On the problems regarding the risk calculation used in IEC 62305

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Abstract. The 2nd part of the international standard on lightning protection (IEC 62305) deals with risk management. The explanations of the mathematical principles and the basic terms of this part facilitate the proper application of the standard. This paper gives additional information for better understanding of the standard and highlights some issues that might occur in its practical application.

1. Introduction
The lightning flash to earth, as a random event, can be modeled using stochastic analysis. Knowing the flash density, the number of the lightning flashes to a given area can be calculated according to a Poisson process. It means, that the parameter describing the time interval between two subsequent lightning flashes has an exponential distribution, and the parameter determining the number of lightning flashes to earth follows a Poisson distribution. Knowing these parameters the probability of the expected number of lightning flashes to a given area during a given time interval can be calculated using simple equations.

2. Risk
The EN 62305-2 standard defines risk as “the value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the object to be protected”. The level of the risk can be calculated by the following equation: \( R = N \times P \times L \), where \( N \) is the number of dangerous events due to flashes, \( P \) is the probability that a dangerous event will cause damage to the structure to be protected and \( L \) is the mean amount of loss (humans and goods) consequent on a specified type of damage due to a dangerous event, relative to the value (humans and goods) of the structure to be protected. If we assume that \( P \approx 1 \) (i.e. a lightning strike will cause damage almost certainly), and \( L = 1 \) (maximum loss is caused), then \( R \approx N \). In this way the risk can be interpreted as the expected annual frequency of the maximum loss in the structure. For example, if the level of this risk is \( 2 \times 10^{-3} \) then this means that a lightning strike that destroys the structure completely can be expected in every 50 000 years.

The risk of loss of human life (\( R_h \)) in the IEC 62305-2 means the annual frequency of the death of all persons in the given building. Let us call this event tragedy. For example, if the value of this risk is \( 5 \times 10^{-3} \) then one tragedy can be expected in every 200 years. But what is the probability that such an event will not occur in e.g. 100 years? For the answer the events caused by lightning should be modeled by a Poisson process.
3. Probabilistic description of the lightning hazards

Let us introduce the following probability variables: \( \xi_1, \ldots, \xi_n \), meaning the time intervals between lightning strikes. They have a “memorylessness” feature, i.e. the remaining time to the next event does not depend on the time elapsed from the previous event. Hence the \( \xi_1, \ldots, \xi_n \) probability variables follow an exponential distribution with parameter \( \lambda \). This is shown in figure 1.

\[ P(\eta_T = k) = \frac{(\lambda T)^k}{k!} \cdot e^{-\lambda T}, \quad k = 0, 1, \ldots \tag{1} \]

where
- \( \lambda \): is the parameter of an exponential distribution, i.e. the rate of the Poisson process.
- \( T \): is the chosen time interval;
- \( k \): is the number of events occurred during time interval \( T \);
- \( \eta_T \): is the parameter of the \( \xi_1, \ldots, \xi_n \) probability variables, i.e. the rate of the Poisson process.

The parameter of an exponential distribution is the reciprocal value of its expected value. After many independent experiments the expected value can be estimated by the mean value of the detected values. Hence the expected value \( \lambda T \) of the \( \xi_1, \ldots, \xi_n \) probability variables equals approximately the reciprocal value of the mean number of events detected during the given time interval. In our case it is the reciprocal value of the annually expected frequency of events. The risk is the annually expected frequency of the events caused by lightning:

\[ \lambda = \frac{1}{M(\xi_1, \ldots, \xi_n)} = R. \tag{2} \]

Hence the parameter of the Poisson distribution related to the probability variable \( \eta_T \), which expresses the number of events occurring during the time interval \( T \geq 0 \), is \( \lambda T \approx R \times T \). The probability of having no occurrence of tragedy in 100 years in a building with \( R_1 = 5 \times 10^{-5} \) is: \( P(k = 0) = e^{0.5} \approx 0.61 \). The probability of one single occurrence of this event under the same conditions is: \( P(k = 1) = 0.5 \times e^{0.5} \approx 0.3 \).

This high value of the risk cannot be allowed. This is guaranteed by the tolerable risks specified in the standard. In the case of loss of human life its value is \( R_{IT} = 10^{-5} \). This means that one tragedy in every 100,000 years in average is tolerable. Table 1 shows the probability of having at least one single occurrence of tragedy during different time intervals (T) if the tolerable risk is \( R_{IT} = 10^{-5} \).
Table 1: Probability of loss of human life during different time intervals

| Time interval [years] | Probability of tragedy |
|-----------------------|------------------------|
| 10                    | \( \approx 9.99 \times 10^{-5} \) |
| 100                   | \( \approx 9.99 \times 10^{-4} \) |
| 1 000                 | \( \approx 9.52 \times 10^{-3} \) |
| 10 000                | \( \approx 0.63 \) |

It can be seen that the probability of the event is not proportional to the time. It is also true when the process is evaluated for a 100-year-long time interval \((T = 100)\) with risk values \(R_1 = 10^{-2}\) and \(R_1 = 2 \times 10^{-2}\) (the risk of loss of human life can be even higher without lightning protection measures). In this case the density functions of a Poisson distribution with parameters \(\lambda \times T \approx 10^{-3} \times 100 = 1\) and \(\lambda \times T \approx 2 \times 10^{-2} \times 100 = 2\) are shown in the following figures.

![Fig. 2: Probability of tragedy in 100 years when \(R_1 = 10^{-2}\)](image)

![Fig. 3: Probability of tragedy in 100 years when \(R_1 = 2 \times 10^{-2}\)](image)

In the first case (Fig. 2) the probability of the tragedy is \(1 - 0.368 \approx 0.63\). In the second case (Fig. 3) this probability is \(1 - 0.135 \approx 0.87\). It can be shown that the probability of the single events is not proportional to the risk. If it was so, then the probability in the second case would be \(2 \times 0.63 = 1.26\), which is impossible. Hence the value of the risk itself does not give the probability of the events but is proportional to the expected value of the probability variable \(\eta_T\), expressing the number of events: \(M(\eta_T) = \lambda \times T = R \times T\). (The expected value of a Poisson distribution is equal to its parameter.)

Sometimes risk defined by the expected value expresses the hazard much better than the given probability values.

4. Application of the risk analysis
At the beginning of the risk analysis it is usually assumed that the structure is not covered by any lightning protection. The value of \(N\) depends on the local lightning activity and the physical parameters of the building. The value of \(P\) can be assumed to be 1 without any protection measure. However the value of \(L\) cannot be estimated very well, since it depends e.g. on the mean values of the loss, the fire hazard and the endangered number of persons and the time per year for which the persons are present in the hazardous zone.

According to our results the accuracy of the risk calculation depends basically on the correct estimation of the losses. For example, let us suppose that we have an office building with 800 m² area,
25 m height and the constant presence of 200 persons. 20 persons are present in the archive of the building. Fig.4 shows the actual risk for the whole building related to the tolerable risk depending on the risk of fire in the archive.

![Risk of fire in the archive](image)

**Table 2:** $R_I/R_T$ via number of persons and the time for which the persons are present in the archive

| Time / day | Number of persons |
|-----------|------------------|
|           | 8    | 9    | 10   | 11   | 12   |
| 24 h      | 1.15 | 1.23 | 1.3  | 1.38 | 1.45 |
| 20 h      | 0.9  | 0.95 | 0.99 | 1.04 | 1.08 |
| 16 h      | 0.82 | 0.86 | 0.89 | 0.93 | 0.96 |
| 12 h      | 0.76 | 0.78 | 0.81 | 0.83 | 0.86 |
| 8 h       | 0.69 | 0.71 | 0.72 | 0.74 | 0.76 |

Based on our experiments we can conclude that knowing the risk of fire in each part of the structure is crucial if we want to calculate the risk accurately. In our example, the total risk of the office building related to the tolerable risk is shown in the following table as a function of the number of persons and the time per day for which the persons are present in the archive when an automatic fire extinguisher is provided.

The endangered number of persons and the time per year in which the persons are present in the hazardous zone are usually poorly estimated. However the necessity of protection measures can only be decided if we know these values. If the exact values are not available, then the worst-case method should be used. Otherwise the planned measures will not meet the requirements of the lightning protection standard.

**5. Conclusions**

The risk analysis described in IEC 62305-2 quantifies the effects of the lightning. However the term “risk” can have different interpretations. The paper identifies the risk used in the standard. The paper helps to clarify the mathematical basis of the risk calculation applied in the IEC 62305 international standard on lightning protection. It focuses on the critical parameters, simplifications, which can lead to false results in the risk calculation followed by improper lightning protection measures. This issue is illustrated by a case study example.

**References**

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