OPTIMIZATION OF LIGHTNING PROTECTION SYSTEM DESIGN FOR MULTI-STORY BUILDINGS BASED ON COST AND PROTECTION COVERAGE ANALYSIS

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Abstract—The installation of a lightning protection system at SMK Bhakti Praja Jepara aims to safeguard the building from the hazards of lightning strikes. The building, which is 23 meters high with an area of ±3,716 m², currently lacks this protective system, making it susceptible to mechanical, thermal, and electrical damage. This study began by planning a lightning protection system in accordance with the PUIPP (General Regulations for Lightning Protection Installation) and SNI 03-7015-2004 standards. The research process involved collecting building data, measuring grounding resistance, and conducting a comparative analysis between two methods: conventional and electrostatic. The grounding resistance measurements yielded values of 3.88 Ohm, 1.39 Ohm, and 3.77 Ohm, all of which meet the SNI standards. The comparative analysis concluded that the conventional system, which requires four lightning rods, has an estimated cost of Rp 7,537,774.00. In contrast, the electrostatic system, due to its wider protection radius, only requires one lightning rod and is more cost-efficient, with an estimated budget of Rp 5,723,774.00. Based on these findings, it is concluded that the electrostatic lightning protection system is a more optimal solution in terms of both protection radius effectiveness and cost efficiency.

Keywords—Lightning arrester, lightning protection system, conventional, electrostatic

1. INTRODUCTION

The construction of multi-story buildings in Indonesia, a solution to land scarcity, presents new challenges related to safety, particularly from natural phenomena like lightning strikes. Indonesia, located on the equator, experiences a high frequency of thunderstorms, making lightning protection a necessity. The SMK Bhakti Praja Jepara building, standing 23 meters tall, is one of the highest in its region yet currently lacks a lightning protection system. This condition poses a significant risk of severe damage to the building's structure and its mechanical, thermal, and electrical equipment, as well as a danger to the safety of its occupants.

To address this issue, this research focuses on planning a lightning protection system for the SMK Bhakti Praja Jepara building. By referring to national standards such as the General Regulations for Lightning Protection Installation (PUIPP) and the Indonesian National Standard (SNI) 03-7015-2004, this study will analyze and compare two primary methods: the conventional system and the electrostatic system. The research will examine the working principles, components used, and relevant technical calculations for both

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methods. The main objective of this study is to evaluate the effectiveness, technical feasibility, and cost-efficiency of each system to determine the optimal solution that not only meets safety standards but is also economically sound. This research is expected to provide practical guidance for designing lightning protection systems for multi-story school buildings in Indonesia.

II. METHOD

In greater detail, the methodology covers (1) site and architectural data capture roof geometry, building height, materials, coordinates, soil resistivity (4-point test), and local lightning density (Ng); (2) risk assessment according to relevant IEC/SNI guidance to establish the Lightning Protection Level (LPL) and required separation distances; (3) sizing and layout of two design alternatives (A) conventional air-termination with discrete air rods, down conductors, and a ring earth, and (B) a roof-mesh air-termination supplemented by surge protective devices (SPDs) on power/telecom entries—using the rolling-sphere, protective-angle, and mesh methods; (4) verification checks for conductor cross-sections, equipotential bonding, touch/step-voltage safety, and target earthing resistance as prescribed by standards; and (5) a life-cycle evaluation that compiles single-line diagrams and bills of quantities for each option, then compares capital cost, maintenance and SPD replacement intervals, and sensitivity to material-price or soil-improvement variability to recommend the most reliable and economical solution for SMK Bhakti Praja Jepara.

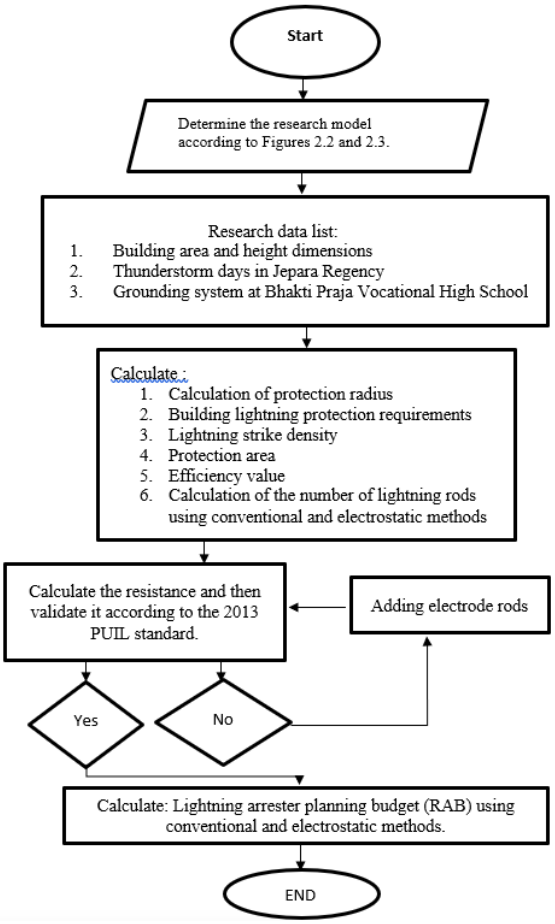


Figure 2.1. Research Flowchart

Object of Study

The object of this research is the SMK Bhakti Praja Jepara building, located at Jl. Hos Cokroaminoto Demaan VIII, Demaan, Jepara, with geographical coordinates of 6°35'42.6"S and 110°39'52.6"E. The site occupies a land area of approximately 4,495 m², with a total building area of about 3,716 m² and a height of 23 meters. Notably, this structure is recognized as the tallest school building in the Jepara region, which makes it a significant subject for lightning protection analysis. A visual representation of the building is provided in Figures 2.2 and 2.3.

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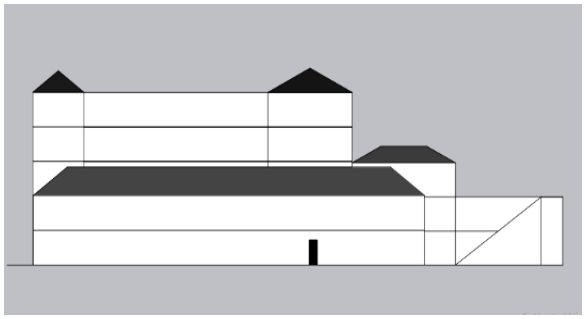


Figure 2.2. Front view of SMK Bhakti Praja Jepara Building

Figure 2.2 resents the front view of the SMK Bhakti Praja Jepara building. It illustrates the primary facade and entrance, providing a clear perspective of its multi-story design and overall scale. This view is crucial for understanding the building's dimensions and visual layout, which are essential parameters for planning and designing an effective lightning protection system.

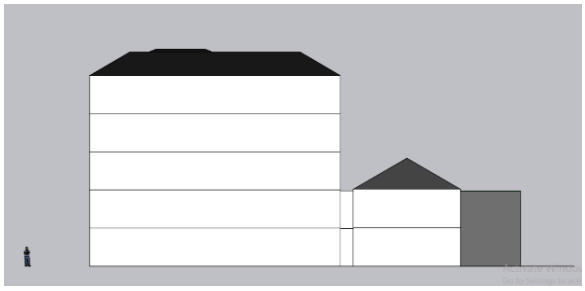


Figure 2.3. Side view of SMK Bhakti Praja Jepara Building

Figure 2.3 provides a side view of the SMK Bhakti Praja Jepara building. The view highlights the building's considerable height and multi-story structure, emphasizing its prominence as a high-rise in the local area. The exposed facade and roofline shown in this perspective are particularly vulnerable points for direct lightning strikes, reinforcing the need for a robust protection system.

Data Collection and Instrumentation

Primary data were collected through direct observation and on-site measurements at the research location. Secondary data were sourced from relevant literature, including books, journals, and official standards. The primary data required for this study included:

1. Building Dimensions: Measured to determine the effective protection area.
2. Isokeraunic Level (IKL): Data on the number of thunderstorm days in Jepara, sourced from the BMKG Klimatologi Semarang. The data for the year 2021 is presented in Table 2.1.
3. Earthing Resistance: Measured using a Kyoritsu 4105A Earth Tester to evaluate the existing grounding system.

Table 3.1. Thunderstorm Days in Central Java (2021)

Month	Thunderstorm Days
January	4
February	2
March	10
April	4
May	4
June	5
July	1
August	1
September	6
October	7
November	7
December	6
Total	**58**

The earthing resistance measurement was conducted by connecting the Kyoritsu 4105A Earth Tester, as shown in Figure 2.4, to two auxiliary electrodes placed at a distance of 5-10 meters from the existing grounding rod. A successful measurement requires the earth voltage to be less than 10V.

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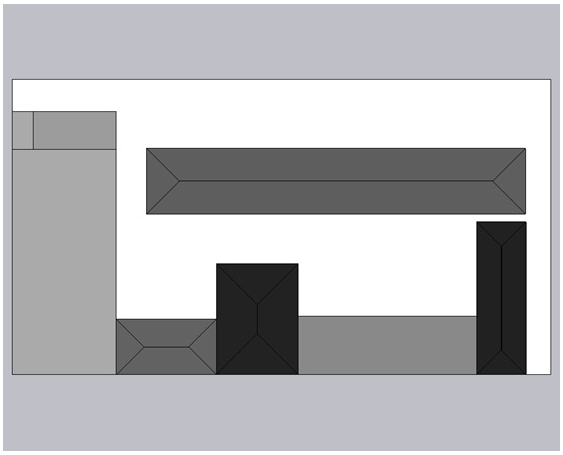


Figure 2.4. Kyoritsu 4105A Earth Tester

Figure 2.4. displays the Kyoritsu 4105A Earth Tester, a specialized measuring instrument used to determine the resistance of a grounding system. The device features a rotary selector for choosing different measurement ranges and functions, as well as connection terminals for the test leads. This tool is essential for the research, as it provides the critical data needed to evaluate the existing grounding system at the SMK Bhakti Praja Jepara building and ensure it complies with the required safety standards.

Analysis and Calculation Methods

The collected data were analyzed using three distinct international and national standards to ensure a comprehensive evaluation

1. **PUIPP Method**: The lightning strike hazard index **(R)** is determined by summing five different risk factors. A value of **R14** indicates a high risk requiring a lightning protection system. The formula is as follows:

$$R = A + B + C + D + E$$

where:

A : Building type index
B : Building construction index
C : Building height index
D : Building location index
E : Isokeraunic level index

2. **NFPA 780 Method**: The lightning strike hazard index **(R)** is calculated by summing various structural and environmental factors and dividing by the Isokeraunic Level. A value of **R7** indicates a high hazard level.

$$R = \frac{A+B+C+D+E}{F}$$

where:

A : Structure type index
B : Construction type index
C : Location index
D : Topography index
E : Building use and content index
F : Isokeraunic Level (IKL) index

3. **IEC 1024-1-1 Method**: The need for a protection system is determined by comparing the acceptable annual flash frequency with the estimated direct flash frequency to the structure. This involves calculating:

- Ground Flash Density (N_g):
  $N_g = 0{,}04 \cdot IKL^{1'25}$ (flashes/km^2/year)
- Local Direct Flash Frequency (N_d):
  $N_d = N_g \cdot Ae \cdot 10^{-6}$ (flashes/year)
- Effective Collection Area (A_e):
  $A_e = ab + 6h\,(a+b) + 9\pi h^2$

where a and b are the length and width of the building, and h is the height. The protection radius (r) for the conventional method is then calculated using the protection angle (alpha) determined from the IEC standard:

$$r = h \; x \; tan \; a$$

Earthing and Economic Analysis

The earthing resistance value must be less than **5** *Omega* as per the Indonesian National Standard (PUIL 2013). If the initial measurement exceeds this value, additional ground rods will be installed, and the resistance will be re-measured until the required value is achieved.

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Finally, a Bill of Quantities (RAB) will be prepared for both the conventional and electrostatic lightning protection systems. This economic analysis will serve as the basis for a comparative conclusion on the most suitable and cost-effective system for the SMK Bhakti Praja Jepara building.

III. RESULTS AND DISCUSSION

This chapter presents the findings from the field study and the subsequent technical and economic analysis of the proposed lightning protection systems for the SMK Bhakti Praja Jepara building. The results from the lightning hazard assessment, grounding system measurements, and a comparative analysis of conventional and electrostatic protection methods are detailed below.

The assessment of the lightning strike risk for the SMK Bhakti Praja Jepara building was conducted using three different standards to ensure a robust and comprehensive evaluation.

1. PUIPP Hazard Index Analysis:

Based on the General Regulations for Lightning Protection Installation (PUIPP), the lightning strike hazard index (R) is a sum of five factors. By assigning values based on the building's characteristics as a school, its construction, height, and isolated location as the tallest structure in the area, the calculation is as follows:

$$R = 4 + 2 + 5 + 6 + 8 = 25$$

With a calculated index of R=25, which is significantly greater than the threshold of 14, it is concluded that a lightning protection system is absolutely necessary for the building.

2. NFPA 780 Hazard Index Analysis:

Following the NFPA 780 standard, the hazard index is determined by summing the assigned values for five different factors. A value of R7 indicates a high risk.

$$R = 3 + 2 + 4 + 0 + 5 = 13$$

The resulting index of R=13, which exceeds the required threshold of 7, also confirms the high risk of lightning strikes and the critical need for a protection system.

3. IEC 1024-1-1 Hazard Index Analysis:

Using the Isokeraunic Level (IKL) data for Jepara (58 thunderstorm days/year), the ground flash density **(N_g)** and the annual direct lightning strike frequency **(N_d)** for the building's effective collection area **(A_e)** were calculated.

- **Ground Flash Density (N_g):**

$$Ng = 0{,}04\ x \frac{Td^{1,25}}{km^2} /year$$

$$Ng = 0{,}04\ x \frac{57^{1,25}}{km^2} /year$$

$$Ng = 0{,}04\ x \frac{156{,}61}{km^2} /year$$

$$Ng = 6{,}26/km^2/year$$

- **Effective Collection Area (A_e)**

Based on the building dimensions, with a height (h) of 23 m, an approximate length (a) of 83 m, and an approximate width (b) of 45 m, the effective area is calculated using these measurements to represent the surface area exposed to potential lightning strikes.

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

$$A_e = 18{,}52\ x\ 48\ ,8 + 6x23\ (18{,}52 + 48{,}8) + 9x3.14x23^2$$

$$A_e = 903{,}776 + 138(67{,}32) + 19.949{,}54$$

$$A_e = 903{,}776 + 9.290{,}16 + 19.949{,}54$$

$$A_e = 30.143{,}476$$

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- **Direct Flash Frequency (N_d):**

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

$$Nd = 6{,}26/km^2/\ year\ x\ 30.143{,}276\ m^2 x\ 10^{-6}\ x\ year$$

$$Nd = 188.698{,}157\ x\ 10^{-6} x\ year$$

$$Nd = 0{,}18 x\ year$$

The risk assessment shows the building could receive a direct strike about once every 4–5 years (1/0.18 ≈ 4.5), placing it in the high-risk category under all three referenced standards and justifying a robust lightning protection system. Safe dissipation of current depends on grounding: PUIL 2013 requires earth resistance ≤ 5 Ω, and compliance was verified by multi-point measurements on site using a Kyoritsu 4105A earth tester.

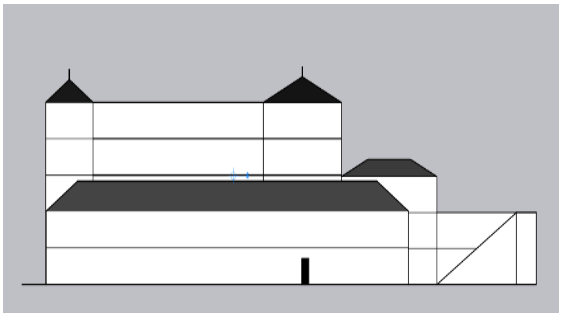


Figure 3.1. Front view of the SMK Bhakti Praja Jepara building.

The initial measurements indicated that the existing earthing resistance did not meet the required standard. To achieve the required value, additional copper ground rods were installed in the designated locations. After the installation of the additional rods, the resistance was re-measured until it fell below the **5** *Omega* threshold, ensuring a safe path for the lightning current.

This study evaluated and compared two primary lightning protection methods: the conventional Franklin Rod system and the Electrostatic (Early Streamer Emission) system.

The conventional system, based on the **Faraday Cage** principle, uses a network of air terminals and down conductors to intercept lightning strikes. The protection radius of a conventional rod is determined by its height and a standard protection angle (alpha). For a building height of 23 meters and an angle of 45 degrees, the protection radius (r) is calculated as:

$$r = h\ x \tan \alpha$$

$$r = 23\ x \tan 45°$$

$$r = 23 \text{ meter}$$

Due to this limited radius, multiple air terminals would be required to cover the entire building, necessitating a complex network of down conductors and ground rods.

The electrostatic (ESE) air terminal creates a much larger protection zone by triggering an early upward leader, improving lightning interception. In this study it achieved a ~70 m protection radius, enough to cover the entire SMK Bhakti Praja building with a single unit (radius depends on height and device specs). In contrast, a conventional system needs multiple rods and more conductors to reach the same coverage, making installation more complex. Thus, the ESE option reduces unit count and streamlines installation while delivering full-site coverage.

Table 4.1. Comparison of Conventional vs. Electrostatic Methods

Feature	Conventional System	Electrostatic System
Working Principle	Faraday Cage	Early Streamer Emission (ESE)
Protection Radius	Limited (≈ 40 m)	Large (≈ 70 m)
Number of Terminals	Multiple	Single
Installation Complexity	High	Low
Effectiveness	Good for small areas	Very good for large areas
Total Cost	Potentially higher due to many components	Competitive and efficient

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Grounding System

One of the critical components in lightning protection planning is the grounding system. In this study, a copper rod with a diameter of 0.01589 m (5/8 inches) and a length of 4 m was selected. Based on the measurements and applying Equation (2.9) from the theoretical framework, the number of rods required for the SMK Bhakti Praja Jepara building was determined. The preliminary calculation for a section of the building, which exhibited a resistance value exceeding 5 Ω, is presented as follows:

$$\boldsymbol{R_{total} = R_1 + R_2 + \cdots + R_n}$$

With the initial values, it was found that one section of the building did not meet the **PUIL 2013** standard, which requires grounding resistance to be less than **5** *Omega*. To rectify this, additional electrodes were added and connected in parallel. The resulting resistance was then calculated using Equation (X) from the theoretical chapter:

a. $R = \frac{\rho}{2\pi L}\ x\ \{ln\frac{4L}{d} - 1\}$

$R = \frac{74,7}{2.3,14.4}\ x\ \{ln\frac{4.4}{0.01589} - 1\}$

$R = \frac{74,7}{25,52}\ x\ \{ln\frac{16}{0.01589} - 1\}$

$R = 2,92\ x\ \{\ln \quad 1006.9 - 1\}$

$R = 2,92x\ \{ln1005.9\}$

$R = 2,92x\ (6,91)$

$R = 20,22\ \Omega$

b. $R = \frac{\rho}{2\pi L}\ x\ \{ln\frac{4L}{d} - 1\}$

$R = \frac{5.17}{2.3,14.4}\ x\ \{ln\frac{4.4}{0.01589} - 1\}$

$R = \frac{5.17}{25,52}\ x\ \{ln\frac{16}{0.01589} - 1\}$

$R = 0.2\ x\ \{\ln \quad 1006.9 - 1\}$

$R = 0.2x\ \{ln1005.9\}$

$R = 0.2\ x\ (6,91)$

$R = 1.39\ \Omega$

c. $R = \frac{\rho}{2\pi L}\ x\ \{ln\frac{4L}{d} - 1\}$

$R = \frac{3.88}{2.3,14.4}\ x\ \{ln\frac{4.4}{0.01589} - 1\}$

$R = \frac{3.88}{25,52}\ x\ \{ln\frac{16}{0.01589} - 1\}$

$R = 0.15\ x\ \{\ln \quad 1006.9 - 1\}$

$R = 0.15x\ \{ln1005.9\}$

$R = 0.15x\ (6,91)$

$R = 1.05\ \Omega$

In the above calculation, using a 4-meter copper rod with a diameter of 5/8 inch, one section was still found to have a resistance value exceeding 5 Ω. Referring to the 2013 PUIL standard, which stipulates that grounding resistance must not exceed 5 Ω, additional grounding electrodes may be installed or connected in parallel. With the addition of electrodes, and by applying Equation (), the results are obtained as follows:

$R = \frac{74.7}{4x3.14x4}\ x\ \left\{ln\frac{4x4}{0.01589} - 1 + \ln(2x4 + \sqrt{3^2} + 4x4^2\right) + \frac{3}{2x4} - \frac{\sqrt{3^2}+4x4^2}{2x4}\}$

$R = \frac{74.7}{50,24}\ x\ \left\{\ln\frac{16}{0.01589} - 1 + \ln(8 + 5 + 64\right) + \frac{3}{8} - \frac{3+64}{8}\}$

$R = \frac{74.7}{4x3.14x4}\ x\ \{5,91 + 4,31 + 0,62 - 8,3\}$

$R = 1.4\ x\ \{5,91 + 4,31 + 0,62 - 8,3\}$

$R = 1.4\ x\ 2,54$

$R = 3,77\ \Omega$

After adding a parallel electrode, the earth resistance dropped to 3.77 Ω, meeting the PUIL 2013 limit of ≤ 5 Ω so the grounding is adequate and no further fixes are needed. The study then prepares BoQs for two options conventional and electrostatic ESE) including item descriptions, specs, quantities, units, unit prices, subtotals, plus labor, testing/commissioning, and contingency. The

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scope covers air terminals, roof/down conductors, bonding and test joints, inspection pits, grounding electrodes, optional soil-improvement compounds, and SPDs for power/telecom lines. For the conventional option, Table 3.2 gives the full cost breakdown (materials, accessories, SPDs, installation, and final tests), enabling easy verification and a direct cost comparison with the ESE alternative.

Table 3.2. Bill of Quantities for Conventional Lightning Protection System

Item Name	Volume	Unit	Unit Price (IDR)	Total Price (IDR)
Lightning Protection Installation Material				
Lightning Rod ¾" 30 cm + socket	4	Unit	285,000	1,140,000
BC Cable 20 mm² (STARDO)	50	m	11,000	550,000
PVC Conduit Pipe ⅝"	6	pcs	34,700	108,200
PVC Conduit Clamp ⅝"	1	pcs	332,000	332,000
Dinabolt 12 mm	4	pcs	6,316	25,574
Secun 50 mm²	2	pcs	10,000	20,000
Grounding Installation Material				
Copper Rod ⅝" × 4 m	4	pcs	1,400,500	5,602,000
Copper Rod Clamp	4	pcs	40,000	160,000
Total				**7,937,774**

Table 3.2 presents a detailed breakdown of the estimated costs for installing the conventional lightning protection system on the SMK Bhakti Praja Jepara building. It lists all necessary materials, including the lightning rods, cables, and grounding components, along with their respective volumes, unit costs, and the resulting total price. The final calculated total of Rp. 7,937,774 serves as a critical data point for the economic analysis and is used to compare the financial viability of this method against the electrostatic protection system. lectrostatic Lightning Protection System RAB

The total cost for the electrostatic system, which includes a single Early Streamer Emission (ESE) air terminal, is provided in Table 3.3.

Table 3.3. Bill of Quantities for Electrostatic Lightning Protection System

Item Name	Volume	Unit	Unit Price (IDR)	Total Price (IDR)
Lightning Protection Installation Material				
Head Protection R-60 m (KURN)	1	Unit	1,746,000	1,746,000
BC Cable 50 mm² (STARDO)	30	m	21,667	650,000
GVS Pipe 2" Thk. 1.5 mm, L = 2 m	1	pcs	236,000	236,000
PVC Conduit Pipe ⅝"	6	pcs	34,700	108,200
PVC Conduit Clamp ⅝"	1	pcs	332,000	332,000
Dinabolt 12 mm	4	pcs	6,316	25,574
Secun 50 mm²	2	pcs	10,000	20,000
Grounding Installation Material				
Copper Rod ⅝" × 4 m	2	pcs	1,400,500	2,801,000
Copper Rod Clamp	2	pcs	40,000	80,000
Total				**5,998,774**

Based on the Bill of Quantities, the total cost for the conventional lightning protection system is Rp. 7,937,774 with a protection radius of 23 meters per rod. In contrast, the total cost for the electrostatic lightning protection system is Rp. 5,998,774 with a protection radius of 60 meters. The economic analysis clearly shows that the electrostatic system is more cost-effective due to its wider protection radius, which reduces the number of components required for comprehensive coverage.

A Bill of Quantities (RAB) was prepared for the installation of both the conventional and electrostatic systems. While the initial unit cost of a conventional air terminal is

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lower, the total cost for the conventional system becomes higher due to the need for multiple units, extensive down conductors, and additional grounding points. Conversely, the electrostatic system's single, more expensive air terminal is offset by the reduced need for other components, making its overall installation cost more competitive and potentially lower for a building of this size. This economic analysis confirms that the electrostatic system is not only more effective but also a highly viable and efficient solution from a cost perspective.

IV. CONCLUSION

Based on the comprehensive research on lightning protection planning for the SMK Bhakti Praja Jepara building, it is concluded that a robust lightning protection system is critically necessary. The multi-standard hazard assessment consistently showed a high risk, with the PUIPP index reaching a value of 25. A comparative analysis of the two primary protection methods revealed that while the conventional system provides a limited radius of 23 meters per rod, the electrostatic (KURN R-60) model offers a significantly wider protection radius of 60 meters. Furthermore, the economic analysis confirmed the electrostatic system's efficiency, with a total estimated cost of Rp. 5,723,774, which is notably lower than the Rp. 7,537,774 required for the conventional system. Additionally, the grounding resistance at the site was successfully brought to a compliant state (below 5 Ω) by adding parallel electrodes, thereby meeting the PUIL 2013 standard. Based on these findings, it is strongly suggested that the SMK Bhakti Praja school administration install an electrostatic lightning protection system. This choice provides superior coverage and a more efficient investment for ensuring the long-term safety of the building and its occupants. The author expresses sincere gratitude to Allah SWT for the success of this project and extends thanks to the academic advisor, faculty, and family for their invaluable support.

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REFERENCES

[1] M. Amir And M. F. Rahmannudin, “Studi Perencanaan Sistem Proteksi Petir Pada Area Berbahaya,” *Sinusoida*, Vol. Xxi, No. 2, Pp. 8–17, 2019.

[2] B. Saragih, J. Purba, And J. Siburian, “Sistem Penangkal Petir Pada Gedung Kemang Gallery Medan,” *Sist. Penangkal Petir Pada Gedung Kemanggallerymedan*, Vol. 9, No. 1, Pp. 44–61, 2020.

[3] B. S. Purwita, A. Solihudin, And R. Prasetyo, “Penentuan Kebutuhan Proteksi Petir Pada Gedung Bertingkat Kantor Bpjs Ketenagakerjaan Cabang Blitar,” *J. Qua Tek.*, Vol. 7, No. 2, Pp. 27–42, 2017.

[4] R. A. Ghani And T. Arfianto, “Perencanaan Sistem Proteksi Petir Eksternal Pada Gedung Wisma Barito

ISSN 3123-5549 (online) DOI 10.30659/pulse-jeib

Pacific Menggunakan Metoda Rolling Sphere," *Sneto*, Pp. 284–292, 2021.

[5] N. Aryani, "Konsep Pendidikan Anak Usia Dini Dalam Perspektif Pendidikan Islam," *J. Potensia*, Vol. 14, No. 02, Pp. 213–220, 2015.

[6] R. Ainun, M. Abu, And B. Sidik, "Evaluasi Sistem Proteksi Petir," *Eval. Sist. Prot. Petir Eksternal Pada Gedung Aula Dan Pus. Kegiat. Mhs. Fak. Ekon. Univ. Sriwij.*, Vol. 2, No. 1, Pp. 116–126, 2020.

[7] C. M. Nadeak And I. Irfan, "Analisis Penangkal Petir Pada Peralatan Antena Radar Di Kantor Airnav Indonesia Cabang Pembantu Pangkalan Bun," *J. Eeict (Electric Electron. Instrum. Control Telecommun.*, Vol. 5, No. 1, Pp. 4–9, 2022, Doi: 10.31602/Eeict.V5i1.6861.

[8] Z. Hakim, "Masjid Raya Mujahidin Menggunakan Metode Bola Bergulir (Rolling Sphere Method)," *Univ. Tanjungpura*, Pp. 1–7, 2017.

[9] R. Rohani, "Evaluasi Sistem Penangkal Petir Eksternal Di Gedung Rektorat Universitas Negeri Yogyakarta," *J. Edukasi Elektro*, Vol. 1, No. 2, Pp. 187–195, 2017, Doi: 10.21831/Jee.V1i2.17423.

[10] J. Siburian, Jumari, And T. Hutagalung, "Studi Sistem Penangkal Petir Pada Menara Lampu Penerangan Parkir Bandara Kualanamu Oleh," *J. Tek. Elektro*, Vol. Viii, No. 2, Pp. 73–80, 2019.

[11] O. : Yahya, T. Ginting, J. Napitupulu, A. Giga, And A. Pane, "Simulasi Tegangan Induksi Kabel Akibat Arus Petir Pada Kawat Penangkal Petir,"

[12] Gholami, R., Ghasemi, E., & Farshidianfar, A. (2023). An analytical and experimental study of early streamer emission lightning rods in high voltage laboratories. *Journal of Electrostatics*, 126, 103856.

[13] Suryani, A., Arfianto, D., & Prasetijo, H. (2022). Comparison of lightning protection systems based on conventional and early streamer emission methods on building. *Journal of Physics: Conference Series*, 2235(1), 012005.

[14] Huda, S. N., Supriadi, A., & Budiman, A. (2021). Evaluation of lightning protection systems using rolling sphere and early streamer emission methods on office building. *IOP Conference Series: Earth and Environmental Science*, 830(1), 012019.

[15] Taufiq, M. H., Fitri, A. A., & Yustana, M. (2020). Technical and economic analysis of lightning protection system on a high-rise building. *International Journal of Electrical and Computer Engineering (IJECE)*, 10(6), 6192-6200.

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