Lightning Risk Assessment of a Structure

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Abstract—This paper presents an analysis of the lightning risk assessment of a building of human life and cultural heritage value at the Chancellery office building at UiTM Shah Alam, Selangor. New software had been developing for risk assessment calculation. The methods for lightning risk assessment due to lightning flashes to a structure based on the Malaysian Standard (MS) of International Electrotechnical Commission (IEC) 62305-2 by using the Microsoft Excel and develop software. The result obtained can be a reference for safety issue of lightning strike protection. The Chancellery office building itself needs extra protections because the risk of human life value was not tolerated with the standard value after calculate the risk assessment using both methods.

Keywords; Risk Assessment, Lightning Protection System (LPS), International Electrotechnical Commision (IEC), Malaysian Standard (MS)

1. INTRODUCTION

Lightning strike to the structure will cause damage to the structure itself, to its occupants and contents and including failure of internal systems. The damages and failures may also extend to the surrounding of the structure and even involve the local environment. The lightning risk assessment and needed for protection measures should be determined using the risk assessment methodology in MS IEC 62305-2 of this guide or by means of commercially available software written specifically for the purpose [2].

The protection of a human life and heritage building should be based on the basic principles and methodologies. Since lightning strike can be a natural risk that threatens buildings of human loss and cultural heritage loss. An LPS helps protect against physical damage to the structure, its contents and injury of living beings. Regarding the LPS implementation, some of the following principles were taken into account [2]:

- The structure itself such as the parameters of that structure need to protect;
- The intervention, which included the LPS installation, was carried out in accordance with local operational guidelines for the protection of human life and cultural heritage;
- As there was no information related to any LPS in the original building, the task of protecting it required a complete analysis of technical, historical, and architectural;
- Persons in the structure or standing in the zones up to 3 meters from the outside of the structure;
- The environment affected by a damage to the structure

Part 2 of the new standard IEC 62305-2 [2] treats the risk management of the protection against lightning. The risk, defined in this standard is the probable average annual loss in a structure and in a service due to lightning flashes. The lightning risk is depends on a lot of parameters (at least 52, if we refer to IEC 62305-2). The new software was created especially to calculate the risk of loss of human life and cultural heritage due to damage on structure as showed in Figure 5 and 6 was establish by using the Matlab GUI software. The interface has been clearly designed to show all parameters simultaneously for more understanding on calculating risk assessment of lightning protection system on a structure, as well as the principal result of risk calculations, the collection areas, the number of dangerous events experienced by the structure and the suggestion what should their do after completing the calculation will be directly to the expert of the lightning protection system by through the official email.

2. METHODOLOGY

The decision to protect a structure or a service against lightning, as well as the selection of protection measures shall be performed according to IEC 62305-1 [1]. The following procedure shall be applied and the Figure 1 shows the procedure for deciding the need of protection:

- Identification of the object to be protected and its characteristics;
- Identifications of all the types of loss in the object and the relevant corresponding risk R (R_1, R_2. R_3 and R_4);
- Evaluation of risk R for each type of loss;
- Evaluation of need of protection, by comparison of R_1, R_2, and R_3 for a structure with the tolerable risk R_T as shown in Table 1;

Table 1: Typical values of tolerable risk R_T

Types of loss	R_T (y^{-1})
Loss of human life or permanent injuries, R_1	10^{-5}
Loss of service to the public, R_2	10^{-3}
Loss of cultural heritage, R_3	10^{-3}

If $R \le R_T$ lightning protection is not necessary. If $R > R_T$ protection measures shall be adopted in order to reduce R until $R \le R_T$ for all risk considered.

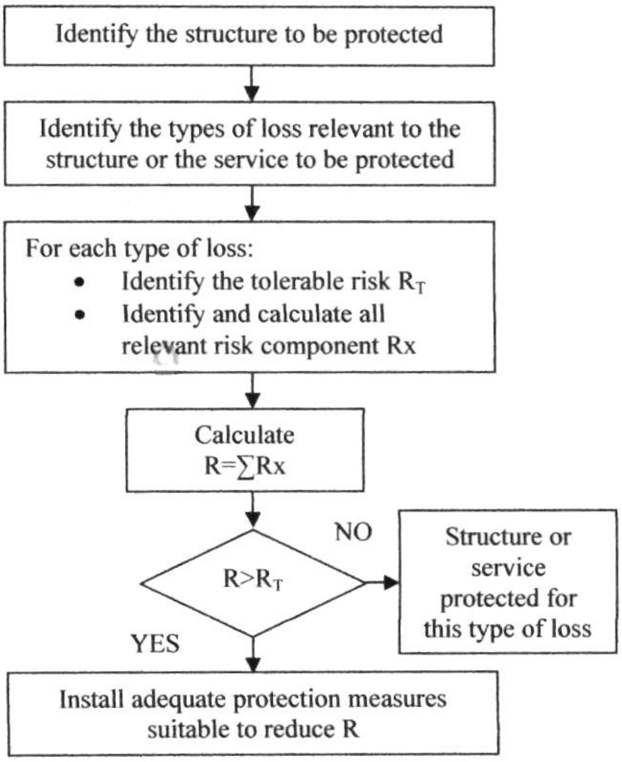

Figure 1: Procedure for deciding the need of protection

2.1 Comments on the structure and air termination system

The Chancellery office building at UiTM Shah Alam, Selangor had been selected because it is stand alone structure on the hilltop and may have a risk of lightning strike. The parameter of the Chancellery building is 33 meters height, 33 meters width and 50 meters length and the layout as shown in Figure 2 and 3. The structure is considered as the rectangular structure. All the detail of Chancellery office building and air termination system was shown in Table 3.

2.2 Power supply and communication systems

The power and commnucation systems connections are underground based on observation and information from the Fasility office of UiTM Shah Alam. the following information was succefull gather which is:

- The power and telecommunication line is underground. The length considered is 1000 m. The building is surrounded by trees of the same height or smaller ($C_d = 0.5$). There is a transformer for service only ($C_t = 1$) and the soil resistivity, ρ is 500Ωm [2].
- All the services are unshielded, $P_{LD} = 1$. Since the LPS install at the structure is level IV [3], there is a Surge Protection Device (SPD) was install according to LPS, $P_{SPD} = 0.03$ [2].
- The lightning ground flash density, $Ng = 0.1{*}T_d$, where T_d averagely 200 thunderstorm day a year at the Peninsular Malaysia, so the value of Ng = 20 strike per km^2 per year [4][5].

The power supply and incoming lines characteristics and data was recorded in Table 3. There is are unknown information that can be decide as assumption value based on MS IEC 62305-2 [2] and the assumption was shown in Table 2.

Table 2: Fixed parameter for calculation and software

Parameter	Symbol	Value
Soil resistivity (Ωm)	ρ	500
Service length line (m)	L_c	1000
Shield at structure boundary	K_{S1}	1
Shield internal to structure	K_{S2}	1

Table 3: Parameter related to the Chancellery building

Parameter	Symbol	Value
Structure characteristics		
Length of structure (m)	L_b	50
Width of structure (m)	W_b	33
Height of structure (m)	H_b	33
Location factor	C_d	0.5
LPS (level IV)	P_B	0.2
People present outside the building	nt	100
Lightning flash density	$Ng^{(1)}$	20
Power line		
length (m)	L_c	1000
Height (m) (underground)	H_c	0
transformer	C_t	1
Line location factor	C_d	0.5
Line environment factor	C_e	0
Line shielding	P_{LD}	1
Internal wiring precaution	K_{S3}	1
Withstand of internal system	K_{S4}	1
Coordinated SPD protection	P_{SPD}	0.03
Communication line		
length (m)	L_c	1000
Height (m) (underground)	H_c	0
Line location factor	C_d	0.5
Line environment factor	C_e	0
Line shielding	P_{LD}	1
Internal wiring precaution	K_{S3}	1
Withstand of internal system	K_{S4}	1
Coordinated SPD protection	P_{SPD}	0.03

$^{(1)}$ Td = 200 thunderstorm day per year [4][5][6].

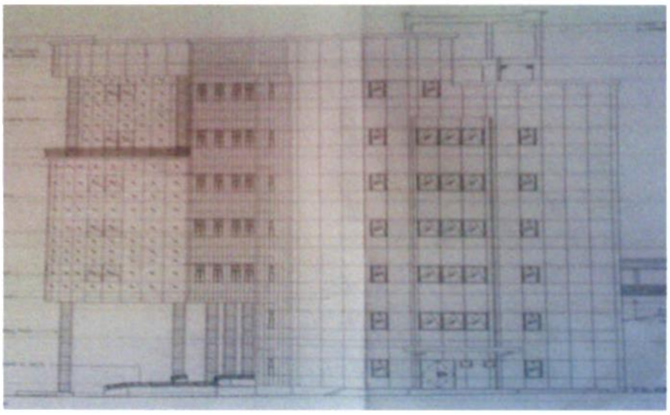

Figure 2: Chancellery UiTM, side view

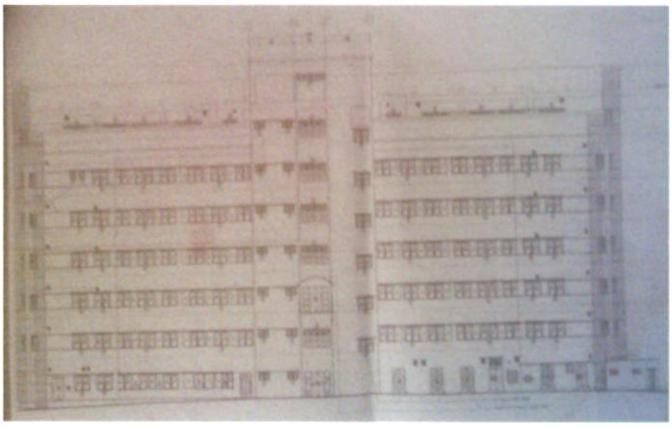

Figure 3: Chancellery UiTM, front view

The Chancellery office building have an unconventional air termination rods (non radioactive) from early streamer emission (ESE) technology. There were installed on the roof, as shown in Figure 4. ESE technology claims to provide more effectiveness however is not accepted worldwide by the scientific community [7]. Consequently, for the present analysis, ESE air terminal effectiveness is considered the same as that of a conventional one and the cost also can be reduced by installing the LPS conventional only [8].

Figure 4: Chancellery UiTM, LPS view (ESE)

2.3 Risk Assessments

All the parameters are taken to calculate the lightning risk assessment for a Chancellery office building. The calculation will be done by using both method which by Microsoft Excel and develop software. For the case under analysis which is Chancellery office building, R_1 risk of loss of human life and R_3 risk of loss of cultural heritage are considered relevant. R_2 risk of loss of service to the public and R_4 risk of loss of economic value is not considered relevant.

2.3.1 Calculation of Risk R_1 and R_3

R_1: risk of loss of human life using the following equation [2].

$$R_1 = R_A + R_B + R_{U(\text{power line})} + R_{V(\text{power line})} + R_{U(\text{telecom line})} + R_{V(\text{telecom line})} \quad (1).$$

R_3: risk of loss of cultural heritage using the following equation [2].

$$R_3 = R_B + R_{V(\text{power line})} + R_{V(\text{telecom line})} \quad (2)$$

Where:

R_A: component related to injury to living beings caused by touch and step voltages in the zones up to 3 meters outside the structure;
R_B: component related to physical damage caused by dangerous sparking inside the structure triggering fire or explosion, which may also endanger the environment,
R_U: component related to injury to living beings caused by touch voltage inside the structure due to lightning current injected in a line entering the structure,
R_V: component related to injury to physical damage (fire or explosion triggered by dangerous sparking between external installation and metallic parts generally at the entrance point of the line into the structure) due to lightning current transmitted through or along incoming services.

The contribution of component R_C, R_M, R_W and R_Z to R_1 were not considered, as the structure has no risk of explosion.

The assessment of risk component formula for the structure is:

$$Rx = Nx * Px * Lx$$

Where:

Nx: the number of dangerous events per annum (annex A) [2];

- The number of Nx of dangerous events is affected by lightning ground flash density (Ng) and by the physical characteristics of the object to be protected, its surroundings and the soil.

Px: the probability of damage to a structure (annex B) [2];

- The probability of damage Px is affected by the characteristics of the object to be protected and the protection measures provided.

Lx: the consequent loss (annex C) [2];

- The consequent loss Lx is affected by the use to which object 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.

Taking into account that the type of surface outside and inside the structure is different and that no spatial shields exist, then the following main zone was decided to calculate the risk assessment at the Chancellery office building at UiTM Shah Alam, Selangor:

- Z_1 entrance area to building;
- Z_2 office;

Characteristics of Z_1 and Z_2 are showed in Table 4 and 5.

Table 4: Characteristics of zone Z_1

Parameter	Comment	Symbol	Value
Soil surface type	Marble	r_a	1.00E-03
Shock protection	None	P_A	1
Loss by touch and step voltages	Yes	L_t	2.00E-02
People potentially in danger in the zone			5

Table 5: Characteristics of zone Z_2

Parameter	Comment	Symbol	Value
Floor surface type	Linoleum	r_u	1.00E-05
Risk of fire	Low	r_f	1.00E-03
Special hazard	Low panic	h_z	2
Spatial shield	None	r_p	1
Internal power system	Yes	connected to LV power line	-
Internal telephone system	Yes	connected to telecom line	-
Loss by touch and step voltages	Yes	L_t	4.00E-04
Loss by physical damage	Yes	L_f	5.00E-04
People potentially in danger in the zone			30

3. RESULT AND DISCUSSION

The result by using Microsoft Excel to calculate the lightning risk assessment was shown in Table 6 which is the collection area of structure and Table 7 is the expected annual number of dangerous event. The final result of lightning risk assessment of R_1 and R_3 was shown in Table 8 for two main zones as mention.

Table 6: Collection area of structure and lines

Symbols	Value
A_d (m)	4.89E+04
$A_{l(power)}$ (m)	2.10E+04
$A_{i(power)}$ (m)	5.59E+05
$A_{l(telecom)}$ (m)	0.00E+00
$A_{i(telecom)}$ (m)	1.00E+06

Table 7: Expected annual number of dangerous events

Symbols	Value (1/year)
N_d (m)	4.89E+01
$N_{L(power)}$ (m)	2.01E-01
$N_{i(power)}$ (m)	0.00E+00
$N_{L(telecom)}$ (m)	0.00E+00
$N_{i(telecom)}$ (m)	0.00E+00

Table 8: Risk component R_1 and R_3 result

Symbol of component	Data from table	Z_1 entrance area	Z_2 offices	Structure
R_A	Table 3 & 4	9.78E-06	-	9.78E-06
R_B	Table 3 & 5	-	9.78E-08	9.78E-08
$R_{U\ (power\ line)}$	Table 3 & 5	-	2.76E-09	2.76E-09
$R_{V\ (power\ line)}$	Table 3 & 5	-	6.90E-07	6.90E-07
$R_{U\ (Telecom\ line)}$	Table 3 & 5	-	1.96E-09	1.96E-09
$R_{V\ (Telecom\ line)}$	Table 3 & 5	-	4.89E-07	4.89E-07
Total R_1	result table	9.78E-06	1.28E-06	1.11E-05
Total R_3	result table	0.00E+00	1.28E-06	1.28E-06

According to the Table 8, the value of R_1 = 1.11E-05 is higher than the tolerable risk of loss of human life or permanent injuries, R_T = 1.00E-05 (year^{-1}). Extra protection measures should be adopted in order to reduce the risk of loss of human life or permanent injuries. To reduce the risk to the tolerable value the following protective measures could be adopted:

- $P_B = 0.1$ (level III LPS)
- $P_{SPD} \leqslant 0.02$ (due to SPD's on incoming lines)
- $P_A <$ current value of P_A

According to the Table 8 also, the value of R_3 = 1.28E-06 is lower than the typical tolerable risk of loss of cultural heritage, R_T = 1.00E-03 (year^{-1}). No need extra protection measures.

The result by using the develop software was shown in Figure 5 and 6. The risk assessment software that had been develop in order to replace the analysis using Microsoft Excel for better understanding, more easier and friendly used was generally similar condition with the analysis calculation even though the value of R_1 = 1.44E-04 and R_3 = 1.28E-04 is different between the analysis by using the Microsoft Excel it is because the develop software protect one zone only which is the building itself comparing the analysis was on two different zone as mention previously. The action taken based on result can be the same as the analysis action by installing the adequate protection measures or by changing the relevant data on develop software. The best way is by asking the expert on lightning risk assessment analysis by through the email given in the software

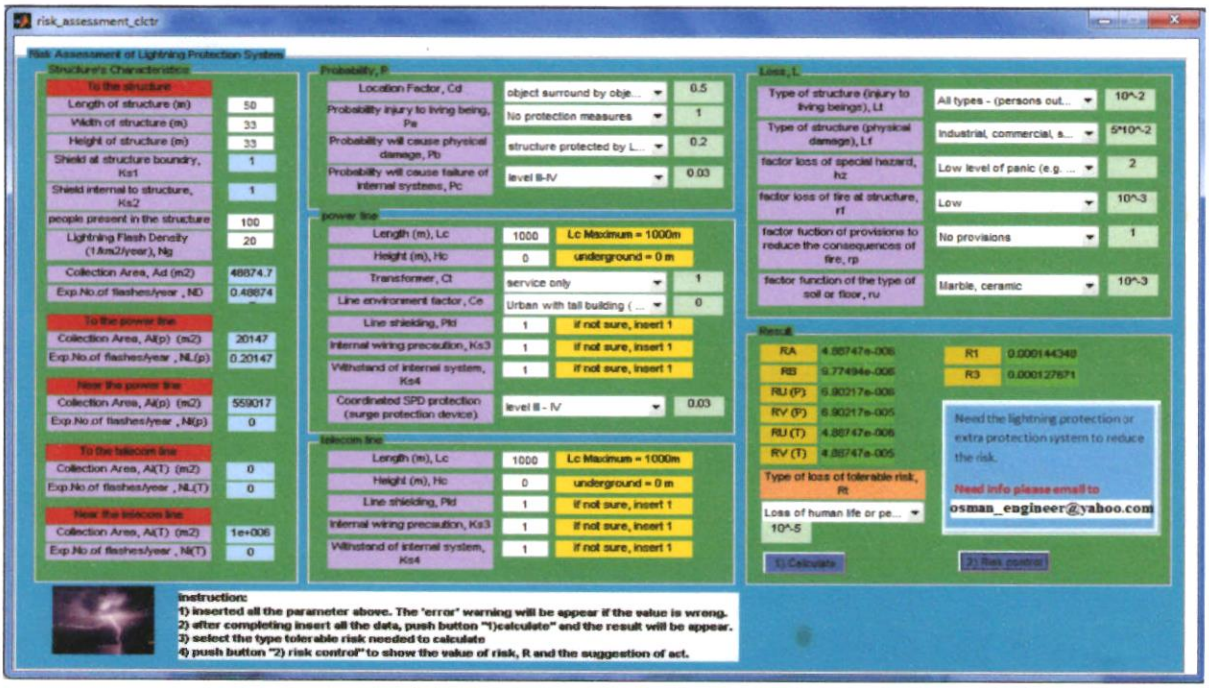

Figure 5: Result of loss of human life or permanent injuries by using risk assessment software

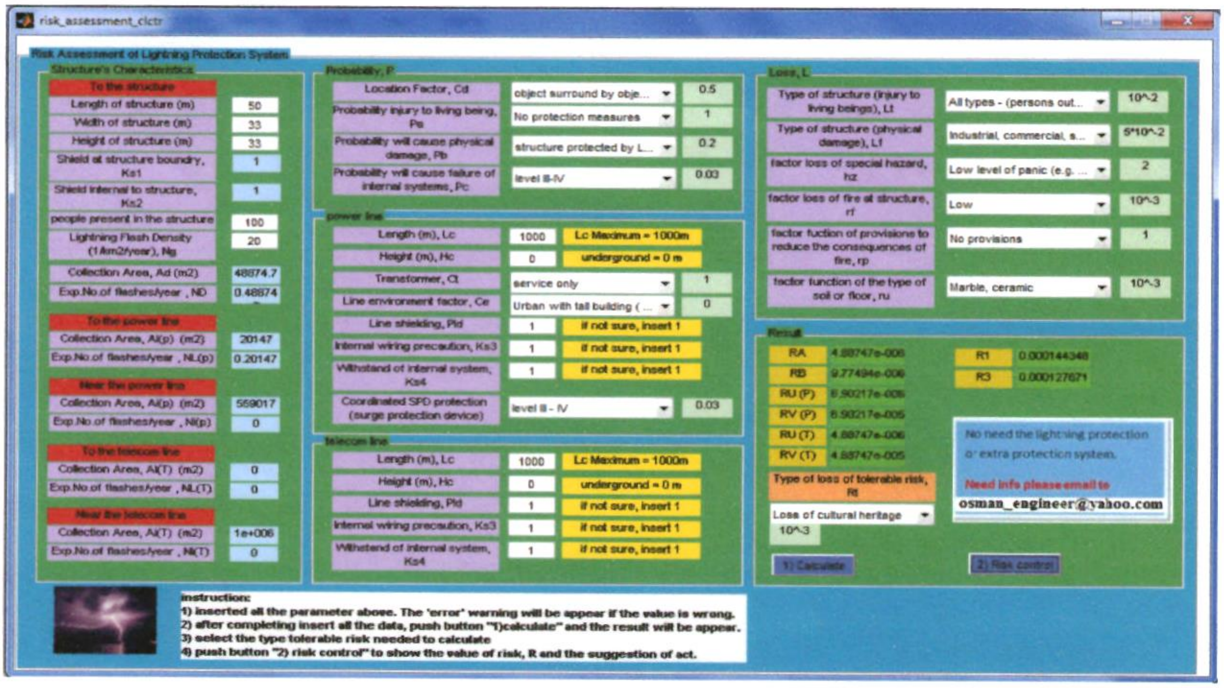

Figure 6: Result of loss of cultural heritage by using risk assessment software

Some important conclusions and recommendation for protecting the building and the human life at surrounding the building was adopted:

- The LPS which is unconventional LPS was not effective and may produce dangerous from lightning strike because it not comply with the IEC Standard of lightning protection.
- A risk assessment showed the risk of loss of human life is higher than the tolerable risk and the risk of loss of cultural heritage is lower than the tolerable risk of cultural heritage. For safety issue, it is possible for the expert and professional of lightning protection to reduce the tolerable risk of cultural heritage for better safety for the structure.
- The Surge Protection Device (PSD) and additional protection must be install and upgrading the existing PSD level based on IEC Standard in order to protect the human life inside and outside the building due to step and touch voltage surge effect from lightning strike.
- On structure taller than 60 meters, flashes to the side may occur, especially to points, corners and edges of surfaces. An air-termination system shall be installed to protect the upper part of tall structure (i.e. typically the topmost 20% of the height of the structure) and the equipment installed on it [3].

4. CONCLUSION

This paper present the characteristics lightning risk assessment at the Chancellery office building in UiTM Shah Alam. Based on IEC 62305 Malaysian Standard was shown that the essential of this analysis in order to protect the human life especially and the building itself. The lightning risk assessment of human life and heritage for structure and their contents against lightning becomes an important requirement in the conservation framework. Essentially, the analysis of lightning risk assessment must be compliance with IEC 62305 Malaysian Standard. Useful new software had been created for the purpose of calculate the lightning risk assessment of a structure with complete parameter for better result and understanding and also regarding to the IEC62305 Malaysian Standard too. The used of unconventional LPS should be thinking carefully for the safety issue is proven.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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