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Comparative Analysis of External Lightning Protection Systems Using Protective Angle and Rolling Sphere Method in Areas That Have High Lightning Intensity

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Abstract

Indonesia is a tropical country with a geographical condition where 71% of its area is water. This is what coueses Indonesia is considered a country with a high density of lightning strikes. This results in buildings in Indonesia being at a high risk of damage caused by lightning strikes. According to data from BMKG, the city of Malang has a high lightning intensity, with 108 thunderstorm days per year, posing a serious threat to the Electrical Engineering Building of the Faculty of Engineering at the University of Malang. Considering the building's age and expansion on the building's side, it is necessary to evaluate the lightning protection system to determine whether the existing system is still working effectively and efficiently. Improving the system's performance against lightning disturbances can be done by analyzing the previous external lightning protection system and then evaluating it using the angle of protection and rolling sphere methods. The analysis and evaluation of the external protection system are based on PUIPP, PUIL, SNI, and IEEE standards.

Keywords

Lightning, Lightning Protection System, Rolling Sphere, Angle of Protection

INTRODUCTION

Lightning is a natural phenomenon that has become a part that cannot be separated from the lives of living things in the world. The positive thing about the lightning phenomenon is that it produces O_3 or ozone in the atmosphere to protect the earth from ultraviolet radiation from sunlight. In today's life, lightning is a very serious obstacle because of its ability to damage infrastructure such as electricity, telecommunications, information and data that is increasingly widespread and complicated (D Wahjudi, 2014). It can be seen from Figure 1.1 map in Indonesia, especially East Java in August in red indicating that lightning strikes that occur from clouds to the ground in the area are very high more than 60.000 times.

Rainfall, temperature and humidity are quite high throughout the year resulting in Malang having a very high average of thunder per year, causing the level of lightning strikes in the Malang area to be quite high. Lightning can occur due to a surge of electrical charge between the cloud and the earth. Lightning strikes can cause damage that can endanger humans and also equipment within the scope of lightning coverage such as buildings. Buildings / tall buildings are very risky to be hit by lightning strikes because they have the closest position to the cloud, making it easier for electrons to move or jump. In this condition, it is imperative for the building to install lightning protection to avoid lightning strikes that can endanger electrical equipment and humans who operate.

This research focuses on a case study of the B12 Electrical Engineering building, Faculty of Engineering, State University of Malang. This calculation is carried out to determine the potential for lightning strikes to the building. This is done because considering that the building is a building that is used as an educational facility and is safe from the dangers that can occur due to lightning strikes. Given that the building is an old building with additional width caused by the addition of space, it is possible that the previous protection system does not work optimally. In an effort to protect the building from the danger of lightning strikes, the system has two protections, namely internal and external.

The external protection system is intended to provide protection to buildings from direct lightning strikes that can harm from outside, while internal protection aims to protect buildings from damage to equipment in buildings from indirect lightning strikes (Arif Karta, 2020). The application of external protection itself can be done with several methods to find out how effectively the protection system works. The method applied can be by using rolling balls and protection angles. The selection of the method used is usually adjusted to the shape of the building.

ISSN: 2720-9598

METHOD

The design in this study uses several stages which can be seen in Figure 1. Based on Figure 1, data collection is carried out by conducting literature studies obtained from books and written documents that can be accessed via the internet. Literature studies are more emphasized on the standards and formulation of the calculation methods used. In calculating the needs of lightning protection systems, existing standards such as the International Electrotechnical Commission (IEC) 1024-1-1 and the General Regulations for Lightning Protection Installations (PUIPP) are used. Data taken in the form of building specifications and the level of lightning strikes per year (thunder days / year).

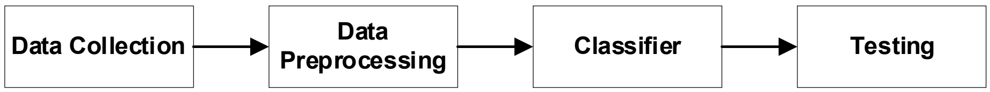

Figure 1. Research Stages

The second stage is the data preprocessing stage. This stage is related to data processing to determine the level of protection that is in accordance with building conditions. This aims to find out whether the existing building external lightning protection system is still in good condition or needs improvement in accordance with existing standards. The method used for the evaluation of the external lightning protection system is the protection angle and rolling ball because this method is very suitable for building infrastructure that has a multi-storey roof. The B12 Electrical Engineering UM building is 50m long by 28m wide and has a height with an air termination of 18m.

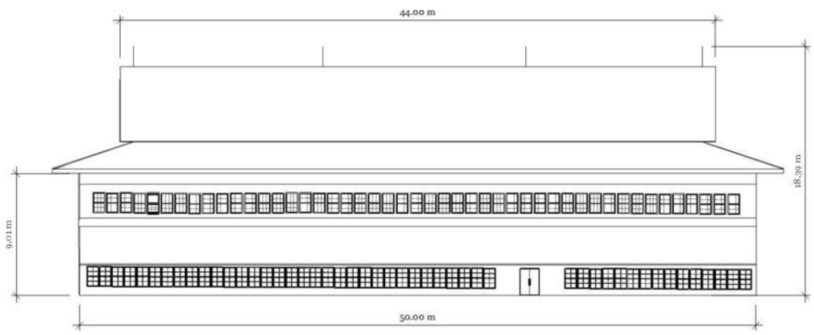

Figure 2. Building front view

Data obtained from BMKG Malang in accordance with the location of the building which is at an altitude of approximately 500m above sea level shows the value of thunder days per year of 108 which indicates that lightning strikes per year are quite high. Then the frequency of lightning strikes per year (Nc) in buildings that have been determined in the building area (Malang City) is 0.1 / year or 10^{-1}. According to PUIPP standards, there are several indices that must be met in determining and calculating protection from lightning strikes on the building and building conditions. Estimated lightning strikes can be determined as follows:

$$R = A + B + C + D + E \tag{1}$$

Where, A is the Hazards according to the use and contents of the building, B is the Hazards according to the construction of the building, C is the Danger according to building height, D is the Danger according to building situation, E is the Danger according to thunderstorm days, R is the Estimated lightning strike.

Based on the IEC 1024-1-1 standard, the calculation of the protection level can be determined by considering several factors, such as the frequency of local direct lightning strikes (Nd) and also the frequency of annual lightning strikes (Nc) in the building to be protected. The density of lightning strikes to the ground on average per year (Ng) in the area where the building stands can be determined by the following formula. Where, Ng is the Lightning strike density to the ground and Td is the Day of thunder.

$$Ng = \frac{\left(\frac{0.4 \cdot Td^{1.25}}{km^2}\right)}{year} \tag{2}$$

Thunder days (Td) are obtained from data issued by the Meteorology and Geophysics Agency (BMKG) in the area where the object of research will be carried out. The annual average direct lightning strike frequency (Nd) to the building object can be calculated:

ISSN: 2720-9598

$$Nd = \frac{Ng \cdot Ae \cdot 10^{-6}}{year} \tag{3}$$

All areas of the building structure that are considered to have an annual frequency of direct lightning strikes are called equivalent coverage areas (Ae). To determine the value of Ae can be calculated using the formula. Where, a is the Length of building structure (m), b is the width of building structure (m), and h is the building structure height (m)

$$Ae = ab + 6h(a + b) + 9\pi h^2 \tag{4}$$

The installation of a lightning protection system on the object can be determined whether or not the system can be found by taking into account Nd and Nc, namely, if the value of Nd is smaller than Nc, the installation of a lightning strike protection system is considered unnecessary, while if the value of Nd is greater than Nc, the lightning protection system is considered necessary to be paired with efficiency can be determined by the following equation:

$$E \geq 1 - \frac{Nc}{Nd} \tag{5}$$

With the level of protection according to the IEC standard described in Table 1 below:

TABLE 1

LIGHTNING PROTECTION SYSTEM EFFICIENCY

Protection Level	SPP Efficiency
I	0.98
II	0.95
III	0.90
IV	0.80

The explanation of table 1 above is to determine the value of the protection level by calculating the results of the protection system efficiency. After obtaining the SPP efficiency value, if the value is between 0 to 0.80, the protection level IV is obtained. If the efficiency value is 0.80 to 0.90, the protection level III is obtained, 0.90 to 0.95 is the protection level II, and if the value is 0.95 to 0.98 or above, the protection level I. The protection level is used to determine the diameter and angle of protection in the rolling ball method and the protection angle method.

RESULTS AND DISCUSSION

The external protection system in Building B12 Electrical Engineering FT UM is divided into three parts, namely, air termination, down conductor, and grounding. To find out the horizontal distance between air terminations in accordance with IEC 62305 on the roof of the building can be calculated by the formula:

$$d = \sqrt{h_1}(300 - h_1) - \sqrt{h_2}(300 - h_2)$$

Where, d is the horizontal distance (m), h_1 is the distance from the highest roof (m), and h_2 distance from the lowest roof (m). With the highest roof height of 16.5m and the lowest roof height of 12m, it can be calculated:

$$d = \sqrt{16.5}(300 - 16.5) - \sqrt{12}(300 - 12)$$

$$d = 9.6m$$

The minimum allowable air termination distance from the formula calculation is 9.6m. With a lower roof length of 55m and an upper roof length of 42m, Building B12 Electrical Engineering installed a total of 5 air terminations.

According to the PUIPP standard, determining the need for a lightning strike protection system is done by summing up the indices that represent the building to be protected. From the description of the index in table 3.1 to table 3.5 obtained:

1. Index A is worth 3, because the building has many people (used for teaching and learning activities).
2. Index B is worth 2, because buildings with concrete construction and non-metal roofs.
3. Index C is worth 3, because the building has a height close to 17 meters.
4. Index D is 0, because the building stands at an altitude of less than 1000 meters.
5. Index E is worth 6, because the thunder day per year is 108.

FRONTIER ENERGY SYSTEM AND POWER ENGINEERING
ISSN: 2720-9598

By summing up all the indices above, the lightning strike hazard in the building (R) is 14. With the value of the danger of lightning strikes (R) of 14 according to table 3.6, it is very necessary to install lightning protection lightning. Based on the IEC 1024-1-1 standard, the calculation of the protection level can be determined using the calculation of several factors, namely determined using the calculation of several factors, namely building structure data, thunder day data, protection area, lightning strike density to the ground (Ng), local direct strike frequency (Nd), and lightning strike frequency per year (Nc) allowed on the object. The value of lightning strike density (Ng) can be determined by formula (2) and the results obtained are:

$$Ng = \frac{(\frac{0.4 \cdot Td^{1.25}}{km^2})}{year}$$

$$Ng = 0.04 \cdot 108^{1.25}$$

$$Ng = 13.93\ km^2/year$$

The equivalent area (Ae) of the object can be calculated by equation (4):

$$Ae = ab + 6h(a + b) + 9\pi h^2$$

$$Ae = 20 \cdot 55 + 6 \cdot 14(20 + 55) + 9\pi 14^2$$

$$Ae = 12941.77\ m^2$$

After obtaining the value of the lightning strike density (Ng) and the equivalent area value (Ae), the value of the average number of direct lightning strikes per year (Nd) can then be calculated using the following equation (3):

$$Nd = \frac{Ng \cdot Ae \cdot 10^{-6}}{year}$$

$$Nd = \frac{13.93 \cdot 12941.77 \cdot 10^{-6}}{year}$$

$$Nd = 0.18/year$$

From the data obtained from BMKG in the local area, the value of the annual lightning strike frequency (Nc) allowed is 10-1 / year. Thus, the value of Nd is greater than the value of Nc ($Nd > Nc$) so that a lightning protection system is needed. Therefore, the efficiency value (E) can be obtained using formula (5):

$$E \geq 1 - \frac{Nc}{Nd}$$

$$E \geq 1 - \frac{0.1}{0.18}$$

$$E \geq 0.44 = 44\%$$

The position of the 4 air terminations is installed horizontally on the highest roof with a distance of approximately 12m from each finial. The 5th air termination is on the upper roof slope with a conducting rod length of approximately 3m. With the efficiency value (E) in Electrical Engineering Building B12 worth 44%, the level of protection in accordance with the table above is level IV protection with an SPP efficiency value of 0% to 80%. After knowing the level of protection, the next step is to determine the radius of the rolling ball and the angle of protection in the building by adjusting the following Table 2:

FRONTIER ENERGY SYSTEM AND POWER ENGINEERING
ISSN: 2720-9598

TABLE 2

DETERMINATION OF PROTECTION ANGLE AND ROLLING BALLS

Protection Level	H (m)	20	30	45	60
	R (m)	α°	α°	α°	α°
I	20	25	-	-	-
II	30	35	25	-	-
III	45	45	35	25	-
IV	60	55	45	35	25

From the data in Table 2, with protection level IV, a rolling ball diameter of 60 meters is obtained and a protection angle with a building height below 20 meters is obtained at an angle of 55°. In the application of the rolling ball method in Building B12 Electrical Engineering FT UM, the front view shows that there are 5 finials on the roof of the building which are 14 meters away from each other with one finial on the roof slope with a height of 4 meters and the height of the other installed finials is 1.5 meters. Thus, the number and height of the finials are sufficient to protect the roof of the building.

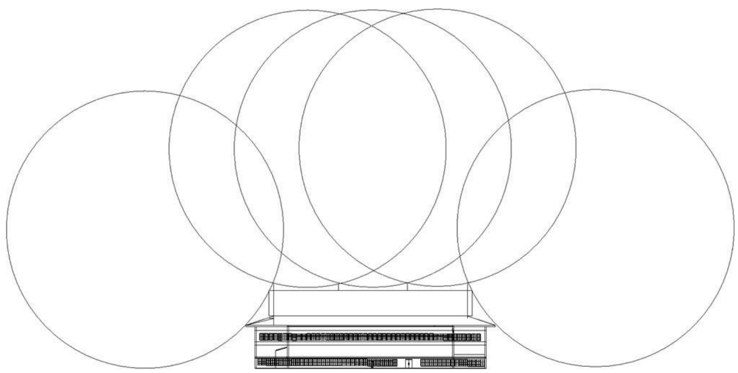

Figure 3. Rolling Ball Method in Building B12 Electrical Engineering FT UM (front view)

The application of the rolling ball method when viewed from the front of the building shows that the ball still touches the edge of the lower roof of the building. Building. This means that the building is still not fully protected from lightning strikes so it is necessary to add air termination to the edge of the roof of the building.

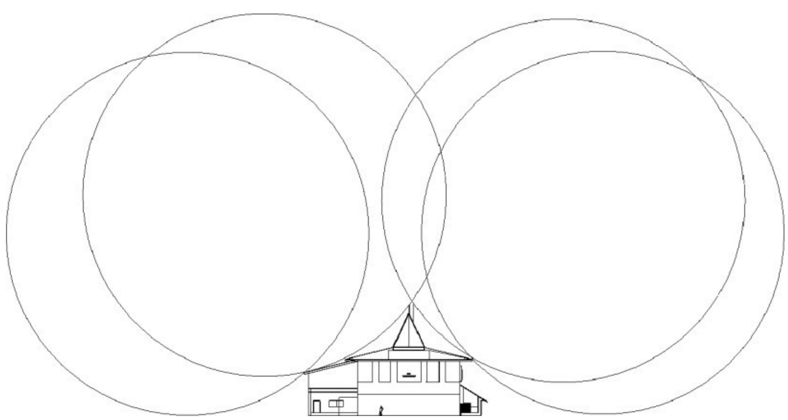

Figure 4. Rolling Ball Method in Building B12 Electrical Engineering FT UM (Side View)

By using the IV protection level that has been determined with a building height of 16.5m and a finial height of 1.5m, the building protection angle in accordance with table 4.3 with reference to the ground is 55° with a protection radius of 27.13m. While the angle of protection of the finial against the roof of the building is 79° with a radius of protection of 10.29m.

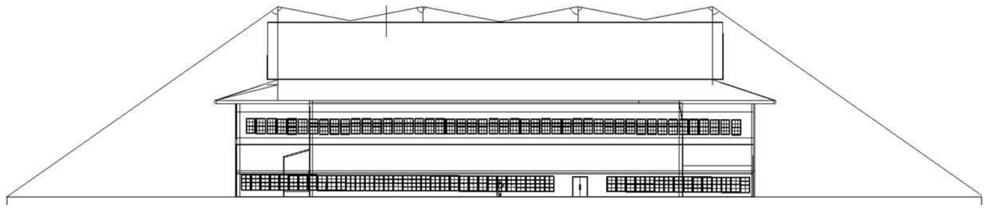

Figure 5. Protection Angle of Building B12 Electrical Engineering FT UM (front view)

The resulting protection angle on the front of the building shows that the building is fully protected from lightning strikes when viewed from the front. So that with the previous existing protection on the roof side of the building no update is required.

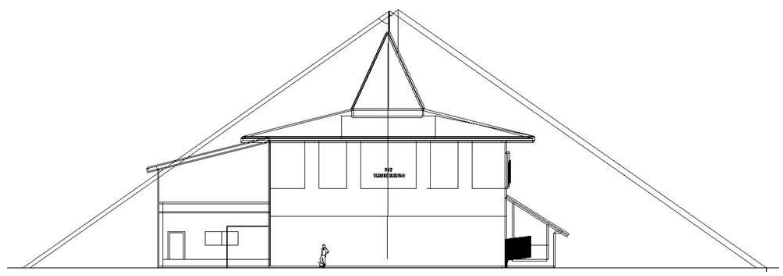

Figure 6. Protection angle of Building B12 Electrical Engineering FT UM (side view)

Calculation of the protection angle on the side of the building shows that the left roof side of the building is outside the protection radius of the protection angle which indicates that the left side of the roof of the building is still not safe from the potential danger of lightning strikes. Thus, it is necessary to add 2 air terminations to the left roof corner of the building which are installed horizontally at the front and rear corners of the HMD TE secretariat roof.

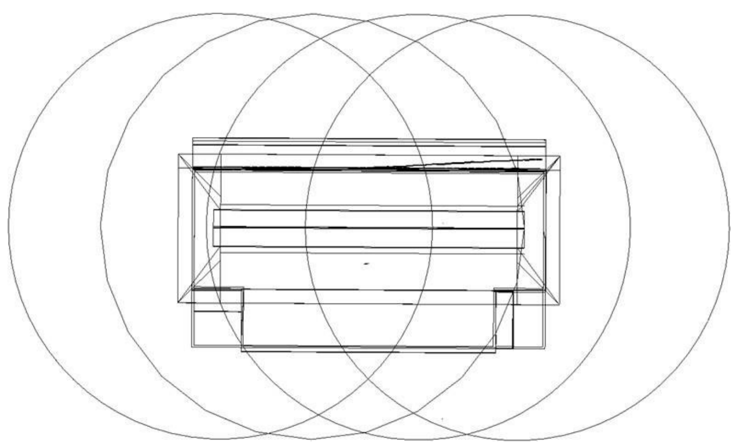

Figure 7. Protection angle of Building B12 Electrical Engineering FT UM (top view)

In the application of the protection angle by looking at the front, side, and top views of the building, it can be seen in the modeling image that Building B12 Electrical Engineering FTUM is completely within the protection radius of the protection angle. The difference from the rolling ball method lies in the accuracy of the protected building. The use of the rolling ball method requires more effort, especially in terms of 3-dimensional depiction to determine areas that require protection. However, the use of the rolling ball method will more accurately provide information by seeing the level of protection of which areas still need to be protected and potentially exposed to lightning strikes. While the security point technique is a strategy whose use is limited to assessing the degree of feasibility of the lightning protection framework that has been planned but provides ease of implementation, the protection angle method is a method that is limited to evaluating the effectiveness of the lightning protection system that has been designed but provides ease of application. In its own application in the B12 Electrical Engineering UM building, it is more suitable to use the rolling ball method compared to the protection angle method, seeing that buildings that have multi-storey roof structures require accuracy in the calculation of the protection system.

FRONTIER ENERGY SYSTEM AND POWER ENGINEERING
ISSN: 2720-9598

CONCLUSION

Based on the analysis that has been carried out using two methods to determine the results, it is concluded that the external lightning protection system mechanism has 3 important elements, namely air termination (finial), down conductor, and grounding where the system works when the air termination gets a large current trigger from a lightning strike then the down conductor works as a link to the grounding system as a conductor of electric current to the earth so as not to cause danger of electric current leakage. The results of the evaluation of the air termination system using the rolling ball method and the protection angle in Building B12 Electrical Engineering FT UM show that the roof of the HMD TE secretariat room is still exposed to the threat of lightning strikes. Building B12 Electrical Engineering FT UM still needs changes in its air termination system to get a maximum protection system.

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