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Sensitivity analysis in lightning protection risk management

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A R T I C L E I N F O

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A B S T R A C T

The total risk R can be expressed by the following equation: $R = NPL$, where N is the number of dangerous events, P is the probability of damage and L measures the amount of loss. These parameters can be regarded as macroparameters in the sense that they can be given as a function of additional parameters (microparameters).

Methods of calculation, check and refinement of parameter values have always been general themes of the standardization. The comparison of standards IEC 62305-2:2006 Ed. 1 and IEC 62305-2:2010 Ed. 2 is a good example of these efforts, as changes underwent in the determination of the collection area of service and the value of some parameters, moreover new parameters were introduced in order to break existent parameters into more components.

Though the international standard contains the value of parameters, it does not give any information about the procedure how these values were determined, nor about the theoretical considerations behind. Therefore it is proper to ask whether the changes of a given parameter value or introduction of a new parameter make radical changes in resulting risk value or not.

In this study sensitivity analysis was used to investigate how the individual macro- and micro parameters influence the risk. Moreover it was determined whether or not new parameters and calculations have an effect on the importance of the respective components of the resulting risk.

The sensitivity analysis was done for two case studies in the standard, a country house and an office building respectively, with both editions of the standard.

1. Introduction

The aim of the second part of the international lightning protection standard [2,3] is to decide the necessity of lightning protection of an object. For this purpose a relatively complicated calculation method is used. At the beginning the losses (the loss of human life, of public services, of cultural heritage and of economical value) shall be determined regarding the striking point of the flash (direct or indirect strike to the structure and to the connecting networks), then the risk values of these losses shall be calculated. The sum of these risk components gives the total risk. If the total risk is higher than the tolerable risk, then protection is needed, decisions shall be made which techniques to adopt in order to reduce the total risk regarding the given structure.

The parameter values needed in the risk calculations are chosen based on the specifications of the building in question (e.g. existing lighting protection measures, coordinated SPD system, etc.). These parameter values are published in the standards and obviously have a decisive effect on the calculated total risk, based on which decisions can be made regarding further protection measures. Therefore it is important to investigate how sensitive the total risk is to the individual parameters given by the standard.

This paper presents such a study. Sensitivity analysis was done for two case studies in the standard: a country house and an office building respectively, using both editions of the standard. Based on the results the order of the resulting risk sensitivities to the different parameters were determined, than a comparison was made between the two editions. This gives an overview about which parameters are the most relevant, and which ones are unimportant in these two cases.

2. Theory

Risk is determined by a function of k parameters: $R = f(\alpha_1,\alpha_2,\ldots,\alpha_i,\ldots\alpha_k,\beta_1,\beta_2,\ldots,\beta_i,\ldots\beta_k)$, where α_i represent the parameters and β_i refer to the chosen value of the parameters.

To highlight the meaning of the α_i, β_i pairs let us take a look at the c_d location factor of the structure. This parameter can take four different values depending on the relative location of the structure. α_i is simply c_d and β_i corresponds to the actual value of the location factor, e.g. 1 in case of an “isolated structure: no other objects

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Table 1
Loss of life risk sensitivities to the parameters in the two editions of the standard.

S_{R_1,N_g}	S_{R_1,A_d^h}	S_{R_1,A_l^p}	S_{R_1,A_l^t}	S_{R_1,c_d^h}	S_{R_1,P_B^h}	S_{R_1,r_p^h}
1	$4.34 \cdot 10^{-2}$	$3.7 \cdot 10^{-1}$	$5.88 \cdot 10^{-1}$	$4.34 \cdot 10^{-2}$	$4.34 \cdot 10^{-2}$	1
S_{R_1,N_G}	S_{R_1,A_D^h}	S_{R_1,A_L^p}	S_{R_1,A_L^t}	S_{R_1,c_D^h}	S_{R_1,P_B^h}	S_{R_1,r_p^h}
1	$4.11 \cdot 10^{-2}$	$3.19 \cdot 10^{-1}$	$6.38 \cdot 10^{-1}$	$4.12 \cdot 10^{-2}$	$4.12 \cdot 10^{-2}$	$9.97 \cdot 10^{-1}$
S_{R_1,h_z^h}	S_{R_1,r_f^h}	S_{R_1,r_u^h}	S_{R_1,L_f^h}	S_{R_1,L_t^h}	S_{R_1,c_t^p}	S_{R_1,c_t^t}
1	1	$9.58 \cdot 10^{-6}$	1	$9.58 \cdot 10^{-6}$	$3.7 \cdot 10^{-1}$	$5.88 \cdot 10^{-1}$
S_{R_1,h_z^h}	S_{R_1,r_f^h}	S_{R_1,r_t^h}	S_{R_1,L_F^h}	S_{R_1,L_T^h}	S_{R_1,c_T^p}	S_{R_1,c_T^t}
$9.97 \cdot 10^{-1}$	$9.97 \cdot 10^{-1}$	$9.97 \cdot 10^{-4}$	$9.97 \cdot 10^{-1}$	$9.97 \cdot 10^{-4}$	$3.19 \cdot 10^{-1}$	$6.38 \cdot 10^{-1}$
S_{R_1,c_d^p}	S_{R_1,c_d^t}	S_{R_1,P_A^h}	S_{R_1,P_U^p}	S_{R_1,P_U^t}	S_{R_1,P_V^p}	S_{R_1,P_V^t}
$3.7 \cdot 10^{-1}$	$5.88 \cdot 10^{-1}$	0	$3.7 \cdot 10^{-6}$	$5.88 \cdot 10^{-6}$	$3.7 \cdot 10^{-1}$	$5.88 \cdot 10^{-1}$
–	–	–	–	–	–	–
–	–	–	–	–	–	–
–	–	–	–	–	–	–
–	–	–	–	–	–	–
S_{R_1,P_{TA}^h}	S_{R_1,P_{TU}^h}	S_{R_1,c_l^p}	S_{R_1,c_{LD}^p}	S_{R_1,c_l^t}	S_{R_1,c_{LD}^t}	S_{R_1,c_E^p}
$4.12 \cdot 10^{-5}$	$9.56 \cdot 10^{-4}$	$3.19 \cdot 10^{-1}$	$3.19 \cdot 10^{-1}$	$6.38 \cdot 10^{-1}$	$6.38 \cdot 10^{-1}$	$3.19 \cdot 10^{-1}$
–		–		–		–
–		–		–		–
S_{R_1,c_E^t}		S_{R_1,P_{LD}^p}		S_{R_1,P_{LD}^t}		S_{R_1,P_{EB}^h}
$6.38 \cdot 10^{-1}$		$3.19 \cdot 10^{-1}$		$6.38 \cdot 10^{-1}$		$9.57 \cdot 10^{-1}$

in vicinity". In the rest of the paper β_i will be discarded from the notation since it only corresponds to the actual numerical values, not the parameters.

Sensitivity analysis answers the question of how the total risk is influenced if a parameter value is changed. Let us denote the nominal values of the parameters (given by the standard) by $(\alpha_{1,0},\alpha_{2,0},\ldots,\alpha_{i,0},\ldots\alpha_{k,0})$. Furthermore let us assume that the parameter values are changed by $(\delta\alpha_1,\delta\alpha_2,\ldots,\delta\alpha_i,\ldots\delta\alpha_k)$, so that the new values are given by:

$$\boldsymbol{\alpha} = \boldsymbol{\alpha}_0 + \delta\boldsymbol{\alpha} = \left(\alpha_{1,0} + \delta\alpha_1, \ldots, \alpha_{k,0} + \delta\alpha_k\right)$$

As a result the risk will also take a perturbed value:

$$R = R(\alpha_1, \ldots, \alpha_k) = R\left(\alpha_{1,0} + \delta\alpha_1, \ldots, \alpha_{k,0} + \delta\alpha_k\right)$$

The risk can be expanded in a Taylor series around the nominal values:

$$\begin{aligned} R &= R(\alpha_1, \ldots, \alpha_k) = R\left(\alpha_{1,0} + \delta\alpha_1, \ldots, \alpha_{k,0} + \delta\alpha_k\right) = \\ &= R(\boldsymbol{\alpha}_0) + \sum_{i_1=1}^{k} \left(\frac{\partial R}{\partial \alpha_{i_1}}\right)_{\alpha_0} \delta\alpha_{i_1} + \frac{1}{2} \sum_{i_1,i_2=1}^{k} \left(\frac{\partial^2 R}{\partial \alpha_{i_1} \partial \alpha_{i_2}}\right)_{\alpha_0} \delta\alpha_{i_1} \delta\alpha_{i_2} + \\ &\ldots + \frac{1}{n!} \sum_{i_1,i_2,\ldots,i_n=1}^{k} \left(\frac{\partial^n R}{\partial \alpha_{i_1} \partial \alpha_{i_2} \ldots \partial \alpha_{i_n}}\right)_{\alpha_0} \delta\alpha_{i_1} \ldots \delta\alpha_{i_n}. \end{aligned}$$

Table 2
Comparison of loss of life risk sensitivities to the parameters in the two editions of the standard.

S_{R_1,c_d^p}	S_{R_1,c_d^t}		S_{R_1,P_A^h}
$3.7 \cdot 10^{-1}$	$5.88 \cdot 10^{-1}$		0
$S_{R_1,(c_l^p \cdot c_E^p)}$	$S_{R_1,(c_l^t \cdot c_E^t)}$		$S_{R_1,(P_{TA}^h \cdot P_B^h)}$
$3.19 \cdot 10^{-1}$	$6.38 \cdot 10^{-1}$		$4.12 \cdot 10^{-5}$
S_{R_1,P_U^p}	S_{R_1,P_U^t}	S_{R_1,P_V^p}	S_{R_1,P_V^t}
$3.7 \cdot 10^{-6}$	$5.88 \cdot 10^{-6}$	$3.7 \cdot 10^{-1}$	$5.88 \cdot 10^{-1}$
$S_{R_1,(P_{TU}^h \cdot P_{EB}^h \cdot P_{LD}^p \cdot c_{LD}^p)}$	$S_{R_1,(P_{TU}^h \cdot P_{EB}^h \cdot P_{LD}^t \cdot c_{LD}^t)}$	$S_{R_1,(P_{EB}^h \cdot P_{LD}^p \cdot c_{LD}^p)}$	$S_{R_1,(P_{EB}^h \cdot P_{LD}^t \cdot c_{LD}^t)}$
$3.19 \cdot 10^{-4}$	$6.37 \cdot 10^{-4}$	$3.19 \cdot 10^{-1}$	$6.37 \cdot 10^{-1}$

Table 3
The parameters in IEC 62305-2:2006 Ed. 1 in descending order of their importance.

IEC 62305-2:2006 Ed. 1							
1.	2.	3.	4.	5.	6.	7.	8.
N_g	A_l^t	A_l^p	A_d^h	r_u^h	P_U^t	P_U^p	P_A^h
r_p^h	c_t^t	c_t^p	c_d^h	L_t^h			
h_z^h	c_d^t	c_d^p	P_h^B				
r_f^h	P_V^t	P_V^p					
L_f^h							

If the risk is linear function of parameters the following holds:

$$R(\alpha_1, \ldots, \alpha_k) = R(\boldsymbol{\alpha}_0) + \sum_{i=1}^{k} \left(\frac{\partial R}{\partial \alpha_i}\right)_{\alpha_0} \delta\alpha_i = R_0 + \sum_{i=1}^{k} S'_i \delta\alpha_i,$$

where $R(\boldsymbol{\alpha}_0) = R_0$ and $S'_i = (\partial R / \partial \alpha_i)_{\boldsymbol{\alpha}_0}$ are the sensitivities of risk to the α_i parameters [1].

3. Application

The sensitivities of the total risk to the parameters were examined in two case studies included in the standard: a country house and an office building respectively. The calculations were done with both the IEC 62305-2:2006 Ed. 1 and the IEC 62305-2:2010 Ed. 2 editions of the standard.

In both cases the risk of human life loss R_1 was examined. By changing the value of parameter α_i with $\delta\alpha_i = (\alpha_i - \alpha_{i,0})$ the corresponding new risk is given by:

$$R_1(\alpha_i) = R_{1,0}(\alpha_{i,0}) + \left.\frac{\partial R_1}{\partial \alpha_i}\right|_{\alpha_{i,0}} \cdot (\alpha_i - \alpha_{i,0}).$$

The relative changes $(\Delta R_1 / R_{1,0})$ can be expressed as:

$$\frac{\Delta R_1}{R_{1,0}} = \left.\frac{\partial R_1}{\partial \alpha_i}\right|_{\alpha_{i,0}} \cdot \frac{(\alpha_i - \alpha_{i,0})}{R_{1,0}} = \underbrace{\left.\frac{\partial R_1}{\partial \alpha_i}\right|_{\alpha_{i,0}} \frac{\alpha_{i,0}}{R_{1,0}}}_{S_{R_1,\alpha_i}} \cdot \frac{(\alpha_i - \alpha_{i,0})}{\alpha_{i,0}},$$

where S_{R_1,α_i} is the sensitivity of the risk to parameter α_i. These sensitivities were calculated for each α_i parameters showing how the total risk changes, if the value of α_i parameter changes with 1%.

4. Result

4.1. Sensitivity analysis of the country house

In the case of the country house the expression forR_1 given in IEC 62305-2:2006 Ed. 1 is: $R_1 = R_B^h + R_U^p + R_U^t + R_V^p + R_V^t$., while the one in IEC 62305-2:2010 Ed. 2 is: $R_1 = R_A^h + R_B^h + R_U^p + R_U^t + R_V^p + R_V^t$.

Table 4
The parameters in IEC 62305-2:2010 Ed. 2 in descending order of their importance.

IEC 62305-2:2010 Ed. 2						
1.	2.	3.	4.	5.	6.	7.
N_G	A_l^t	A_l^p	A_D^h	r_t^h	P_{TU}^h	P_{TA}^h
r_p^h	c_T^t	c_T^p	c_D^h	L_T^h		
h_z^h	c_E^t	c_E^p	P_h^B			
r_f^h	c_l^t	c_l^p				
L_F^h	c_{LD}^t	c_{LD}^p				
P_{EB}^h	P_{LD}^t	P_{LD}^p				