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Lightning Risk Evaluation – Field experience

Alain Rousseau, Fernanda Cruz
SEFTIM
Vincennes, France
alain.rousseau@seftim.fr

Sébastien Sarramegna
SEFTIM NC
EMR
Nouméa, New Caledonia

Semi Taofifenua, Wacapo Taine
DSI
Province des Iles Loyauté
Lifou, New Caledonia

***Abstract*— Lightning risk assessment using IEC/EN 62305-2 standard method was conducted on various buildings of many types (hospital, civil buildings, museum etc.) on a same place. This study was motivated by many damages on telecom and data equipment in the last years. All these buildings being important for the user, he decide to launch a general analysis instead of providing lightning and surge protection measures for the damaged equipment occurred. Comparison is made between field results and the risk analysis. Based on this, proposals for improvement of 62305-2 are made.**

Keywords- Lightning, risk, assessment, standard, field experience

I. Introduction

Risk assessment is nowadays a well-known practice to determine which structures need to be protected and at which level of protection. The usual method is described in IEC or EN 62305-2 standard. This standard is by now at its 2nd edition and a 3rd edition is under preparation. A lot of comments on this method are emitted by people and organization who want to refine the method by adding more accuracy on formulas. On the other hand, a lot of comments are also emitted by people and organization, and sometimes by IEC technical committees, that consider the method as too complex and not taking care of field experience.

The Province des Iles Loyauté (PIL) located in the southern hemisphere is part of New Caledonian archipelago that includes 3 provinces (north and south province for the main land - Grande Terre - and a third province, named Province des Iles Loyauté, in short PIL, that regroups 4 islands: Lifou, Mare, Ouvea and Tiga. These last islands are of course in close connection with the main land and most of the connections are made by airplanes. Airplanes and boats are also making connections between the Loyalty Islands themselves. The PIL has the responsibility of many airports, of administrative buildings, hospitals, museums, and research institutes and so on. It is vital for the PIL that these buildings are well protected against lightning. Absence of airplanes and absence of hospital may have big consequences especially for the smallest islands having a single hospital. Telecommunication is also very important for human activity as well as for safety.

Following damages occurring in field on various equipment and mainly data and telecom equipment in the last 3 years, the PIL has decided to launch a wider risk analysis on most of their critical buildings instead of providing only lightning and surge protection measures of the damaged equipment. This study occurred in 2015. It is covering a large number of structures of various types and applications but all with similar flash to ground density (Ng). Results are interesting to define a protection planning. However, it is necessary to check if the result of the study is matching well with field experience. Sites that are experiencing most of the damages don’t appear to be with the highest risk level. In other words, should the protection plan be based only on risk assessment, the protection would not have been provided on the sites that are experiencing problems in practice. It is a valid approach to question this apparent contradiction.

One of the answers relates to the type of calculated risks. Primary risk to be calculated is named R1 in standard IEC 62305-2 [1] [2]: risk for people. This is purely a safety issue. This is not related to equipment damage. A second risk is named R2: risk for public service. Should a power plant be damaged for example, it will have a consequence on power supply of many users. It is a global approach of the service and this is not addressing the damage of a specific equipment used for telecommunication for example. Risk R3 if for national heritage buildings and this is not covering most of the applications of the PIL. Last possible Risk is economic risk R4. It has already being explained [3] that this method is not easy to use generally due to a lack of data from the user. In addition, the fact of missing one telecom equipment or line may not be related only to an economic loss but to a function loss. The risk proposed by Ed. 2 of IEC 62305-2 are not enough to cover the need of the present study.

Another answer relates to the formulas used for calculation of the risk. The method described in Ed.2 is based on too simplified formulas. Ed. 1 was more detailed but found too complex and Ed.2 has been simplified. The depth level of the method should be adjusted to the need. It is of course possible to change parameters using the magical “national rules” but in fact the risk should not depends on national rules or designer rules and the way of calculating should be the same for all. Software gives access today to more complex calculations and it should be possible to used detailed parameters or default values depending on the target.

This papers presents the study, its results and described possibilities to make the risk calculation more accurate. Draft for Ed. 3 will be also used as a guidance for future improvements.

II. STUDY PARAMETERS

A. Scope of the study

The study deals with building that are important for the PIL on the islands Lifou, Ouvea, Mare and Tiga of New Caledonia (see Figure 1). The study concentrates on buildings that have a public service, telecommunication, territory continuity or cultural function.

It should be noted that many copper conductors will be soon replaced by optical fibers for data or even telephone. In general, we have studied the projected situation (with optical fibers) that will be less stressed than the present one (using copper conductors). When the copper replacement was too far, the present situation was kept.

Risk R1 (human risk including fire and physical damage to the building, is calculated for all buildings. Risk R2 (loss of service) is calculated on building operating water, gas, radio, TV, electricity, telecom and by extension to the airports and PIL buildings being telecom and data centers. Risk R3 (national heritage) is calculated for historical buildings, museums and by extension to “farés”.

Figure 1. The studied islands being North of Grande Terre

B. Data related to the study

The flash ground density Ng is lower for the Islands that it is for Grande Terre (respectively between 0.5 and 1 for the Islands compared to 1.6 for Grande Terre).

For Lifou the study was concerning 6 buildings being part of the Hôtel de la PIL (main administrative structure. A branch in each Island), as well as 6 administrative buildings, a Faré, a research center and 2 hospitals (each of them being made of 2 main buildings).

For Ouvea the study concerned the hospital (made of 3 buildings), the airport, and the branch of the PIL made of 4 buildings.

For Mare the study concerned one hospital made of 3 buildings and another one with a single building), the airport, and the branch of the PIL made of 6 buildings as well as 4 buildings belonging to the Cultural Center (including a Museum).

Finally, for Tiga, the smallest of the Islands the study was concerning the hospital and the airport.

The services were connected to LV power lines and telecom lines that could be underground or overhead depending on the situation. For each case, the type of line, its length and its characteristic (underground, overhead) was identified as well as the building connected at the other side of the line (adjacent building).

Except hospitals that are of course operating 24h a day, the time of presence has been determined for each structure being part of the study.

On average, the time for the fire brigade to come to a site should an alarm be triggered is as follows: Mare and Lifou 15 minutes, Ouvea 10 minutes and Tiga 5 minutes. Most of the buildings are equipped by a fire detection.

At the present time only most of the hospitals are equipped by surge protection of Type 2 (for induced surges). There is no lightning protection.

III. THE IEC/EN 62305-2 METHOD

A. General principles

The risk due to lightning (including overvoltages) is the sum of different risk components, differing in their source of damage (S1, S2, S3, S4) and their type of damage (D1, D2, D3). We distinguish between:

- S1: flashes to the structure;
- S2: flashes near the structure;
- S3: flashes to the lines connected to the structure;
- S4: flashes near the lines connected to the structure.

and:

- D1: injury to living beings by electric shock;
- D2: physical damage (fire, explosion, mechanical destruction, chemical release) due to lightning current effects, including sparking;
- D3: failure of internal systems due to LEMP.

In total, with that we get the eight risk components R_A, R_B, R_C, R_M, R_U, R_V, R_W and R_Z. Each of this risk component is expressed by the following general equation:

$$R_X = N_X \cdot P_X \cdot L_X \tag{1}$$

where:

N_X is the number of dangerous events per annum (see also Annex A of [2]).

P_X is the probability of damage to a structure (see also Annex B of [2]).

L_X is the consequent loss (see also Annex C of [2]).

The number N_X of dangerous events is affected by the lightning ground flash density (N_G) and by the physical characteristics of the structure to be protected, its surroundings, the connected lines, and adjacent and connected buildings.

The probability of damage P_X is affected by the efficiency of the Lightning Protection System and Surge Protective Devices as well as on other parameters related to the shielding effect of the structure.

The consequent loss L_X is affected by the use to which the structure is assigned, the attendance of persons, the type of service provided to public, the value of goods affected by the damage and the measures provided to limit the amount of loss. When N_X and P_X are well justified parameters, L_X appears to be more questionable as related to a few parameters that are not scientifically justified.

B. Loss factors

The values of amount of loss L_X should be evaluated by the lightning protection designer. Typical mean values of loss L_X in a structure given in [1, 2] are values proposed by the IEC. L_X needs to be calculated for each of the losses associated to the calculated risks (R1 to R3 in our case).

C. Loss of human life (L1)

The loss value L_X for each zone can be determined according to (2), (3) and (4), considering that:

- the loss of human life is affected by the characteristics of the zone. These are taken into account by increasing (h_z) and decreasing (r_t, r_p, r_f) factors;
- the maximum value of loss in the zone must be reduced by the ratio between the number of persons in the zone (n_z) versus the total number of persons (n_t) in the whole structure;
- the time in hours per year for which the persons are present in the zone (t_z), if it is lower than the total 8760 h of a year, also will reduce the loss.

$$L_A = L_U = r_t \cdot L_T \cdot n_z/n_t \cdot t_z/8760 \qquad (2)$$

$$L_B = L_V = r_p \cdot r_f \cdot h_z \cdot L_F \cdot n_z/n_t \cdot t_z/8760 \qquad (3)$$

$$L_C = L_M = L_W = L_Z = L_O \cdot n_z/n_t \cdot t_z/8760 \qquad (4)$$

where:

L_T is the typical mean relative numbers of victims injured by electric shock (D1) due to one dangerous event (see Table I);

L_F is the typical percentage of persons injured by physical damage (D2) due to one dangerous event (see Table I);

L_O is the typical percentage of persons injured by failure of internal systems (D3) due to one dangerous event (see Table I);

r_p is a factor reducing the loss due to physical damage depending on the provisions taken to reduce the consequences of fire (see Table II);

r_f is a factor reducing the loss due to physical damage depending on the risk of fire or on the risk of explosion of the structure (see Table III);

h_z is a factor increasing the loss due to physical damage when a special hazard is present (see Table IV);

n_z is the number of persons in the zone;

n_t is the total number of persons in the structure;

t_z is the time in hours per year for which the persons are present in the zone.

Types of damage D1 and D2 are relevant for the type of structure selected by the PIL. D3 needs also to be taken into account for hospitals as an overvoltage can result in a danger for human beings in such a case.

TABLE I. TYPE OF LOSS L1: TYPICAL MEAN VALUES OF L_F AND L_O

Type of damage	Typical loss value		Type of structure
D1 injuries	L_T	10^{-2}	All types
D2 physical damage	L_F	10^{-1}	Risk of explosion
		10^{-1}	Hospital, hotel, school, civic building
		$5{\cdot}10^{-2}$	Public entertainment, church, museum
		$2{\cdot}10^{-2}$	Industrial, commercial
		10^{-2}	Others
D3 failure of internal systems	L_O	10^{-1}	Risk of explosion
		10^{-2}	Intensive care unit and operation block of hospital
		10^{-3}	Other parts of hospital

TABLE II. REDUCTION FACTOR r_p AS A FUNCTION OF PROVISIONS TAKEN TO REDUCE THE CONSEQUENCES OF FIRE (TABLE C.4 IN [1, 2])

Provisions	r_p
No provisions or structures with a risk of explosion	1
One of the following provisions: extinguishers; fixed manually operated extinguishing installations; manual alarm installations; hydrants; fire compartments; escape routes	0.5
One of the following provisions: fixed automatically operated extinguishing installations; automatic alarm installations [a]	0.2
a only if protected against overvoltages and other damages and if firemen can arrive in less than 10 min.	

If more than one provision has been taken, the value of r_p should be taken as the lowest of the relevant values.

TABLE III. REDUCTION FACTOR r_f AS A FUNCTION OF RISK OF FIRE OR EXPLOSION OF STRUCTURE (TABLE C.5 IN [1, 2])

Risk	**Amount of risk**	r_f
Explosion	Zones 0, 20 and solid explosive	1
	Zones 1, 21	10^{-1}
	Zones 2, 22	10^{-3}
Fire	High	10^{-1}
	Ordinary	10^{-2}
	Low	10^{-3}
Explosion or fire	None	0

Structures with a high risk of fire may be assumed to be structures made of combustible materials or structures with roofs made of combustible materials or structures with a specific fire load larger than 800 MJ/m^2.

Structures with an ordinary risk of fire may be assumed to be structures with a specific fire load between 800 MJ/m^{2}and 400 MJ/m^2.

Structures with a low risk of fire may be assumed to be structures with a specific fire load less than 400 MJ/m^2, or structures containing only a small amount of combustible material.

Specific fire load is the ratio of the energy of the total amount of the combustible material in a structure and the overall surface of the structure.

TABLE IV. FACTOR h_z INCREASING THE RELATIVE AMOUNT OF LOSS IN PRESENCE OF A SPECIAL HAZARD (TABLE C.6 IN [1, 2])

Kind of special hazard	h_z
No special hazard	1
Low level of panic (e.g. a structure limited to two floors and the number of persons not greater than 100)	2
Average level of panic (e.g. structures designed for cultural or sport events with a number of participants between 100 and 1 000 persons)	5
Difficulty of evacuation (e.g. structures with immobile persons, hospitals)	5
High level of panic (e.g. structures designed for cultural or sport events with a number of participants – greater than 1 000 persons)	10

D. Unacceptable loss of service to the public (L2)

The method is very similar but only D2 and D3 are considered.

The loss value L_X for each zone can be determined according to (4) and (5):

$$L_B = L_V = r_p \cdot r_f \cdot L_F \cdot n_z/n_t /8760 \quad (5)$$

$$L_C = L_M = L_W = L_Z = L_O \cdot n_z/n_t \cdot/8760 \quad (6)$$

where:

L_F is the typical mean relative number of users not served, resulting from physical damage (D2) due to one dangerous event (see Table V);

L_O is the typical mean relative numbers of users not served resulting from failure of internal systems (D3) due to one dangerous event (see Table V);

n_z is the number of users served by the zone;

n_t is the total number of users served by the structure;

TABLE V. TYPE OF LOSS L2: TYPICAL MEAN VALUES OF L_F AND L_O

Type of damage	**Typical loss value**		**Type of structure**
D2 physical damage	L_F	10^{-1}	Gas, water, power supply
		10^{-2}	TV, telecommunications lines
D3 failure of internal systems	L_O	10^{-2}	Gas, water, power supply
		10^{-3}	TV, telecommunications lines

E. Loss of irreplaceable cultural heritage (L3)

Once again the method is very similar to *L1* but only D2 is considered.

The loss value L_X for each zone can be determined according to (7):

$$L_B = L_V = r_p \cdot r_f \cdot L_F \cdot C_z/C_t \quad (7)$$

where:

L_F is the typical mean relative value of all goods damaged by physical damage (D2) due to one dangerous event (see Table VI);

C_z is the value of cultural heritage in the zone;

C_t is the total value of building and content of the structure (sum over all zones);

TABLE VI. TYPE OF LOSS L3: TYPICAL MEAN VALUES OF L_F

Type of damage	**Typical loss value**		**Type of structure**
D2 physical damage	L_F	10^{-1}	Museums, galleries

IV. THE RESULTS

A. Gross results

The study has been performed using software Jupiter 2.2 version avoiding misinterpretation of parameters and misused of standardized values.

The results of the study are summarized in Tables VII to X. It is the not purpose of this paper either to discuss the details of the analysis or the results in details but to give a global approach and to compare this with field experience.

The results are presented in a summarized way with the level of protection needed for the structure or for the services. When, the structure or the service or both don't need any protection (this means that the probability of failure is below the acceptable level) it is indicated as self-protected. When the structure is indicated as self-protected this means that the risk due to direct lightning is low. However, SPDs may still be needed to take care of stresses coming from the incoming lines.

It may appear strange that parts of hospital don't deserve lightning protection but only surge protection. This is explained by the type of structure, its size, the low Ng as well as part time presence of people in some parts of the hospital.

TABLE VII. LIFOU RESULTS

	Administrative building 1 to 4
Structure and services	*Self-protected*
	Hospital N°1
Structure	Self-protected
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Hospital N°1 - operation block
Structure	LPS level III
Services	Coordinated SPD system as per EN 61643-12 et 22 Level greater than I (Pspd <0,005)
	Hospital 2
Structure	*Self-protected*
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Hospital N°2 - operation block
Structure	*LPS level III*
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Research Center
Structure	Self-protected
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Pil builidngs 1 to 6
Structure and services	Self-protected
	Faré de la PIL
Structure	Self-protected
Services	Coordinated SPD system as per EN 61643-12 et 22 Level IV

TABLE VIII. OUVEA RESULTS

	Hospital 1 - operation block
Structure	LPS level III
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Hospital 1
Structure and services	Self-protected
	Hospital 1 - Administration
Structure and services	Self-protected
	Airport
Structure and services	Self-protected
	PIL Branch - building 1 to 4
Structure and services	Self-protected

TABLE IX. TIGA RESULTS

	Centre Médical
Structure	Self-protected
Services	Coordinated SPD system as per EN 61643-12 et 22 Level greater than I (Pspd <0,005)
	Aérogare
Structure and services	Self-protected

TABLE X. MARE RESULTS

	Airport
Structure and services	Self-protected
	PIL Branch - building 1 to 6
Structure and services	*Self-protected*
	Hospital 1
Structure	LPL Level III
Services	Coordinated SPD system as per EN 61643-12 et 22 Level greater than I (Pspd <0,005)
	Hopsital 2
Structure	Self-protected
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Hopsital 2 - operation block
Structure	LPL Level III
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Hopital 2 - other building
Structure	Self-protected
Services	Coordinated SPD system as per EN 61643-12 et 22 Level I
	Cultural Center - building 1 to 4 (Museum included)
Structure and services	Self-protected

B. Field experience

The PIL has collected a few damages over the last years but most of them in buildings that are not clearly outlined by the study. The amount of damages on the last 3 years exceeded 60 k€. Damages occurred only on equipment and mainly telecom and data equipment. This includes main distribution frame, server, switch, UPS, PC, telecom equipment. No damage has been observed on structure.

Most of the damages occurred in Mare and mainly at the PIL Branch (Building 1 to 6 in Table IX and especially building 1). Other damages occurred at Lifou in a computer building (Administrative building 1 in Table VII) and to a hospital (Hospital 2 in Table VII). These buildings are indicated in Italics in Table VII to X. Amongst these damaged buildings only Hospital 2 appears as needing Surge protective devices. Most of the other damages have been observed in places that are considered as self-protected by the risk analysis.

V. IEC/EN 62305-2 IMPROVEMENT

The first main conclusion that can be drawn from that study when we compare the calculation of risk level with IEC/EN 62305-2 and the field experience is that they don't match very well.

It is understandable that the method can identify structure that have not been damaged yet due to statistical spread. Risk is calculated as an average per year and it may be necessary to wait many years before the first damage. These structures and equipment surely deserve a special attention for the next protection plan. On the other hand, it is expected that buildings having already experienced damages are more sensitive than other buildings. They should then appear by the method as being at risk when in fact most of them appear as self-protected. This can be understood for one structure but for many it is more questionable. It may be due to the method itself. Another possible explanation could be that the damages buildings have telecom and electrical installation of different nature than others. But what make this study specific is that the same entity manage all the buildings that are all made with same type of equipment and networks. A careful site analysis of all buildings either damaged or not, has not shown specificities that could explain the results.

The comparison of IEC/EN 62305-2 with experience has very often been discussed or even challenged. A lot of chemical and oil/gas companies are considering that this method is too severe compared to field experience. On the reverse, the present study is showing that the method may be under-estimating the risk for more usual buildings without explosive areas, risk for environment or high fire risk.

It is likely that the influence of surge on lines is overestimated on chemical plants where many metallic element (cable trays, piping, structures …) reduce the overvoltages. For those sites some formulas are clearly over exaggerating the level of surges. This may be one of the reasons why the calculated risk is often not supported by field experience. A few additional parameters to better characterize the environment are needed for those complex sites.

Ed.2 of the standard uses formulas that are much simpler than in Ed1. This has been introduced to simplify the method but these formulas are probably too simple by now to be close to reality. For some cases, such as industrial site it overestimate the risk and for more common structures it underestimate the risk. Unfortunately these formulas has not been improved in the draft for Ed.3 [3] and many parameters are left to the national committees for more detailed calculation. As previously said, this may only lead to various results depending on the designer. In addition, use of software allows to implement detailed parameters and it would be better that a complete method is described in Ed3. with default parameters in case of simpler studies.

Another point is that the method doesn’t identify the need of protection of some risk such as R2 and R3 in a satisfactory way. For example, Risk R2 is related to the number of user that are not served by the service but doesn’t take into account neither the duration of service interruption nor the fact that losing a service may be critical even if there is a single user.

The loss concept itself, is leading according to us, to a lot of shortcuts and misinterpretations. The concept of frequency of damaged being N multiplied by P that was used in the old Technical Report IEC 61662 and recently reintroduced for the proposed revision 3 of IEC 62305-2 seems to be a better way of evaluating the risk. Each can then decide what the frequency of damage he can accept is. Such an approach would better fit with the need of the present study provided that N is calculated in a more accurate way. The introduction of the draft Ed3. Indicates “The concept of frequency of damage that may impair the functionality of the internal systems within the structure has been introduced”. We guess that it is exactly what will cover the need of the present study.

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