the probability of damage **$P_X$** and the consequent loss **$L_X$** so that $R_X = N\ P_X\ L_X$ .

The various *risk components* R are analysed, both for a structure and for a service. Here, we only give these components for the structure:

- *for a direct strike to the structure* ($S_1$),
the standard considers three different risk components:
**$R_A$** = shock of living beings due to touch and step voltages
**$R_B$** = fire, explosion, mechanical and chemical effects inside the structure due to mechanical and thermal effects including dangerous sparking,
**$R_C$** = failure of electrical and electronic systems due to overvoltages on internal installations and incoming services;

- *for a strike to ground nearby a structure* ($S_2$),
**$R_M$** = failure of electrical and electronic systems due to overvoltages on internal installations, mainly caused by the magnetic field generated by the lightning current;

- *for a direct strike to the incoming line* ($S_3$),
**$R_U$** = injuries of living beings caused by touch voltage inside the structure due to lightning current injected in a line entering the structure,
**$R_V$** = fire, explosion, mechanical and chemical effects inside the structure due to mechanical and thermal effects including dangerous sparking between incoming lines and metal installations (generally at the entrance point of the line into the structure),
**$R_W$** = failure of internal systems caused by overvoltages induced on incoming lines and transmitted to the structure;

- *for a strike to ground nearby the incoming line and services* ($S_4$),
**$R_Z$** = failure of electrical and electronic systems due to overvoltages induced on incoming lines and transmitted to the structure.

The total risk **R** must be compared to the **tolerable** value of the risk **$R_T$** ; R must always be smaller or equal to $R_T$ (a little arbitrarily defined for the first three types of possible losses:
$10^{-5}$ 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 each type of damage.

The design engineer decides if the protection is required and, if it is, the suitable protection measures (following the selected lightning protection level) must be selected with eventual additional measures to limit:

1) **touch and step voltages** ($R_A$),
- by adequate insulation of exposed conductive parts,
- by equipotentialisation (meshed earthing system),
- by physical restrictions and warning notices,…

2) **physical damages** such as the development and propagation of the fire ($R_F$), by designing a convenient LPS for the structure and shielding wires for the services;

3) **failures of electrical and electronic systems** ($R_W$),
- by installing SPD at the entrance point of the lines entering the structure, in the internal installations, along the service and at the line termination,
- by setting magnetic shields on the structure and/or the installations inside the structure and/or the lines entering the structure and on the cables,
- by routing the wiring internal to the structure.

The flow chart related to a structure shows the procedure of selection:
- identification and characterization of the object to be protected;
- identification of all the types of losses in the object and estimation of the relevant corresponding risk components ($R_1$ to $R_4$);

- evaluation of need of protection by comparison of the total risk R with the tolerable risk $R_T$ :
if **$R < R_T$** , lightning protection is not necessary;
if **$R > R_T$** , protection measures shall be adopted in order to reduce R for all risks to which the object is subjected.

The assessment of risk components for services is similar to the one related to a structure, taking into account the relevant risk components (see IEC 62305-2).

Some case studies are completely treated in the standard (IEC 62305-2) for structures (annex H) and for services (annex I).

## 5. PHYSICAL DAMAGE TO STRUCTURES AND LIFE HAZARD

This part 3 of the standard (IEC 62305-3) deals with the protection in a structure against physical damages (use of both an external and an internal LPS) and injuries of living beings due to touch and step voltages (physical restriction and warning notices, insulation of exposed conductive parts and increase of the surface soil resistivity).

The **external LPS** is intended to intercept direct strikes to the structure (air termination system, including the sides of the structure), to conduct the lightning current to the earth (down-conductor system) and to disperse it into the earth (effective earth termination system).

The characteristics of an LPS are determined by the ones of the structure to be protected and by considering the level of protection (I to IV) selected on the basis of a risk assessment. The design for the type and location of the LPS will use natural metallic components and respect the electrical continuity (electrical continuity of steelwork in reinforced concrete structures). Detailed information is given in annex F of IEC 62305-3 (guidelines for the design, construction, maintenance and inspection of LPS).

A properly designed air termination system is composed of any combination of rods, catenary wires and meshed conductors. Particular care is given to the protection of exposed points, corners and edges, especially on the top levels and on the upper parts of the facades. Three methods can be used in determining the positioning: the RSM (rolling sphere method, suitable in all cases), the “protection angle” method (only applicable for structures limited in height) and the “mesh” method (suitable form of protection for plane surfaces).

The down-conductor system is arranged in such a way that from the point of strike to earth several parallel current paths exist, the length of the current paths is kept to a minimum and an effective equipotential bonding to conducting parts of the structure is performed.

The earth termination system will experience the lowest earthing resistance. When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground whilst minimising any potentially dangerous overvoltages, the shape and dimensions of the earth termination system are the important criteria. A single integrated structure earth termination system is preferable and suitable for all purposes (lightning protection, power systems and telecommunications systems).

Two types of earthing arrangements are used: type A (horizontal or vertical earth electrodes connected to each down-conductor) and type B (ring conductor external to the structure in contact with the soil or foundation earth electrode). Special care is brought for fixing, connections and test joints.

The **internal LPS** prevents dangerous sparking within the structure using either equipotential bonding or a separation distance (electrical insulation) between the external LPS components and other electrically conducting elements inside the structure.

Equipotentialisation is achieved by interconnecting (bonding conductors or surge protective devices SPD) the LPS with structural metal parts, metal installations, external conductive parts and internal systems (electrical and electronic system within the structure to be protected).

All the conductors of each line entering the structure to be protected should be bonded directly or with an SPD. The eventual screens and conducts shall also be bonded near the entering point.

The vicinity of the down-conductors of LPS outside the structure may be hazardous to life even if the LPS has been correctly designed; in this case, protection measures shall be adopted against injuries of living beings:

- protection measures due to **touch voltages** either by insulating the exposed down-conductors or by imposing physical restrictions and warning notices;
- protection measures due to **step voltages** by equipotentialising with a meshed earthing system and by using the same other protection measures imposed for the touch voltages.

Regular **inspections** and **maintenance** of any LPS are required.

If we summarise, the **basic criteria of protection** are:

1) protection against physical damages (fire and explosion danger and life hazards): 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: LPZ (lightning protection zones) with earthing, shielding and bonding (see IEC 62305-4). The protection of services entering the structure (cables, telecommunication lines, pipelines, power lines are now out of the scope of this standard).

## 6. ELECTRICAL AND ELECTRONIC SYSTEMS WITHIN STRUCTURES

Due to their high energy electromagnetic effects (LEMP: lightning electromagnetic impulses), lightning flashes may affect electrical and electronic systems (generally sensitive to some mJ) within the structure, causing permanent failures
- by possible conducted and induced surges transmitted to apparatus via connecting wiring,
- by the effects of radiated electromagnetic (EM) fields directly into apparatus itself.

Surges can be generated either externally (lightning flashes striking incoming lines or the ground nearby the lines and transmitted to electrical and electronic systems via the lines themselves) or internally (coupling due to lightning flashes striking the structure or the ground nearby the structure) to the structure. The coupling can be resistive (due to equivalent resistance of earth termination system of the structure or due to cable shield resistance), magnetic (due to loops in wiring of electrical and electronic systems or inductances of bonding conductors) or electric (due to rod antennas, generally negligible).

Radiated EM fields can be generated from the current flowing in the lightning channel or from partial lightning currents flowing in conductors (down-conductors of an external LPS or external spatial shield).

IEC 62305-4 deals with the protection against LEMP, via a LPM system capable to reduce the risk of permanent failures of electrical and electronic systems.; it does not cover protection against EM interference due to lightning, except for an evaluation of the disturbances which is reported in its annex A.

Protection against LEMP is based on the concept of LPZ, the lightning protection zones, characterised by significant changes of the LEMP severities compatible with the immunity level of the internal systems.

A full LPM system will protect against conducted surges as well as against radiated magnetic fields. The following LPZ are defined:

*outer zones:
- **LPZ 0** = zone endangered by unattenuated lightning magnetic and electric field and by surges up to full or partial lightning current; it is subdivided into
- **LPZ $0_A$** endangered by direct lightning strikes, by surges up to full lightning current and by full lightning field, and
- **LPZ $0_B$** protected against direct lightning strikes but endangered by surges up to partial lightning current and by full magnetic field;

* inner zones (protected against direct lightning strikes):
- **LPZ 1** where surges are limited by current sharing and by SPD at the boundary; the lightning field can be attenuated by spatial shielding;
- **LPZ 2, … N** where surges are further limited by current sharing and SPD at the boundary; the lightning field is usually attenuated by spatial shielding.

Basic protection measures against LEMP are:

**- earthing** (conduction and dispersion of the lightning current into the earth) and **bonding** (minimising potential differences); suitable earthing and bonding is based on a complete earthing system combining the earth termination system (dispersing the lightning current into the soil) and the bonding network (minimising potential differences and reducing the magnetic field); earthing and bonding shall always be provided, especially each conductive service incoming to the structure shall be bonded directly or via suitable SPD at the entrance point.; the other LEMP protection measures can be used alone or in combination among them;

**- magnetic shielding** (**spatial shielding** by grid-like or continuous metallic shields attenuating the magnetic field inside LPZ arising from lightning strikes direct to or nearby the structure and reducing internal surges, **shielding of internal lines** using shielded cables or cable ducts minimising internal surges induced into the installation, **shielding of external lines** incoming to the structure reducing external surges transmitted to the connected electrical and electronic system) and **line routing of internal lines** (by minimising induction loops and reducing internal surges);

**- surge protective device system (SPD system)**, limiting both external and internal surges; this system generally consists of a co-ordinated set of SPDs.; because of the high diversity of electronic systems characteristics, rules for selection and erection of an SPD system are different from those relevant to electrical systems; in a full LPM system using the LPZ concept with more than one LPZ, SPD shall be located at the line entrance into each LPZ.

The selection of SPD shall be made with regard to the protection level and with regard to location and discharge current; SPDs shall withstand the discharge current expected at their installation point (MB: main distribution point at line entrance to LPZ 1 or boundary of LPZ $0_A$/1 or LPZ $0_B$/1; SB: secondary distribution board or boundary of LPZ 1/2 and higher; SA: socket outlet close to apparatus or terminal of apparatus.

The efficiency of an SPD system depends not only on proper selection of SPD but mainly on proper erection, by taking into account the location of SPD, the connecting conductors and both protective distances related to oscillation phenomena and induction phenomena.

## 6. CONCLUSION

IEC TC81 has arrived at a consequent work on the means of lightning protection applicable to all the countries in the world.

Europe has adopted the IEC TC81 standards inside CENELEC (CLC TC81X) ; both 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..

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