APPLICATION OF CONE PROTECTION AND ROLLING SPHERE METHODS IN EXTERNAL LIGHTNING PROTECTION ANALYSIS ON 214 RADAR TOWER

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ABSTRACT
Indonesia is located in a tropical region which has a high frequency of lightning strike. The 214 radar site is an area that is susceptible to lightning strikes since it has many high buildings. These buildings are equipped with electrical power system and other communication equipment that are sensitive to lightning. Objective of this research was to analyze the external lightning protection system based on radar tower placement of air terminations. The analysis was performed by using a cone protection and rolling sphere methods. Analysis using cone protection method concludes that the addition of air termination height to 35 m in order to protect the building tower and radar antenna. Application of rolling sphere method as far as 110 m radius obtained so as to protect the tower and radar antenna from the danger of lightning.

KEYWORDS: *Lightning, radar, external lightning protection system, cone protection method, rolling sphere method*

I. INTRODUCTION

Indonesia is located in tropical region and surrounded by oceans. Hence, Indonesia is one of the nations that has a high frequency of lightning strikes. Therefore, lightning density in Indonesia is much higher than the one in Europe or Japan. Located in equatorial region with high amount of insulation and approximately 70 % of ocean in its area, Indonesia has high number of evaporation. Thus, it is the most active convective area and therefore has three lighting cloud built requirements is easily achieved [1]. Lightning can damage and causing disturbance in local infrastructure such as, electrical power system, telecommunication system, and other electronic equipment [2].

Indonesian Air Force is tasked to uphold national air sovereignty [3] by operating integrated radar system. To obtain maximal coverage, radar is installed on top of a tower with specific height in order to avoid obstacles.

Radar is also equipped with electrical power source, communication and electronic equipment devices are very sensitives to disturbance by lightning either directly or indirectly [4], therefore need comprehensive protection. Lightning protection system on a radar tower has yet evaluated the performance of protection.

In this paper, external lightning protection system of 214 radar tower will be analyzed using cone protection and rolling sphere methods. The data used must be adapted to the characteristics of lightning in the tropics [5]. With the analysis and selection of appropriate methods is expected to protect radar systems and other equipment from harm due to lightning. In addition, authors will also give theirs suggestion if the existing protection system is not capable to protect 214 radar tower properly. Using analysis and proper method selection will optimize the protection of radar and other equipment against lighting strikes.

II. EXTERNAL LIGHTNING PROTECTION SYSTEM

External lightning protection system is the installation and other equipment that are located outside of a structure to catch and direct lightning strikes to grounding system by a conductor. External protection plays a major role in catching electrical charge and lightning current in the highest area of protected building/region [6].

Based on IEC standard 1024-1-1, selection of proper protection level of a lightning protection system is based on local direct lightning strike frequency N_d which is estimated in protected area and annual local lightning strike frequency N_c that is allowed [7]. Average annual density of lightning in the area N_g can be calculated by [8]:

$$\boldsymbol{N_g = 0.04 * T^{1,25}} \text{km}^2/\text{year} \quad (1)$$

Where protected area A_e is:

$$\boldsymbol{A_e = ab + 6h(a + b) + 9\pi h^2} \quad (2)$$

Thus, local direct lightning strike frequency N_d which is estimated in protected area can be calculated by:

$$N_d = N_g * A_e * 10^{-6}/\text{year} \quad (3)$$

Where is a = length of building's roof (m), b is width of building's roof (m), h is height of building's roof (m), T is thunderstorm days in a year, N_g is densitasity of lightning (striking/km^2/year), A_e is area that has lightning strike value of N_d (m^2), N_d is average annual direct lightning strike (10^{-6}/ year), N_c is average annual lightning strike that is allowed in the area.

To determine whether the lightning protection system must be installed in a building or not, it is based on calculation of N_d and N_c [9]:

1. If $N_d \le N_c$, then lightning protection system is not needed.
2. If $N_d > N_c$, then lightning protection system is needed with efficiency is equal to:

$$E \ge 1 - \frac{N_C}{N_d} \quad (4)$$

Table 1. Efficiency of lightning protection system [9]

Protection Level	Efficiency of lightning protection system
I	0.98
II	0.95
III	0.90
IV	0.80

Graph of the critical point of lightning protection system efficiency is based on the ratio of N_c and N_d as can be seen in Figure 1.

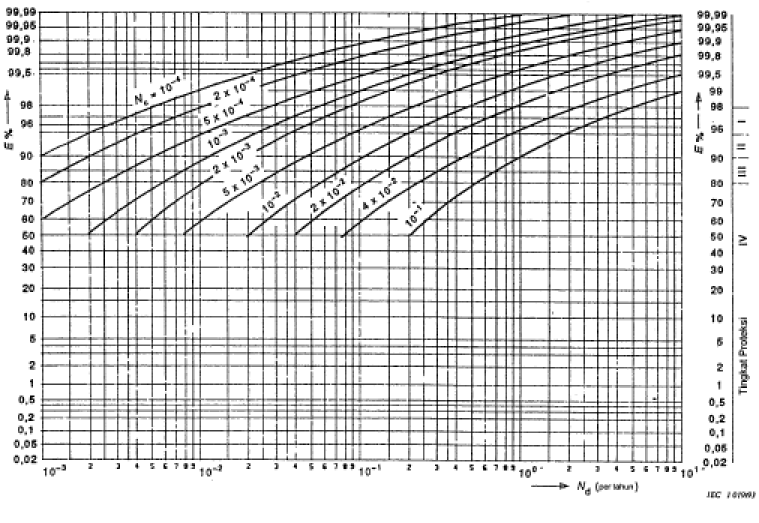

Figure 1. The critical point of lightning protection system efficiency

2.1. Cone Protection Method

The protected area is the area inside a cone with specific protection angle as can be seen in Table 2.

Table 2. Protection level, protection radius, protection angle and mesh width[6]

Protection level	H(m)	Protection angle (α°)				Mesh width (m)
	R(m)	20 m	30 m	45 m	60 m	
I	20	25	*	*	*	5
II	30	35	25	*	*	10
III	45	45	35	25	*	10
IV	60	55	45	35	25	20
* only use *rolling sphere* and *mesh*						

2.2. Rolling Sphere Method

Using electrogeometry theory with protection area is based on intersection with reference plane, building and rolling sphere circumference and radius that is based on protection level [6] as shown in Table 2.
In rolling sphere method, peak current I can be calculated using equation:

$$R = I^{0.75} \quad (5)$$

According to White Head equation [10], striking distance is:

$$\boldsymbol{r_s = 8 * I^{0.65}} \quad (6)$$

While protection radius can be calculated using equation:

$$\boldsymbol{r = \sqrt{2r_s h - h^2}} \quad (7)$$

Where rs is striking distance (m), I is average of peak lightning current (kA), h is height of mast (m), and r is protection radius (m).

Table 3. Minimum value of lightning parameter and radius of rolling sphere according to IEC 60235-1 [9]

Criteria	Symbol	Unit	Protection level			
			I	II	III	IV
Peak lightning current minimum	i	kA	3	5	10	16
Radius of rolling sphere	R	m	20	30	45	60

III. The 214 Radar Site

The 214 radar site is located in Tegal district, Middle Java with annual average of thunderstorm days is 198 and isokreunik level 54.34 (high risk level). Tower radar is situated in open area, therefore it has a prominent height.

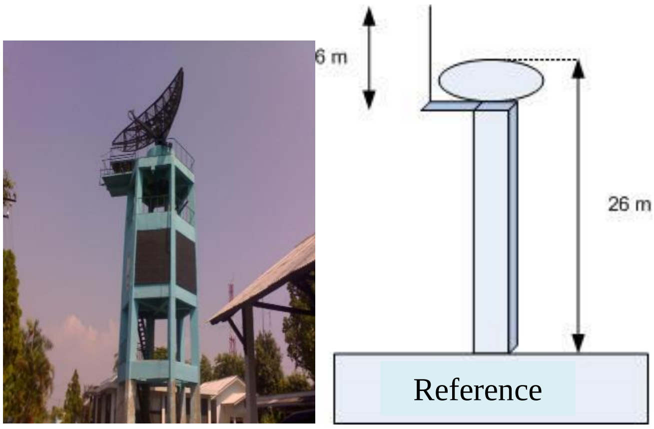

Figure 2. The 214 radar tower observed at this research

Tower radar has 24 m height, 2 m antenna, and 6 m air termination from the top of the tower, therefore the total air termination height is 30 m. There are single mast protection system (30 m height) in 10 m distance from the tower.

IV. RESULTS AND DISCUSSION

The data of 214 radar site is inserted into aforementioned equations, we can perform the calculations and analysis. Annual average of lightning density N_g in area where the building is located based on Equation 1. is:

$$N_g = 0.04 * T^{1.25}$$
$$N_g = 0.04 * 198^{1.25}$$
$$N_g = 29.709 \text{ lightning strike/km}^2\text{/year}$$

Area of ground surface that is assumed as a structure with annual direct lightning strike frequency is:

$$3h = 3 * 26$$
$$3h = 78 \text{ m}$$

The radar tower 214 is a hexagonal prism with the length of each edge in hexagonal base is 2,5 m and the prism height is 26 m, therefore the value of a and b must be calculated. Using trigonometric calculation, the value of a = 5 m and b = 4,33 m.

Protection area A_e is:

$$A_e = ab + 6h(a + b) + 9\pi h^2$$
$$A_e = 5 * 4{,}33 + 6 * 26(5 + 4.33) + 9 * 3.14 * 26^2$$
$$A_e = 20{,}280.89 \text{ m}^2$$

Local direct lightning strike frequency N_d that is assumed to aim to the protected structure can be calculated using Equation 3:

$$N_d = N_g * A_e * \ 10^{-6} \text{ /year}$$
$$N_d = 29{,}709 * \ 20.580{,}89 * 10^{-6}$$
$$Nd = 611.437{,}661 * 10^{-6}$$
$$Nd = 0.611 \text{ lightning strike/year}$$

From the data of Indonesian Agency of Meteorology, Climatology and Geophysics station in Tegal, annual local lightning strike frequency N_c that is allowed is 10^{-1}/year. Since the value of N_d is larger than N_c therefore the building needs a lightning protection with efficiency:

$$E \leq 1 - \frac{N_c}{N_d}$$
$$E \leq 1 - \frac{10^{-1}}{0.611}$$
$$E \leq 1 - 0.163$$
$$E \leq 0.837$$
$$E \leq 83.7\%$$

By observing the graph of the critical point of lightning protection system efficiency in Figure 1., the calculated efficiency is located in protection level III with efficiency range is 0.8 – 0.9. Hence, the proper lightning protection for radar tower is protection level III.

4.1. Calculation with Cone protection Methods

Based on Table 2., in lightning protection level III and the height of protected object is approximately 30 m, therefore the protection angle is 35°. To obtain protection radius of lightning protection system, we use this calculation:

Radius of tower radar cone:

$$x = \frac{30}{\cos 35°} * \sin 35° = 21 \text{ m}$$

Protection area of radar tower that is added with air termination using cone protection method is:

$$A = \pi * r^2$$
$$A = 3.14 * 21^2$$
$$A = 1{,}384.74 \text{ m}^2$$

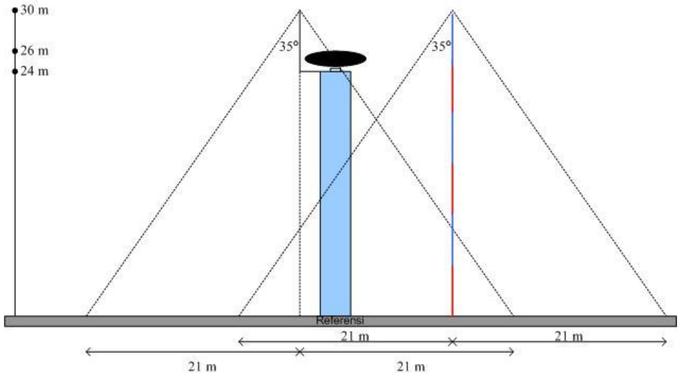

Figure 3. Cone protection methods in tower radar and single mast

The calculation and Figure 3. we can observe that lightning protection system in radar tower and single mast is not sufficient to protect radar antenna against direct lightning strikes. Therefore, the air termination height in tower radar will be increased to 35 m from the ground.

Radius of radar tower protection after increasing the height of air termination to 35 m is:

$$x = \frac{35}{\cos 35°} * \sin 35° = 24.5 \text{ m}$$

Protection area of tower radar that is added with 35 m air termination using cone protection method is:

$$A = \pi * r^2$$
$$A = 3.14 * 24{,}5^2$$
$$A = 1{,}884.785 \text{ m}^2$$

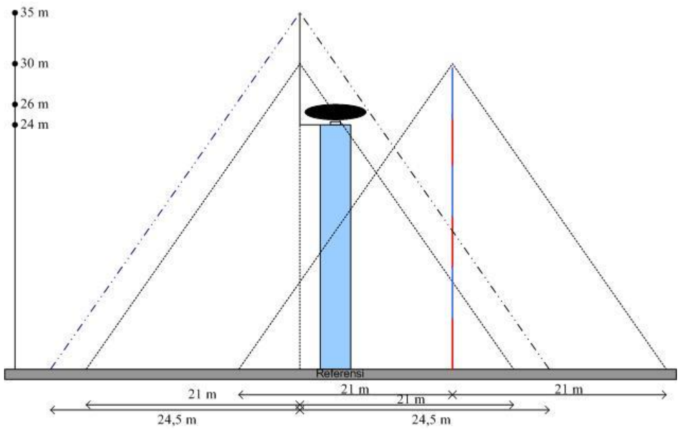

Figure 4. Cone protection methods in tower radar and single mast with the increase of air termination height

Based on the calculation and Figure 4 after the increase of air termination height in tower radar, all area of radar antenna is protected against direct lightning strike.

4.2. Calculation with Rolling Sphere Method

The rolling sphere method is based on the idea that the lightning strikes the nearest object on the earth situated at the so-called orientation distance from the descending leader's head. Thus, one can imagine one sphere which is moving towards the ground and which has the radius equal with the orientation distance. The head of the descending leader is considered to be in the center of this sphere. The first object touched by this virtual sphere will be stricken by the lightning [11].

In rolling sphere method, the lightning protection level is calculated using the efficiency of lightning protection system, which is 0.83. Based on Table 1, it falls into protection level III with the radius of rolling sphere is 45 m. The current I of a possible lightning strike can be calculated as:

$$R = I^{0.75}$$
$$I = \sqrt[0.75]{R}$$
$$I = \sqrt[0.75]{45}$$
$$I = 160.06 \text{ A}$$

The number means that radar tower is capable to withstand current of 160.06 A. If the lightning current is larger than this value, the current will be diverted to the ground by lightning protection system.

According to White Head, striking distance r_s can be calculated using equation:

$$r_s = 8 * I^{0.65}$$

By inserting the obtained value of *I* (160,06 A), we can calculate the striking distance:

$$r_s = 8(160.06)^{0.65}$$
$$r_s = 216.7 \text{ m}$$

To determine the protected radius of tower radar using rolling sphere method, we can use the equation:

$$R = \sqrt{2r_s h - h^2}$$
$$R = \sqrt{2 * 216.7 * 30 - 30^2}$$
$$R = 110 \text{ m}$$

With protection area of tower radar:

$$A = \pi * r^2$$
$$A = 3.14 * 110^2$$
$$A = 37{,}994 \text{ m}^2$$

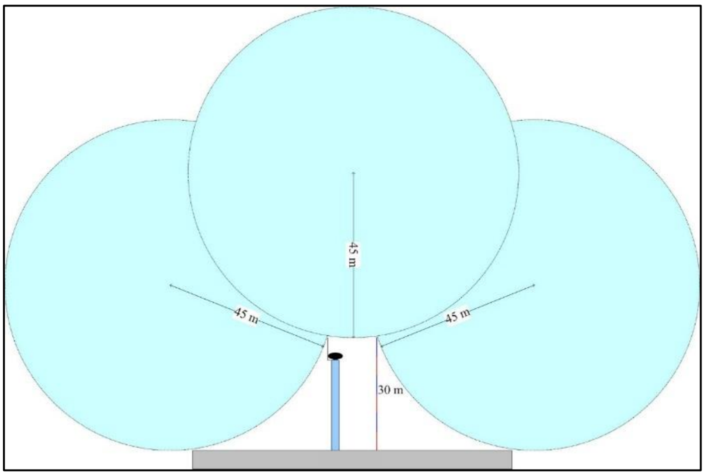

Figure 5. Calculation using rolling sphere method in radar tower and single mast

Based on Figure 5 and the calculation result, all area of the tower and radar antenna is protected against direct lightning strike.

V. CONCLUSIONS

Analysis result of lightning protection system in tower radar using cone protection method shows that the existing lightning protection does not cover all area of the radar antenna. Author suggest to increase the height of air termination to 35 m. Analysis of rolling sphere method shows that protection radius of 110 m and it is capable to protect all area of the tower and radar antenna against lightning strike. The comparison of analysis between both methods shows that rolling sphere method has wider protection radius than cone protection method.

VI. FUTURE WORK

Based on these results, it is necessary to further study on the internal lightning protection system.

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