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Some Masterpoints about Risk due to Lightning

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***Abstract*— The present paper aims to provide insights for a better and simpler approach to risk assessment due to lightning. Reference is made to the documents recently issued in the frame of the International and European Standards.**

Keywords - lightning protection, risk assessment.

I. INTRODUCTION

Risk management is a basic method to determine the need of protection, to select and optimize the protection measures and to evaluate the economic benefit [1, 2] of installing the selected measures against lightning.

The basic and general principles on risk assessment of systems involving structures are reported in [3] where a general framework as well as a procedure is provided to identify hazards and estimate and treat risks of structures and systems involving structures.

The results of development process of the risk analysis, evaluation and management for the lightning protection of structures and systems internal to such structures is presented in IEC 62305-2 Ed 2,0 issued 2010-12 [5].

At present, discussion at IEC and also at CENELEC level is open with the aim to analyze Ed 2,0 document and to develop a clear procedure towards the Ed 3,0 of such standard.

Therefore, aim of the present contribution is to reconsider some master points about the risk in order to better define the whole matter involved and to find appropriate solutions for the risk evaluation.

II. THE RISK *R*

The fundamental terms for the risk management can generally be defined as follows.

The risk is the probable loss, in a fixed period of time, caused to an item by dangerous events related to a source of damage.

With reference to risk due to lightning, in IEC 62305:

- the source of damage is lightning
- the item is a structure
- the period of time is 1 year.

The risk so defined may be evaluated by the formula :

$$R = N \times P \times L \qquad (1)$$

being:

N the number of events which may cause damage (dangerous event) to the considered item in a fixed period of time

P the probability that a dangerous event will cause damage

L the loss consequent to the damage caused by a dangerous event.

The product $F = N \times P$ is the frequency of damage, that is the number of damages to or in a structure due to dangerous events.

It is to note that the risk *R*, so defined and evaluated by means of this formula, shall not be confused with the term "risk" often used (even in technical literature) to indicate "the dangerous condition or the dangerous event able to cause damage" usually measured by the probability to have such damage.

The risk *R* is not a probability, it is a probable loss and then to evaluate the risk *R* it is necessary:

- to identify the item for which the risk is to be evaluated (i.e. an object, a part or zone of a structure, a structure, a town, a country, etc. etc.)
- to identify the source of damage to the item (i.e. lightning)
- to fix the period of time to which the evaluation is referred (i.e. 1 year).

It is clear that, if in the item under consideration different type of loss appear which cannot be measured with the same measure unit (i.e. money), the relevant risks *R* should be evaluated individually and cannot be summed up.

In the actual standard [4, 5] four types of risk are identified as not being be summed up, namely:

- R_1 : risk of injury of leaving beings
- R_2 : risk of loss of service to the public
- R_3 : risk of cultural heritage
- R_4 : risk of economic loss

Each type of risk *R* in the item can be evaluated as an absolute value or as a percentage of the relevant value of the item.

As an example for a building whose value is € 500.000 with a 200 people occupancy, considering as source of damage the lightning and fixing as period of time 1 year, if we obtain a loss of 2 persons and € 500 as result of risk evaluation, it is possible to say:

- the risk R of the building due to lightning is 2 persons/ year and € 500/year, or
- the risk R of the building due to lightning is 1% of occupancy/ year and 0,1%/year of its value.

Finally, if the evaluated risk R is to be compared to a tolerable level R_T, such level shall be expressed in the same way as the evaluated risk R, i.e. absolute value or relative (percentage) value.

When risks belongs to the loss of items of social value, like risks R_1, R_2 and R_3, they are regulated by society and the relevant judgements on the value of tolerable risk R_T cease to be in the hands of the individuals who bear the risk.
For risk R_4, where lightning could result in the economic loss only, the values of tolerable risk R_{T4}, is under the responsibility of the individuals who bear the risk.

The tolerable level of risk evolves with social, ethical and economic community and the importance assigned to human values. Also it evolves with scientific knowledge, with the technical possibilities. Therefore, the tolerable level of risk is to be understood in a dynamic and statistical way. Data on accidents are essential to verify if the risk level, considered tolerable in theory, provide the expected results in practice.

III. THE TOLERABLE RISK R_{T1} FOR HUMAN LIFE

'Tolerability' refers to a willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce still further if and as we can [6].

The levels of tolerable value and of negligible of risk when people are involved, have been the subject of numerous studies over the world.

The most detailed and thorough document on the tolerability of risk seems the one developed by the Dutch government in 1988 entitled: "Premises for Risk Management" [7]. According to this document criteria of tolerability of frequency of damage is reported in Fig.1, from which criteria of tolerability of risk can be derived, see Fig.2. Assuming that the damage resulting from each hazardous event is constituted by death of one person (N = 1), risk R_1 lower than 10^{-5} per year can be considered negligible.

If however, we consider values of N further, the levels tolerable and negligible vary with a law proportional to $1/N^2$. That is, an increase in the number of deaths by a factor N is acceptable only if the frequency of occurrence of this event is less than a factor N^2 for both status [8].

In Fig. 1 and Fig. 2, two status are identified, the first where risk is so great or the outcome so unacceptable that it must be refused altogether (inacceptable risk status); the second where the risk is, or has been made, so small that no further precaution is necessary (negligible risk status).

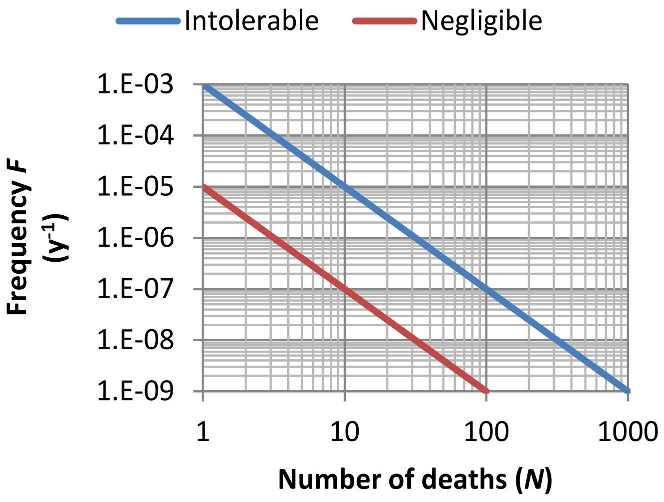

Figure 1. Criteria of frequency tolerability in The Netherlands [6].

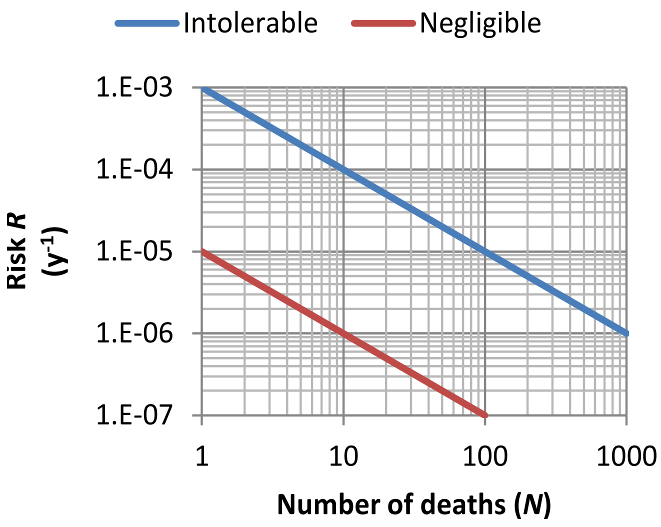

Figure 2. Criteria of risk tolerability.

If a risk falls between these two status, the injunction laid down in safety law is that any risk must be reduced so far as reasonably practicable, or to a level which is' as low as reasonably practicable' (ALARP principle), bearing in mind the benefits flowing from its acceptance and taking into account the costs of any further reduction.

A certain margin between the tolerable and negligible level must be held to account for uncertainties associated with estimates of risk and to be able to correctly distinguish the two levels.

According to [9] it should bear in mind that :

"Human life cannot be evaluated in money, but nevertheless one can easily understand that in many situations the possibilities for society to save human lives are limited by lack

of resources. The scarcity of resources is a fact and does not imply any desire to put a price on human life "

In IEC 62305-2 the value for R_{T1} relevant to loss of human life is fixed in $R_{T1} = 10^{-5}$, expressed in relative way as the number of injured person relative to the number of potential victims.

IV. The Tolerable Risk R_T for not Human Life

Risks not belonging to human life are purely economic or social nature (public services, cultural heritage), can be evaluated in a single unit of measure: money.

Consequently, it is possible to define a single risk of "economic loss" for the structure. Therefore loses significance in these cases to define a tolerable risk: the limit of tolerability could be assessed by analyzing the ratio cost / benefits from losses avoided on the one hand and cost of protection measures plus remaining losses on the other hand. At the most, for the services may, in addition, be set a limit to the frequency of damage tolerated depending on the quality of service provided.

V. Field Observations

A. Risk R_1 of loss of human life

The data considered here are from Italy [10] and are consistent with those observed in similar countries (temperate regions, level of industrialization, social activities, etc..). Where the statistical data are different from those here considered, different conclusions may be drawn.

Because of lightning there are about 1,000 deaths a year in the world during 16 million thunderstorms annually occurring on our planet, mostly in the equatorial belt.

In Italy, in the last 30 years lightning flashes have caused 600 deaths, mostly men (80,3%), whose average age is just over 40 years. Fortunately, the event is not so common and, indeed, has declined substantially over time: in fact, the annual number of deaths has dropped from 40÷45 people in the early seventies to 7÷10 in recent years.

Among the reasons for this decline are definitely worth mentioning: the increased protection of buildings by means of lightning protection measures, the spread of construction techniques of buildings which provide for a wider use of structural metallic elements (metallic framework, reinforced concrete), a wider dissemination of basic knowledge on some risky behaviors to avoid, and a significant improvement of medicine and of efficiency of services. Consider, for example, the fact that many serious burns once had a fatal outcome, whereas today, thanks to advances in techniques for tissue reconstruction and materials used, burn mortality rates have more than halved. Then there is also to consider some depopulation of mountain areas and countryside where once the majority of victims occurred between farmers and herders.

These “protective” factors are found worldwide. For example, in the United Kingdom [6], where the records of mortality are active and reliable for a long time, there was a net decrease in cases of mortality, from 19 cases on average in the second half of 1800 to the current 5, and this compared to an increase in population, which has even tripled.

In Italy, mortality (studied for 33 years from 1969 to 2002) decreased by 83,3 %. In fact, during the years 1969-1979 the average mortality rate was equal to 6,54 deaths per 10,000,000 res. / year, while in the next decade it fell to 2.60, and between 1990 and 2002 the rate fell to 1,40 deaths per 10,000,000 res. / year.

In particular the last five years for which data of death are available to date (1998-2002) it appears to have stabilized around an average rate of 1,26 deaths per 10,000,000 res. / year. It is to point out that in the period 2000-2012 all deaths occurred open air, no one being registered inside buildings.

Fortunately, only ¼ of the people struck by lightning catches consequences so serious that lead to the immediate death. In terms of direct costs of health care, a person struck by lightning and hospitalized, “costs” about 4,000 euros.

From these observations it appears that the level of risk naturally present (in the order of 10^{-7}) is far below that considered tolerable by the standard IEC 62305-2 (10^{-5}) and falls within the status of negligibility.

In contrast the level set by the standard ($R_{T1} = 10^{-5}$) is inadequate for structures in which a single hazardous event may result in more deaths contemporaries, such as structures in which the risk can be exported outside (structures with a risk of explosion or contamination) .

It remains a clear need to protect human life in special cases of structures in which the risk can be exported outside of the structure [12].

The finding that deaths occurred at open-air, no one being registered inside buildings, implies the recognition of a "natural" self-protective effect of structures against lightning. This effect, that from the data collected on field observation is very significant, is not considered adequately by the standard IEC 62305-2.

B. Other risks (R_2, R_3 and R_4) not including the loss of human life

While there is no significant evidence of loss of cultural heritage (mainly because fire due to lightning) so plausibly it falls in the negligible risk status, statistics and numerous field observations show that the surge due to lightning are the main cause of damage to electrical and electronic installations and equipment.

Even the loss of public service is essentially due to damages, caused by surges, of installations and equipment that perform the service.

The cost of these losses can be significant in relation to the consequences that the failure of even a single device has the service provided. Usually the cost of "plant shutdown" (lack of production, interruption of service, repair, etc..) are dominant by some orders of magnitude compared to the cost of the equipment damaged [11, 12].

This, on one hand highlights the importance of providing the structures for effective protection against surges due to lightning, the other seems to confirm that generally “to protect against lightning" mainly means "to protect against surges due to lightning”.

VI. Risk Evaluation According to IEC 62305-2

The remarks made earlier suggest a substantial revision of the standard IEC 62305-2 according to the guidelines set out below.

A. Risk evaluation in front of the tolerable risk R_T

The reliability of risk evaluation depends on the accuracy by which the loss factors L are determined. It is therefore crucial the understanding of this factor on the basis of accurate statistical analysis, unless provided by an authority having jurisdiction.

For risk for human life R_1, being the natural background level of risk $R_{1T} = 10^{-7}$ lower of one or two order of magnitude in front of the one ($R_T = 10^{-5}$) set by the standard, it is meaningless to evaluate it for all types of structures and spend money to reduce a risk which can be disregarded in front of many other more important risks.

It is wise to disregard R_1 in general in terms of risk assessment. The decision, whether a structure has to be protected against lightning or not, then should be given by the authority having jurisdiction.

However, for special cases (structures with risk of explosion, structures with risk of environmental pollution) R_1 should be evaluated. In these cases a tolerable value R_T of risk lower than $R_T = 10^{-5}$ should be fixed according to the amount of consequential losses, as shown in Fig.2. Such amount can be found in environmental impact studies which are almost always conducted before the construction of this type of structures.

According to Fig.2, it should be noted that the tolerable risk R_{1T} is not a fixed value for all structures in all cases but decreases as the consequential loss for each dangerous event increases. This is due to the increased sensitivity of people to events that cause a high number of casualties in a single shot (catastrophic event) than the same number of victims spread over several events.

For risks R_2 (loss of service to the public) R_3 (loss of cultural heritage) and R_4 (purely economic loss), as mentioned in Section IV, loses significance to define a tolerable risk being the limit of tolerability assessed by analyzing the ratio cost / benefits. Alternatively:

- For risk R_2 (loss of service to the public), the proper value of R_{T2} can be derived by the value of the tolerable frequency F_{T2} fixed by the authority having jurisdiction. Often the annual number of outages is in fact a parameter of the supply contract of service
- For risks R_3 (loss of cultural heritage) and R_4 (purely economic loss), it is possible to refer the proper values of R_{T3} and R_{T4} to the insured capital. Statistical data on the loss due to lightning are available from insurance companies. In the absence of specific data, reference could be made to the insurance premium paid to.

However, because of the difficulty of finding reliable values of the loss L, the assessment of risks R_1, R_2, R_3 and R_4 remains problematic.

B. Risk evaluation in front of the tolerable frequency F_T

In the absence of accurate statistical analysis, the severe difficulties involved in assessing reliable values of loss factors L make it preferable to choose as a parameter limit the tolerable frequency of damage F_T, rather than the tolerable risk R_T, overcoming the difficulties relevant to the assessment of values of L. In fact evaluation of frequency of damage F is under the technical control of the designer.

For risk for human life, the value of the tolerable frequency F_{T1} for special structures is in general fixed according to Fig.1, by the authority having jurisdiction as result of environmental impact studies conducted before the construction of this type of structures.

For the risk of loss of public service, the proper tolerable frequency of damage F_{T2}, is fixed by the authority having jurisdiction, being the annual number of outages a parameter of the supply contract of service.

Similarly, for the risk of loss of cultural heritage, the proper tolerable frequency of damage F_{T3}, should be fixed by the authority having jurisdiction.

For the risk of economic loss the proper tolerable frequency of damage F_{T4}, could be fixed by the owner or operator of the facility, taking into account the characteristics of the exploited service, the expected life for the structure, the organization for maintenance and repair and the associated costs.

C. Risk evaluation for direct and indirect lightning flashes

According to IEC 62305 the lightning current is the primary source of damage. The following sources are then distinguished by the point of strike:

– S1: flashes to a structure,

– S2: flashes near a structure,

– S3: flashes to a line,

– S4: flashes near a line,

and the relevant risk components are identified, (see Tab. 1).

Each risk, R, is the sum of its risk components. When calculating a risk, the risk components may be grouped according to the source of damage and the type of loss.

An effective tool to simplify the risk assessment and to select the proper protection measures to reduce it, is to determine whether the risk components related to direct strike of the structure and line are so small as to be negligible. Typically this occurs when is negligible the number N_D of direct lightning strikes on the structure and the number N_L of direct lightning strikes to the line.

TABLE I. RISK COMPONENTS TO BE CONSIDERED FOR EACH TYPE OF RISK IN A STRUCTURE

Source of damage	**S1**			**S2**	**S3**			**S4**
Loss type and risk component	R_A	R_B	R_C	R_M	R_U	R_V	R_W	R_Z
R_1	*	*	* [a]	* [a]	*	*	* [a]	* [a]
R_2		*	*	*		*	*	*
R_3		*				*		
R_4	* [b]	*	*	*	* [b]	*	*	*

[a] Only for structures with risk of explosion, and for hospitals or other structures where failure of internal systems immediately endangers human life.

[b] Only for properties where animals may be lost.

The limit values of N_D and N_L can be chosen in an absolute way or determined by comparison with the expected lifetime of the structure, facilities or activity carried on there. At present the standard IEC 62305-4 [13] establishes the limits of negligibility of N_D and N_L using the following relationship

$$(N_D + N_L) < 0.01 \tag{2}$$

i.e. the sources of damage S1 and S3 due to direct flashes to the structure and the line can be disregarded, if the occurrence of dangerous events is less than 1 every 100 years.

When relationship (2) is verified, the risk is composed only by risk components R_M (relevant to surges induced in internal systems by flashes nearby the structure) and R_Z (relevant to surges induced on lines by nearby flashes and transmitted to internal systems of the structure).

The needed protection measures in this case usually consist of SPD systems; being the cost of an SPD system only few percent of electric and electronic systems to be protected, the ratio cost / benefits from losses avoided on the one hand and cost of protection measures plus remaining losses on the other hand is usually substantially less than 1.

Moreover, an SPD system has no significant cost increases with the protection level (LPL) for which it is dimensioned.

Therefore, in these cases, evaluation of risk R_4 of economic loss can be avoided and the required SPD system dimensioned directly for the highest protection level (LPL I) without significant cost increases.

VII. CONCLUSIONS

On the base of the discussed items the following conclusions could be formulated:

- from field observations it appears that the level of risk of human life naturally present is in the order of 10^{-7} and falls within the status of negligibility;
- the finding that deaths occurred at open-air, no one being registered inside buildings, implies the recognition of a "natural" self-protective effect of structures against lightning, which should be taken into account in the standard;
- while there is a clear need to protect human life in special cases of structures in which the risk can be exported outside of the structure (structures with risk of explosion, structures with risk of environmental pollution), it is meaningless to evaluate such risk for common structures;
- in cases of common structures the authority having jurisdiction could decide, whether protection against lightning is necessary or not;
- it is confirmed for common structures that generally damages are essentially of economic nature, and "to protect against lightning" mainly means "to protect against surges due to lightning";
- the tolerable risk for human life is not a fixed value for all structures in all cases but decreases as the consequential loss for each dangerous event increases;
- risks not belonging to human life are purely of economic or social nature (public services, cultural heritage) and can be evaluated in a single unit of measure: money. The limit of tolerability may be assessed by analyzing the ratio cost / benefits;
- to overcome the difficulties relevant to the assessment of values of loss factors, the tolerable frequency of damage F_T, rather than the tolerable risk R_T, may be selected as the limit of tolerability;
- where effects of direct flashes to the structure are negligible, protection measures may consist of SPD system only. In this case evaluation of risk of economic loss can be avoided and the required SPD system can be dimensioned directly for the highest protection level (LPL I) without significant cost increases.

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