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Design of Lightning Protection System on Village Hall Building in Residential Area Using Rolling Sphere Method Based on Air Terminal Height Variations

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ABSTRACT (9 pt)

This study evaluates the design of a lightning protection system for a residential village hall using the rolling sphere method per IEC 62305 standards. Quantitative engineering calculations were conducted to assess the protection coverage of a Franklin rod air terminal installed on a 5-m-high structure across three height variations: 1 m, 1.5 m, and 2 m. The results demonstrate a direct correlation between air terminal height and protection coverage. Increasing the terminal height from 1 m to 1.5 m and 2 m expanded the protection radius from 21.93 m (1,510 m²) to 23.30 m (1,705 m²) and 24.66 m (1,910 m²), respectively. Technical and economic trade-off analyses identify the 1.5-m Franklin rod as the optimal configuration, delivering effective structural protection while maintaining construction feasibility and cost efficiency. These findings provide a practical benchmark for designing lightning protection systems in small-scale public infrastructure within residential areas.

INTRODUCTION

Lightning is an atmospheric discharge phenomenon presenting severe hazards to human life, structural integrity, and electrical infrastructure. Lightning strikes occur due to electrostatic charge accumulation between clouds and the earth's surface, triggering transient discharges of high electrical energy. In tropical environments such as Indonesia, elevated keraunic levels (thunderstorm frequency) significantly increase direct strike risks on exposed buildings and public infrastructure. Direct strikes induce physical destruction through explosive thermal forces, mechanical fracturing, side-flashing, and high-voltage surges that compromise electrical safety and public security.

Within residential areas, public service buildings play a critical role in daily civic administration. Village halls (*balai desa*) function as primary hubs for community meetings, local governance, and public welfare operations. Due to high occupancy rates and the integration of electronic administrative equipment, these facilities require robust external lightning protection systems (LPS) to preserve structural integrity and ensure continuous public service. Despite their operational importance, small-scale public buildings in rural and residential settings are frequently unequipped with standardized LPS, leaving occupants and electrical assets vulnerable to atmospheric transients.

An external LPS mitigates lightning risks by safely capturing direct strikes and conducting impulse currents to the earth ground mass. A standard external LPS comprises three principal subsystems: air terminals (interception elements), down conductors (conduction channels), and earth grounding networks (dissipation systems).

Design parameters for external LPS must align with international codes, specifically the International Electrotechnical Commission (IEC) 62305 standard series, which governs risk evaluation, physical damage mitigation, and geometric protection zoning.

Prior studies have extensively investigated external LPS applications using geometric modeling techniques such as the protective angle method, mesh method, and Rolling Sphere Method (RSM). Existing research primarily focuses on high-rise educational buildings, industrial storage tanks, high-voltage outdoor substations, and commercial passenger terminals. However, technical investigations focusing specifically on optimizing air terminal height configurations for low-rise municipal facilities in residential areas remain limited. Small-scale public facilities exhibit distinct roof geometries, modest building elevations (≈ 5 m), and mechanical constraint profiles that make complex multi-mast networks unviable.

The Rolling Sphere Method (RSM) represents a physically realistic geometric model based on the electro-geometric striking distance concept. The method simulates an imaginary sphere rolled over the structure; points touched by the spherical envelope represent prospective impact zones, while recessed surfaces beneath the sphere fall within the shielded volume. Because the protection radius generated by an air terminal scales with its elevated apex, varying the terminal height directly alters the protected ground radius and horizontal surface coverage.

To address the specific protection requirements of low-rise public infrastructure, this study evaluates the external LPS design for the Megale Village Hall building located in Bojonegoro, East Java. Using RSM simulations governed by IEC 62305-3 criteria under Lightning Protection Level III (LPL III), three passive Franklin rod air terminal heights (1.0 m, 1.5 m, and 2.0 m) were analyzed. A comprehensive technical and economic trade-off analysis was performed to identify the optimal air terminal elevation that maximizes protected surface area while minimizing mechanical wind loads, structural anchoring demands, and capital expenditures.

RESEARCH METHOD

2.1 Research Type and Approach

This study employs a quantitative approach utilizing engineering calculation analysis methods to evaluate the design of lightning protection systems for public facility buildings in residential areas. The quantitative approach was selected because this research focuses on the analysis of technical parameters that can be objectively measured and compared, namely the building protection level resulting from variations in air terminal height. The method used in this study is the Rolling Sphere Method, referencing the International Electrotechnical Commission (IEC, 2024) 62305 standard. This method is a geometric approach used to determine protection zones against lightning strikes by modeling an imaginary sphere rolled over the surface of the object to be protected based on the concept of striking distance (Mora Martínez et al., 2022). Points touched by the sphere are considered potential lightning strike locations, whereas untouched areas reside within the protection zone (Schober et al., 2022). The use of the Rolling Sphere Method is based on its capability to represent potential lightning strike paths more

realistically compared to other geometric methods, making it widely utilized in the design of lightning protection systems for buildings, industrial installations, and public facilities (Almaazmi, 2023; Negara et al., 2021; Putra et al., 2023).

2.2 Research Location and Object

This research was conducted at the village hall building located in Megale Village, Kedungadem District, Bojonegoro Regency. This location was selected because it is a public facility utilized as a center for administrative activities and community services, thereby requiring an adequate lightning protection system to ensure the safety of the building and the electrical equipment in use (Efendi, 2025; Firnando et al., 2024). The object of research is the external lightning protection system designed to protect the village hall building from direct lightning strikes. The protection system analyzed encompasses the air terminal, down conductor, and the protection zone generated based on the Rolling Sphere Method. The research focus is directed at the effect of air terminal height variations on the effectiveness of building protection.

2.3 Research Variables and Parameters

The variables in this study consist of independent variables, dependent variables, and control variables.

The independent variable is the height of the air terminal installed on the roof of the village hall building. The variations in air terminal height used in this research are:

- 1 meter
- 1.5 meters
- 2 meters

The selection of these variations is based on the general application of lightning protection systems in small to medium-scale public facility buildings while considering the technical and economic aspects of installing a lightning protection system (Almaazmi, 2023; Mora Martínez et al., 2022; Putra et al., 2023).

The village hall building in this study is assumed to have a height of ±5 meters above ground level, resulting in effective protection system heights of:

- 6 meters (5 m + 1 m)
- 6.5 meters (5 m + 1.5 m)
- 7 meters (5 m + 2 m)

The dependent variable in this research is the protection zone formed over the village hall building based on the Rolling Sphere Method simulation results. The protection zone is analyzed based on the coverage degree of the roof and building against potential direct lightning strikes.

The control variables include the Rolling Sphere Method and the IEC 62305 standard, which are applied consistently across all test variations so that the obtained results can be objectively compared.

The fixed parameter used in this study is a protection sphere radius of 45 meters, referencing Lightning Protection Level (LPL) III according to the IEC 62305 standard

(IEC, 2024). This protection level was selected as it is suitable for public facility buildings with moderate risk levels (IEC, 2024; Sethi et al., 2022).
In general, the air terminal height is one of the crucial parameters affecting the coverage area of the protection zone generated by a lightning protection system (Almaazmi, 2023; Efendi, 2025; Putra et al., 2023).

2.4 Type of Air Terminal

This research utilizes a Franklin Rod type air terminal as the lightning strike interception component in the external lightning protection system. The Franklin Rod is a conventional lightning protection system that operates passively by capturing lightning strikes and discharging them to the ground through a down conductor.
This type of air terminal is widely used in residential buildings as well as public facilities due to its simple construction, ease of installation, and compliance with the Rolling Sphere Method recommended in the IEC 62305 standard (IEC, 2024; Sethi et al., 2022).
The Franklin Rod was selected because it suits the characteristics of the village hall building, which has a relatively small size and uncomplicated protection requirements. Therefore, the study focuses on analyzing the effect of Franklin Rod air terminal height variations on the protection zone of the building (Almaazmi, 2023; Aprillia, 2022; Firnando et al., 2024).

2.5 Instruments and Data

The instruments used in this research consist of technical parameters and design standards for lightning protection systems. The primary instrument employed is the IEC 62305 standard, which serves as the basis for determining the analytical methods and design criteria for the lightning protection system (IEC, 2024; Schober et al., 2022).
The data utilized are secondary data obtained through literature studies of scientific journals, reference books, international standards, and relevant publications regarding lightning protection systems. These data encompass information regarding the characteristics of lightning protection systems, the Rolling Sphere Method, air terminal height variations, as well as relevant results from previous studies (Almaazmi, 2023; Aprillia, 2022; Negara et al., 2021; Putra et al., 2023). The use of secondary data aims to establish a solid theoretical foundation and ensure that the method employed has been applied and validated in prior research.

2.6 Calculation Methods

Analysis was conducted using the Rolling Sphere Method based on the IEC 62305 standard (IEC, 2024). This method utilizes the concept of an imaginary sphere with a specified radius rolled across the surface of the object to determine protected areas and areas that remain susceptible to lightning strikes (Mora Martínez et al., 2022; Schober et al., 2022).
In this study, a protection sphere with a radius of 45 meters was used, corresponding to protection level LPL III. Simulations were performed on a model of the village hall

building with a building height of 5 meters and air terminal height variations of 1 meter, 1.5 meters, and 2 meters.

The imaginary sphere was rolled over the top and sides of the building. Building areas not touched by the sphere are considered to be within the protection zone, whereas areas reachable by the sphere are considered potentially vulnerable to direct lightning strikes (IEC, 2024; Mora Martínez et al., 2022).

The simulation results were used to evaluate the building protection coverage and to determine the most effective air terminal height variation in providing protection for the village hall building (Almaazmi, 2023; Aprillia, 2022).

2.7 Data Analysis

Data analysis techniques were carried out quantitatively using a comparative approach. The Rolling Sphere simulation results from each variation in air terminal height were compared to evaluate the effect of changes in air terminal height on the protection zone formed over the village hall building.

The analysis stages comprise:

1. Modeling of the village hall building.
2. Rolling Sphere simulation for the 1-meter air terminal height variation.
3. Rolling Sphere simulation for the 1.5-meter air terminal height variation.
4. Rolling Sphere simulation for the 2-meter air terminal height variation.
5. Analysis and comparison of the resulting protection zones.
6. Determination of the most effective air terminal height variation.

In addition to protection effectiveness, the analysis also considers installation efficiency and implementation feasibility for public facility buildings (Putra et al., 2023; Sethi et al., 2022).

2.8 Systematic Research Flow

The research flowchart is structured systematically to ensure that each phase of the study is conducted in an organized manner. The research commences with a literature review regarding lightning protection systems and the Rolling Sphere Method, followed by problem identification and the determination of research parameters.

The subsequent phase involves modeling the village hall building and simulating the Rolling Sphere Method for each air terminal height variation. The simulation results are then analyzed and compared to determine the most effective configuration for providing building protection.

The final phase of the research is drawing conclusions based on the obtained analytical results. This approach is employed to ensure that the research outcomes possess good validity and can serve as a reference in designing lightning protection systems for public facility buildings (Daulay et al., 2023; Firnando et al., 2024; Negara et al., 2021).

RESULTS AND DISCUSSION

Protection Radius Calculation Results

The calculation of the protection radius for the lightning protection system was conducted using the rolling sphere method based on the International Electrotechnical Commission (IEC, 2024) 62305-3 standard. In this study, Lightning Protection Level (LPL) III was utilized with a protection sphere radius of 45 meters. The selection of LPL III was based on the category of public facility buildings with a moderate protection requirement, as recommended in the IEC 62305 standard (IEC, 2024).

The village hall building serving as the research object is assumed to have a height of ±5 meters above ground level. The analyzed air terminal height variations are 1 meter, 1.5 meters, and 2 meters above the building roof. Consequently, the effective heights of the protection system relative to ground level are 6 meters, 6.5 meters, and 7 meters, respectively.

The rolling sphere method is a geometric approach used to determine the lightning protection zone based on the concept of striking distance (Aprillia, 2022; Mora Martínez et al., 2022). The relationship between the effective height of the protection system and the protection radius is expressed by the equation:

$$Rp = \sqrt{2rh - h^2}$$

Where:

R_p = protection radius (m)

r = rolling sphere radius (45 m)

h = effective height of the protection system (m)

Calculation Results

1. Air Terminal 1 meter

Effective height of the protection system:

$$h = 5 + 1 = 6 \text{ meter}$$

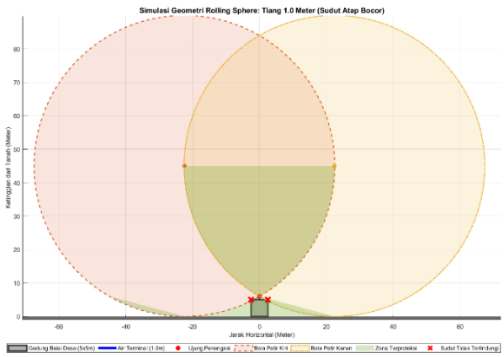


Figure 3.1 Geometric Simulation of Rolling Sphere for 1 Meter Pole

Protection Radius:

$$R_p = \sqrt{2(45)(6) - 6^2}$$
$$R_p = \sqrt{540 - 36}$$
$$R_p = \sqrt{504}$$
$$R_p \approx 22.45 \text{ m}$$

Protection Area:

$$L = \pi R^2$$
$$L = 3.14(22.45)^2$$
$$L \approx 1{,}582 \text{ m}^2$$

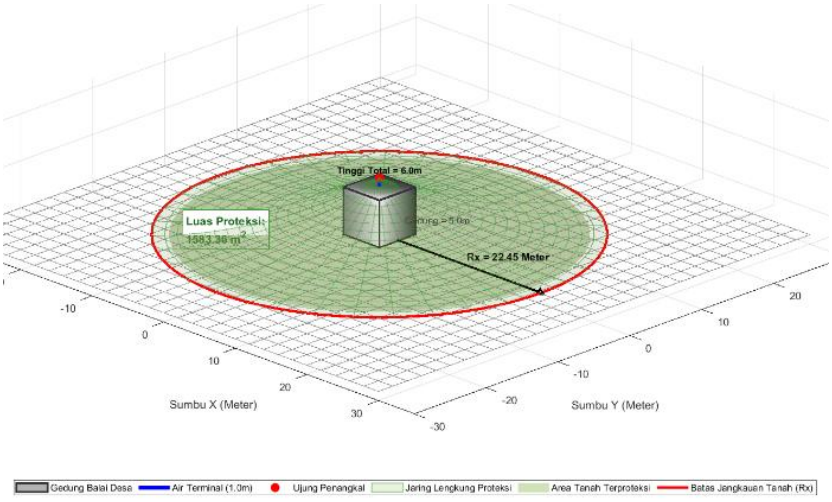


Figure 3.2 Simulation of Protection Radius and Protection Area Coverage for 1-Meter Pole

2. Air Terminal 1,5 meter

Effective height of the protection system:

$$h = 5 + 1.5 = 6.5$$

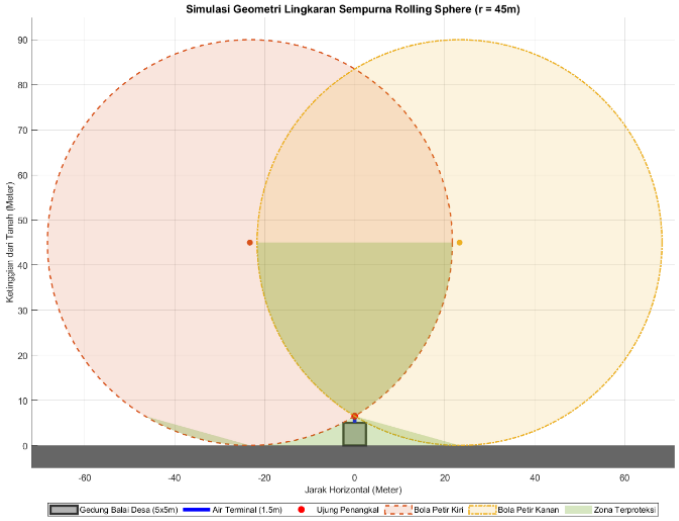


Figure 3.3 Geometric Simulation of Rolling Sphere for 1.5-Meter Pole

Protection Radius:

$$R_p = \sqrt{2(45)(6.5) - 6.5^2}$$
$$R_p = \sqrt{585 - 42.25}$$
$$R_p = \sqrt{542.75}$$
$$R_p \approx 23.30 \text{ m}$$

Protection Radius:

$$L = 3.14(23.30)^2$$
$$L \approx 1{,}705 \text{ m}^2$$

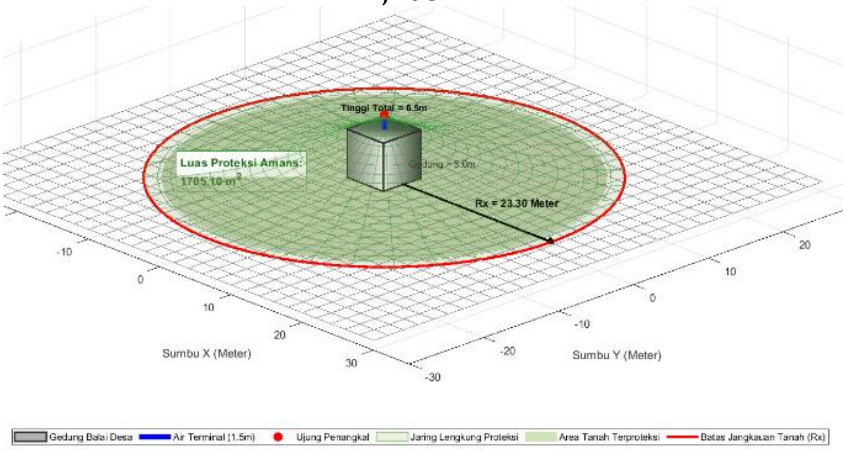


Figure 3.4 Simulation of Protection Radius and Protection Area Coverage for 1.5-Meter Pole

3. Air Terminal 2 meter

Effective height of the protection system:

$$h = 5 + 2 = 7$$

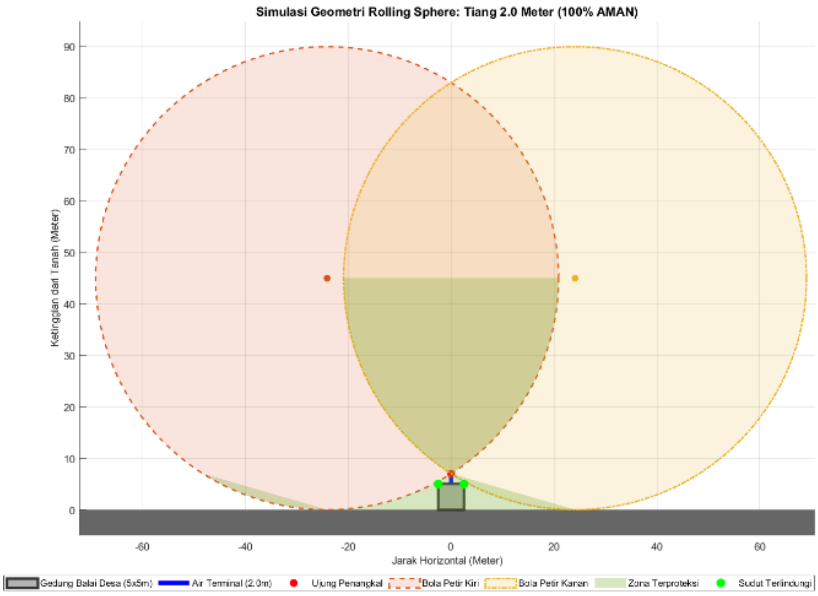


Figure 3.5 Geometric Simulation of Rolling Sphere for 2-Meter Pole

Protection Radius:

$$R_p = \sqrt{2(45)(7) - 7^2}$$
$$R_p = \sqrt{630 - 49}$$
$$R_p = \sqrt{581}$$
$$R_p \approx 24.10 \text{ m}$$

Protection Radius:

$$L = 3.14(24.10)^2$$
$$L \approx 1{,}824 \text{ m}^2$$

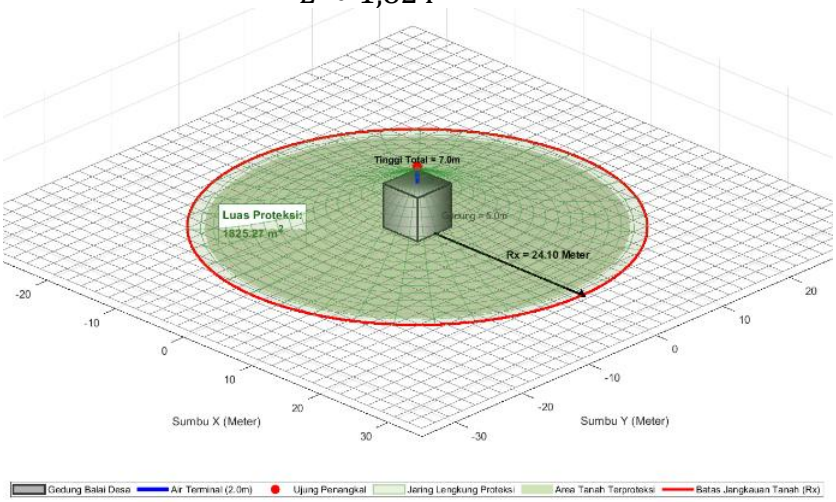


Figure 3.6 Simulation of Protection Radius and Protection Area Coverage for 1-Meter Pole

Table 3.1 Results Comparison of protection radius and area coverage for varying air

terminal heights.

No	Air Terminal Height (m)	System Effective Height (m)	Protection Radius (m)	Protection Area Coverage (m²)
1	1	6	22.45	1,582
2	1.5	6.5	23.30	1,705
3	2	7	24.10	1,824

CONCLUSION

Based on the research and analysis conducted, several conclusions can be drawn as follows::

1. The rolling sphere method based on the IEC 62305 standard can be utilized to determine the protection radius and area coverage of a lightning protection system for a village hall building in a residential area.
2. Variations in air terminal height affect the resulting protection area coverage. An increase in air terminal height yields a larger protection radius and area coverage for the lightning protection system.
3. Calculation results indicate that the application of a Franklin rod type air terminal at heights of 1 m, 1.5 m, and 2 m produces an incremental increase in the protection radius, thereby expanding the area protected against direct lightning strikes.
4. The deployment of an excessively tall air terminal is not necessarily the most efficient option, as the expansion of the protection area must be balanced against installation costs, structural stability, and implementation feasibility for the village hall building.
5. Based on technical and economic analyses, the optimal configuration identified in this study is the application of a Franklin rod type air terminal with a height of 1.5 meters above the roof of the approximately ±5-meter-high village hall building.
6. This configuration yields a protection radius of approximately 23.30 meters with a protection area coverage of approximately 1,705 m², which is evaluated as sufficiently effective to protect the village hall structure and its surrounding area from direct lightning strike hazards.

The findings of this study are expected to serve as a reference in designing lightning protection systems for small-scale public facility buildings, particularly village halls or residential structures sharing similar characteristics.

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