# Lightning Risk Assessment for Structure at Remote Location

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*Abstract* -**This paper presents the method of lightning risk assessment for the structure by using the Malaysian Standard. The aim of this study is to determine the risk for the structure located at remote area from lightning activity and to provide the suitable lightning protection measures in order to reduce the risk for the structure lower than tolerable risk. To achieve this aim, the following objectives have been identified: to evaluate the risk analysis for the structure using Malaysian Standard and to determine the suitable protection for the structure. In order to evaluate whether or not lightning protection of an object is needed, risk assessment in accordance with the procedures contained in IEC MS 62305. This method will allow more precise selection of lightning protection devices. Based on the assessment, the risk, $R_1$ shall be determined and compared with the tolerable value $R_T = 10^{-3}$. The protection is required if the risk $R_1$ is higher than tolerable risk, $R_T$. Based on the calculation, the $R_1 = 1.7972 \times 10^{-3}$ is higher than the tolerable value, $R_T = 10^{-3}$, the lightning protection is required for the structure. To reduce the risk $R_1$, the best solutions is to install coordinated SPD at the service entrance to protect both power and telecom lines.**

***Keywords** -lightning protection; risk assessment; lightning flash density ; tolerable risk*

## I. INTRODUCTION

Structure located at remote area normally being targeted by the lightning activity. In general, lightning may produce surge currents and overvoltage causing isolation breakdown in equipment. Lightning strikes affecting a structure can cause damage to structure itself, to its occupant and contents including failure of the internal systems. The idea begins when there is a structure which is located at the remote area without any lightning protection device. For information, Shah Alam has the highest lightning activities in Malaysia. So, the risk for the structure is higher compared to structure at other place. The structure to be protected is Environmental Monitoring (EMS) structure.This structure is placed in rural area and not surrounded by other objects in the vicinity. The EMS structure can monitor and measure the air temperature, humidity, rainfall, wind speed and solar radiation.

In order to protect the building from damage by the lightning, the lightning risk assessment is the best solution to the structure in order to determine the risk for the building. A risk lightning assessment is presented by using Malaysian Standard in order to determine the risk of the structure whether or not lightning protection device is needed. The present of the protection measures will reduce the risk for the structure into the safe condition.

Lightning is an atmospheric discharge of electricity accompanied by thunder, which typically occur during thunderstorm, and sometimes during volcanic eruption or dust storms[1]. Naturally, the formation of lightning is related to the enormous electrical discharge which is caused by an imbalance between positive and negative charges [3].

### *A. Sources and Types of Damage*

The lightning current is the primary source of damage and lightning flashes can be distinguished by four major sources depending on the strike attachment point – flashes to the structure, flashes near the structure, flashes to the services and flashes near the services.

For the risk assessment, it is useful to distinguish between three types of damage. They are: **injury to living beings** (due to step and touch voltages), **physical damages** (due to fire, explosion and mechanical destruction) and **failure of internal systems** (due to LEMP) [5].

### *B. Types of losses*

There are four types of loss associated with the structure —**loss of human life, loss of services to the public, loss of cultural heritage** and **loss of economic**. Loss of human life, loss of services to the public and loss of economic value may be treated as **social loss** and the last one as purely an **economic loss** [5].

### *C. Risk Management*

The risk is defined as the value of probable average annual loss. It depends on three multiplying factors: the **annual number (Nx)** of lightning flash influencing the structure and services, **the probability (Px) of damage** by one of the influencing lightning flashes and the **mean amount of consequential loss (Lx)** [6].

$$\text{Risk} = N_X . P_X . L_X$$

The number of flashes influencings the structure and the services depends on the dimensions and the characteristics of the structure and of the service as well as on lightning ground flash density in the region where the structure and the services are located [10].

In the risk assessment, the average annual number of dangerous events due to the lightning flashes depends on the thunderstorm activity of the region where the structure is located and on its characteristics.

*D. The lightning flash density*

The lightning ground flashes density, $N_g$ is the number of lightning flashes per $km^2$ per year. The application of the lightning ground flash density ($N_g$) in lightning risk assessment may be evaluated as the product of

$$N_g = 0.1T_d \qquad (1)$$

In (1), $T_d$ is the thunderstorm days per years, which can be obtained from the isokreaunic maps[6].

*E. Protection measures*

The structure to be considered for the risk assessment includes the structure itself and its contents, and the internal systems (telecom and power line). The electrical designer should consider the suitable protection measures in order to reduce the risk due to lightning lower than tolerable risk. Among different protection measures, the following are considered in the IEC standard document. [7, 8]:

*1)* **Lightning protection system (LPS)** to intercept, conduct and disperse the lightning current into earth; bonding measures to minimize the potential differences and to limit surge by suitable surge protection devices (SPD) are included in internal LPS;

*2)* **SPD System,** defined as coordinated SPDs properly selected and erected to internal systems against surges. SPD at the point of entry of incoming services reduces essentially the risk related to the over voltages by resistive coupling due to direct flashes to the structure and the over voltages transmitted through the lines [4].

For this aim, a risk analysis has to be performed to assess the main contribution to the total risk related to failure or physical damages to the structure due to lightning flashes.

## II. METHODOLOGY

In general, the procedure to assess the risk consists of 4 main steps. For this project, the detail procedures are shown in figure 1.

*A. Basics procedure*

The following procedure shall be applied: (1) identification of the structure to be protected and its characteristics; (2) identification of all types of loss in the object and the relevant corresponding risk R, (3) evaluate of the risk R for each type of loss, (4) evaluate the need of protection, by comparing the risk $R_X$ for a structure with the tolerable risk, $R_T$ [5].

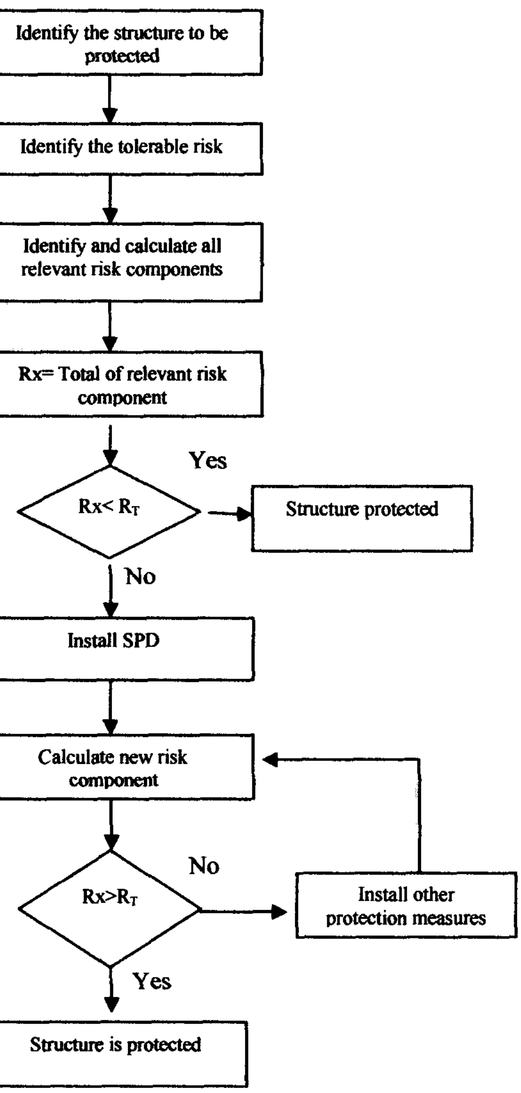


FIGURE 1 PROCEDURE FOR DECIDING THE NEED OF PROTECTION

*B. Identify the Structure to be Protected*

The structure to be considered for the risk assessment includes the structure itself, the installation in the structure, content of the structure, person in the structure or standing in the zone up to 3km and environment affected by damage to the structure.

*C. Identify the Tolerable Risk, $R_T$*

For each type of loss to the structure is capable to identify the value of tolerable risk, $R_T$. The values of tolerable risk $R_T$ involve the loss of human life, loss of social and loss of cultural values.

*D. Evaluate the Need of Protection*

The next step is to evaluate the need of protection, by comparing the risk $R_X$ for a structure with the tolerable risk, $R_T$. In order to evaluate whether or not lightning protection for the structure is needed, risk assessment in accordance with the procedures contained in IEC MS 62305 - 2 shall be made. Protection against lightning is required if the risk $R_x$ (R1 to R3) is higher than the Tolerable risk $R_T$. In this case, protection measures shall be adopted in order reduce the risk $R_X$ (R1 to R3) lower than tolerable level $R_T$, $R_X \leq R_T$. Lightning protection is not necessary if $R \leq R_T$ .

## III. RESULTS AND DISCUSSION

The EMS structure, with dimension $L_b$ = 5.55m, $W_b$ = 4.93m, $H_b$ = 4.10m, is placed in rural area and not surrounded by other objects in the vicinity, in other words, isolated object. The building is supplied by 2.5kW power line of 1000m length, buried in a soil of resistivity = 500 *Ohm* meter, with a HV/LV transformer delivering an internal systems. No LPS are provided to reduce the physical damages due to lightning.

TABLE H.2 DATA AND CHARACTERISTICS OF LINE AND CONNECTED INTERNAL SYSTEM.

| Parameter | Comment | Symbol | Value |
|---|---|---|---|
| Soil Resistivity | Ohm (m) | $\rho$ | 500 |
| **LV power line and its internal system** | | | |
| Length (m) | - | Lc | 1000 |
| Height (m) | Buried | Hc | - |
| Transformer | Yes | Ct | 0.2 |
| Line location factor | Isolated | $C_d$ | 1 |
| Line environment factor | Rural | Ce | 1 |
| Line shielding | None | $P_{LD}$ | 1 |
| Internal wiring precaution | None | $K_{S3}$ | 1 |
| Withstand of internal system | Uw = 2,5 kV | $K_{S4}$ | 0.6 |
| Coordinated SPD location | None | $P_{SPD}$ | 1 |
| **Telecom line and its internal system** | | | |
| Length (m) | - | Lc | 1000 |
| Height (m) | Buried | Hc | - |
| Transformer | Isolated | Ct | 1 |
| Line location factor | Rural | $C_d$ | 1 |
| Line environment factor | None | Ce | 1 |
| Line shielding | None | $P_{LD}$ | 1 |
| Internal wiring precaution | Uw = 1,5 kV | $K_{S3}$ | 1 |
| Withstand of internal system | None | $K_{S4}$ | 1 |

TABLE H.3 ZONE 2 (INSIDE)

| Parameter | Comment | Symbol | Value |
|---|---|---|---|
| Floor surface type | Concrete | $r_u$ | $10^{-2}$ |
| Risk of fire | Low | $r_f$ | $10^{-3}$ |
| Special hazard | None | $h_z$ | 1 |
| Fire protection | None | $r_p$ | 1 |
| Spatial shield | None | $K_{s2}$ | 1 |
| Internal power systems | Yes | Connected to LV power line | - |
| Internal telephone systems | Yes | Connected to telecom line | - |
| Loss by touch and step voltages | Yes | $L_t$ | $10^{-2}$ |
| Loss by physical damages | Yes | $L_f$ | $10^{-2}$ |

*A. Calculation of relevant quantities*

TABLE H.4 COLLECTION AREA OF STRUCTURE AND LINES

| Symbol of area | Equation for collection area | Value $m^2$ (x $10^5$) |
|---|---|---|
| $A_d$ | To the structure: $Ad = Lb \times Wb \times 6Hb \times (Lb \pm Wb) + 9\pi Hb^2$ | 0.0076 |
| $A_{l(p)}$ | To the power line $Al = \sqrt{\rho} + [Lc - 3Hb]$ | 2.21 |
| $A_{i(p)}$ | To the power line $Ai = 25 \times \sqrt{\rho} \times Lc$ | 55.9 |
| $A_{l(T)}$ | To the telecom line $Al = \sqrt{\rho} + [Lc - 3Hb]$ | 2.21 |
| $A_{i(T)}$ | To the telecom line $Ai = 25 \times \sqrt{\rho} \times Lc$ | 55.9 |

TABLE H.5 EXPECTED ANNUAL NUMBER OF DANGEROUS EVENT

| Symbol of number | Equation for number of flashes (x $10^{-6}$) | Value ( 1/year) | |
|---|---|---|---|
| | | *Case (a)* *Ng = 19.2* | *Case (b)* *Ng = 5* |
| *Nd* | To the structure: $Nd = Ng \times Ad \times Cd$ | 0.014646 | 0.0038 |
| *Nl(p)* | To the power line $Nl(p) = Ng \times Al(p) \times Cd(p) \times Ct(p)$ | 0.8486 | 0.221 |
| *Ni(p)* | To the power line $Ni(p) = Ng \times Ai(p) \times Ct(p) \times Ce(p)$ | 21.8 | 0.559 |
| *Nl(T)* | To the telecom line $Nl(T) = Ng \times Al(T) \times Cd(T)$ | 4.243 | 1.105 |
| *Ni(T)* | To the telecom line $Ni(T) = Ng \times Ai(T) \times Ce(T)$ | 107 | 27.95 |

The risk $\mathbf{R_1}$ can be expressed by the following sum of components:

$$R_1 = R_B + R_{U\,(power\ line)} + R_{V\,(power\ line)} + R_{U\,(telecom\ line)} + R_{V\,(telecom\ line)}$$

TABLE H.6 RISK COMPONENT INVOLVED AND THEIR CALCULATION.

| Symbol of Component | Equation for Number of Flashes | Value (X $10^{-3}$) | |
|---|---|---|---|
| | | *Case (a)* *Ng = 19.2* | *Case (b)* *Ng = 5* |
| $R_B$ | To the structure: $RB = Nd \times hz \times rp \times rf \times Lf$ | 0.0000002 | 0.0000004 |
| $R_{U(p)}$ | To the power line $Ru = (Nl + NDA) \times ru \times Pu \times Lt$ | 0.08486 | 0.0221 |
| $R_{V(p)}$ | To the power line $Rv = (Nl + NDA) \times Pv \times hz \times rp \times rf \times Lf$ | 0.218 | 0.0559 |
| $R_{U(T)}$ | To the telecom line $Ru = (Nl + NDA) \times ru \times Pu \times Lt$ | 0.4243 | 0.1105 |
| $R_{V(T)}$ | To the telecom line $Rv = (NL + NDA) \times Pv \times hz \times rp \times rf \times Lf$ | 1.07 | 0.2795 |
| Total $R_1$ | $R_A + R_B + R_{U(power\ line)} + R_{V(power\ line)} + R_{U(telecom\ line)} + R_{V(telecom\ line)}$ | 1.7972 | 0.468 |

## IV. DISCUSSION

This project have use two values of lightning ground flash density ($N_g$) obtained from different sources. The data collection is through Surge Transient Sdn. Bhd and TNB Research.

When the risk for the structure was analyzed, the risk of $R_X$ is compared to the tolerable risk, $R_T$ in order to evaluate whether or not the lightning protection of the structure is needed. Protection against lightning is required if the risk $R_X$ (R1 to R3) is higher than the Tolerable risk $R_T$,

$$\mathbf{R_X > R_T}$$

In this case, the protection measures shall be adopted to reduce the value of probability of damage $P_X$. The reducing in Px value automatically reduce the risk $R_X$ (Rl to R3) lower than tolerable level $R_T$.

$$\mathbf{R_X \leq R_T}$$

If the risk of $R \leq R_T$, lightning protection is not necessary. That means the structure is safe from the lightning activity. For each type of loss, there are many protection measures which, individually or in combination, make the risk Rx reduce lower than tolerable risk, $R_T$.

The risk $R_1$ normally is influenced by the failure of internal systems (component $R_V$ and $R_U$) and physical damage (component $R_B$) to the structure. The risks $R_1$ may be reduced by reducing the component of $R_B$ or $R_V$ or $R_U$.

Components $R_B$ may be reduced either by install the LPS conforming to IEC 62305- 3 for the whole of structure or providing the zone 2 with the protection measures to reduce the consequences of fire (such as extinguishers, automatic fire detection system, etc.).

Component $R_V$ and $R_U$ may be reduced by: Providing the internal power and telecom systems with a coordinated SPD protection conforming to IEC 62305-4 or provide the structure with the adequate spatial grid- like shield conforming to IEC 62305- 4.

The protection against lightning for the structure can be less expensive than repair or replacement of the damaged equipment. It is better to provide the protection measure for the structure placed at remote area.

**For case (a)**
$R_1 = 1.7972 \times 10^{-3}$ is higher than the tolerable value $R_T = 10^{-3}$, the lightning protection for the structure is required.

**For case (b)**
$R_1 = 0.468 \times 10^{-3}$ is lower than the tolerable value $R_T = 10^{-3}$, lightning protection is not necessary for the structure. The structure is safe from the lightning activity.

According to the table H.6, the main contibution to the value of risk given by;

TABLE H.7 PERCENTAGE OF THE RISK COMPONENT INVOLVED

For case (a)

| Symbol of Component | Percentage |
|---|---|
| $R_U$(power line) | 4.7% |
| $R_V$(power line) | 12.1% |
| $R_U$(telecom line) | 23.6% |
| $R_V$(telecom line) | 59.5% |
| $R_B$ | 0.1% |

For case (b)

| Symbol of Component | Percentage |
|---|---|
| $R_U$(power line) | 4.7% |
| $R_V$(power line) | 11.9% |
| $R_U$(telecom line) | 23.6% |
| $R_V$(telecom line) | 59.7% |
| $R_B$ | 0.1% |

From the analysis, it shows that the risk $R_1$ is influenced by failure of the internal systems (telecom and power line).The failure of the internal system consists of the physical damage and shock in the internal systems.

**The composition that the risk $R_1$** for the structure is mainly **due to physical damage of telecom line and shock in the telecom line.**(component $R_V$(telecom line) for 59.5% and component $R_U$(telecom line) for 23.6%.).

To reduce the risk $R_1$, the best solutions is to install coordinated SPD at the service entrance to protect both power and telecom lines. By applied the coordinated SPD, it will reduce the value of $P_U$ and $P_V$ (due to the SPD on connected lines). The solution to be adopted shall be selected with allowance for technical and economic aspects.

For protection measures, the following solutions could be adopted:

*1)* First solution

Install the enhanced coordinated SPD protection with Pspd = 0.03 on internal systems

*2)* Second solution

Install the enhanced coordinated SPD protection with Pspd = 0.02 on internal systems

*3)* Third solution

Install the enhanced coordinated SPD protection with Pspd = 0.01 on internal systems

TABLE H.7 VALUE OF RISK COMPONENT ACCORDING TO SOLUTION CHOSEN

| Risk Component | Case (a) | Coordinated SPD protection (x $10^{-3}$) | | |
|---|---|---|---|---|
| | | $P_{SPD} = 0.03$ | $P_{SPD} = 0.02$ | $P_{SPD} = 0.01$ |
| $R_B$ | 0.00000015 | 0.00000015 | 0.00000015 | 0.00000015 |
| $R_{U(P)}$ | 0.08486 | 0.0025 | 0.0017 | 0.00085 |
| $R_{V(P)}$ | 0.218 | 0.00654 | 0.00436 | 0.0028 |
| $R_{U(T)}$ | 0.4243 | 0.0127 | 0.008486 | 0.004243 |
| $R_{V(T)}$ | 1.07 | 0.0321 | 0.0214 | 0.0107 |
| Total $R_1$ | 1.7972 | 0.05384 | 0.0359 | 0.01797 |

The table shows that all the solutions reduce the risk lower than tolerable value. The solution to be adopted is subject to the best technical and economic compromise.

The designer is better for the jobs because they know the main contribution to the value of total risk $R_1$. So they can identify the critical parameters to determine the suitable and efficient measure to reduce the risk $R_1$.

## V. CONCLUSION

Based on the assessment, the risk $R_1 = 1.7972x10^{-3}$ is higher than the tolerable value $R_T = 10^{-3}$, the lightning protection for the structure is required for the structure. To reduce the risk $R_1$, the best solutions is to install coordinated SPD at the service entrance to protect both power and telecom lines.

## VI. RECOMMENDATION

It is recommended to provide the structure with the adequate spatial grid- like shield conforming to IEC 62305- 4 in order to reduce the risk $R_1$ due to physical damage and shock in internal systems.


## VII. ACKNOWLEDGEMENT

Many people have made invaluable contributions, both direct and indirectly to my paper. I wish to thanks my supervisor, Miss. Dalina bt. Johari for providing me valuable advice.


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