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Analysis for Lightning System on PPKA Building Depok Station

Sunardi Sunardi[1], Santi Triwijaya[1], Efendy Prih Raharjo[1], Elysaa Reinaningtyas[1]

[1]Indonesia Railway Polytechnic, JI Tirtaraya, Pojok, Nambangan Lor, Kec. Manguharjo, Madiun, 464788, East Java, INDONESIA

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Abstract

The PPKA building contains vital railway equipment components. In a high level of lightning density, external protection is required to prevent damage due to direct lightning strikes. By raising and changing the position of the spritzer diagonally to a height of 12 meters , the protection radius is 27.42 meters ; by moving one of the splitzer positions in building B and raising it to a height of 9 m, the protection radius is 26 m and 20.7 meters , the same thing is done with a height of 12 meters , the protection radius is 30.6 m and 24.5 meters ; This optimization is able to protect the entire building. Rolling method sphere (RSM) obtained a radius of 60 meters. RSM Prevectron3 S50 obtained a ΔL value of 50 meters with r_{ESE} of 110 meters , while RSM Viking V6 obtained an ΔL value of 70 meters , with $r_{ESE \text{ of}}$ 130 meters , with the design planning option using rolling sphere is able to protect the entire building.

Keyword: Lightning, External Lightning Protection, Ball Rolling Method.

Corresponding Author:

Name: Sunardi Sunardi
Email: sunardi@ppi.ac.id

1. Introduction

External lightning protection systems are designed to protect structures and buildings from the damaging effects of lightning strikes . This system helps direct electrical energy from lightning strikes into the ground to prevent damage to building structures and their occupants [1] . The strike occurs because there is a negative charge at the bottom of the cloud and the induction of a positive charge above the ground surface to form an electric field. The greater the potential difference between the charge on the cloud and the earth's surface, the discharge of the charge in the form of lightning occurs [2] . For cloud-to-ground lightning, different flashback velocities are often reported during the propagation process along the lightning path [3] . Lightning strikes can cause harm to structures, living creatures and surrounding objects, including system failure.

The lightning protection system to protect objects from direct strikes is an external protection system that flows current through the transmission medium to the earth system which consists of an air termination system, a conductor system and an earth termination system [4] . Meanwhile , the internal protection system consists of *arresters , shielding and bonding* [5]. Determining the level of protection in reducing the risk of damage due to direct strikes, the lightning strike density parameter states the

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frequency of lightning striking the earth within one year in an area, expressed in km [2] per year. Calculation of lightning strike density (Ng) is calculated via [6] ,

$$Ng = 0{,}04\, Td^{1{,}25}/km2/per\ year \ \ldots\ldots (1)$$

For the frequency of direct lightning strikes per year (Nd), expressed in equation [6] ,

$$Nd = \ Ng \times Ae \times 10^{-6} \ \ldots\ldots (2)$$

Ae is the ground surface area that is considered a building with the value of the annual frequency of direct lightning strikes. Obtained from [6] ,

$$Ae = ab + 6h(a+b) + 9\pi h^2 \ \ldots\ldots (3)$$

Ae is influenced by other objects or buildings around it a . Then the equivalent coverage area is reduced by the value Xs. Xsobtained through,

$$X_s = \frac{d+3(hs-h)}{2} \ \ldots\ldots (4)$$

A building needs protection from lightning or not if [6], [7] , if $Nd \leq Nc$then no protection is needed and if if then it $Nd \ > \ Nc$needs protection with an efficiency level (E) of;

$$E \geq 1 - \frac{Nc}{Nd} \ \ldots\ldots (5)$$

efficiency value obtained is determined by the level of protection based on,

Table 1. External lightning protection level [8]

Protection Level	Efficiency
I	98 %
II	95 %
III	90 %
IV	80 %

The protection angle method is derived from the ratio of the horizontal distance in radius (r) to the height of the barrier (h), the value of which is proportional to the angle of attack tan ∝ [9], expressed through the equation;

$$tan \propto = \frac{r}{h} \ \ldots\ldots (6)$$

$$r \ = tan \propto \times h \ \ldots\ldots (7)$$

During the time (S) the conductor will flow current (I) from the air termination to the earth termination system, the minimum cross-sectional area of the transmission cable (A) at a certain temperature (T) is [10] ,

$$A = I\sqrt{\frac{8{,}5 \times 10^{-6} \times S}{log10\,(\frac{T}{274}+1)}} \ \ldots\ldots (8)$$

Rolling Sphere Method (RSM) is imagined as an imaginary ball with radius r rolling on an object and the steps for the lightning protection system are as follows [11]

1. Determine the lightning strike distance using equation [11] ,

$$r_s = \ 6{,}7\ i^{0{,}8} \ldots\ldots (9)$$

2. Draw a circle with a radius $r_s$with the center of the circle at the highest part of the building.

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3. Draw an imaginary line on the ground $r_s$surface as high as the left and right sides of the structure and connect it with a straight line.
4. The straight line that cuts the arc of the initial circle is the center point of the next circle.
5. The area outside the new circle located around the structure is a protected area.

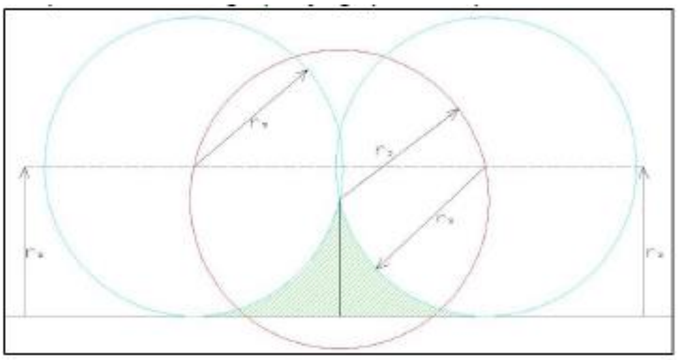

Figure 1. Determination of shaded protected areas

Early air termination system *streamer emissions* installed in buildings must be placed at the highest point of the building or structure. The initial flow emission $\Delta T$is the efficiency value used of 10-60 μs. ΔTthose less than 10 μs are not categorized as early flow emissions. The strike radius of an initial stream emission is the efficiency level $\Delta T$and the strike speed follows the equation,

$$r_{ESE} = r + \Delta L \qquad (10)$$

$$\Delta L = v \times \Delta T \qquad (11)$$

Table 2. Types and specifications of lightning rods

No	Name	Type	Length		Weight		Diameter		Radius	
			Inch(es)	cm	Pounds(s)	Kg	Inch(es)	cm	Yard(s)	m
1	Prevectron3	S60	-	36.5	-	3.9	-	20.0	-	109
		S50	-	36.5	-	3.3	-	20.0	-	98
2	vikings	V6	-	-	-	4.3	-	-	-	109
		V4	-	-	-	4.1	-	-	-	120

Table 3. Placement of air terminations according to level of protection

Protection levels	h(m)	20	30	45	60	Mesh Width (m)
	R(m)	α	α	α	α	
I	20	25	-	-	-	5
II	30	35	25	-	-	10
I, I, I	45	45	35	25	-	10
IV	60	55	45	25	25	20

*) Rolling Sphere and Mesh only apply in this case

2. Research Method

The number of lightning strikes and peak current are identified for fault analysis and maintenance of the external lightning protection system. Grounding in structures is used by foundations to direct lightning currents to the bottom with appropriate resistance [10] . The RSM external protection system based on air termination placement is analyzed and evaluated. The protection angle is increased to 38

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m from the ground to protect against direct lightning strikes, with 4 air terminals capable of protection with a protection radius of 45 m. Antenna elevation uses collection volume analysis [12] . RSM concept with vertical guide rods installed for external lightning protection analysis [5] . The Light Protection Area (LPA) is only verified if a vertical conductor bar is installed with direct impact [7] . The external protection system [13] of the tallest building has a hazard forecast at protection level III, analysis of the angle and radius of protection is capable of meeting the building's needs with just one barrier. The blocking conductor [14] uses BC50 mm ^{2} and 35 mm $^{2\ \text{cables}}$, for earth termination in terms of grounding resistance of 1.6 Ω [10] . Conductor system [15] The diameter used is 50 mm ^{2} , the resistance value of 3.52 Ω - 4.28 Ω is already below 10 Ω so it meets the minimum requirements. The Collection Volume Method (CVM) applies the striking distance which is influenced by the strength of the lightning current, the angle of incidence of the lightning, and the height of the building to be protected.

The total size of the Train page Dispatcher (PPKA: ed.Ind) and Equipment Room (ER) is 27,675 ×17,550 m. With building details , the ER-MDP-PPKA room has a length of 14,675 m, width 9,175 m, height 9.2 m. Furthermore, *the Battery* -Genset-SDSH- *Maintenance Room* building has a length of 27,675 m, width 5,425 m, height 5.2 m. And the total dimensions of the yard are 27,675 x 17,550 m.

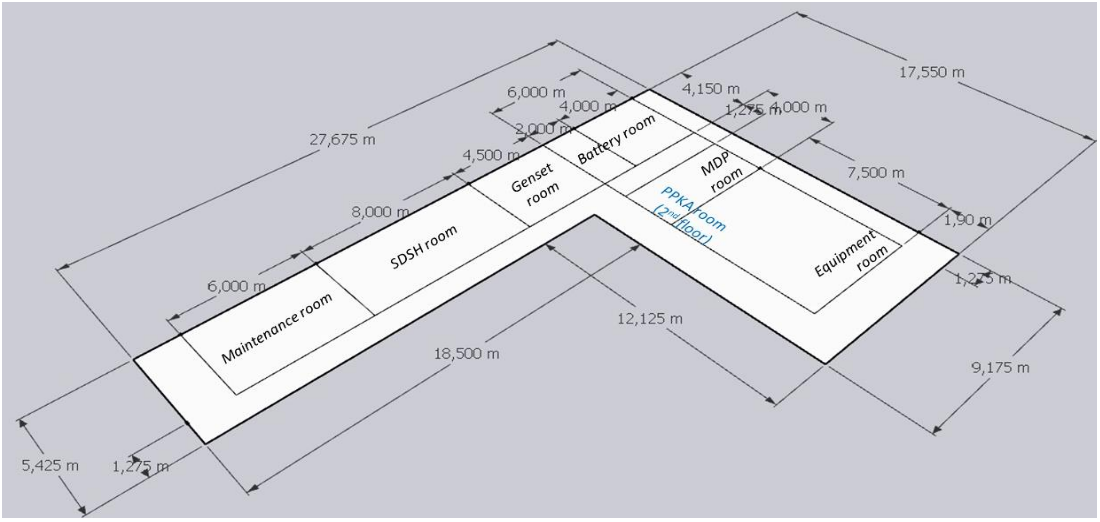

Figure 2. Building size trains dispatcher

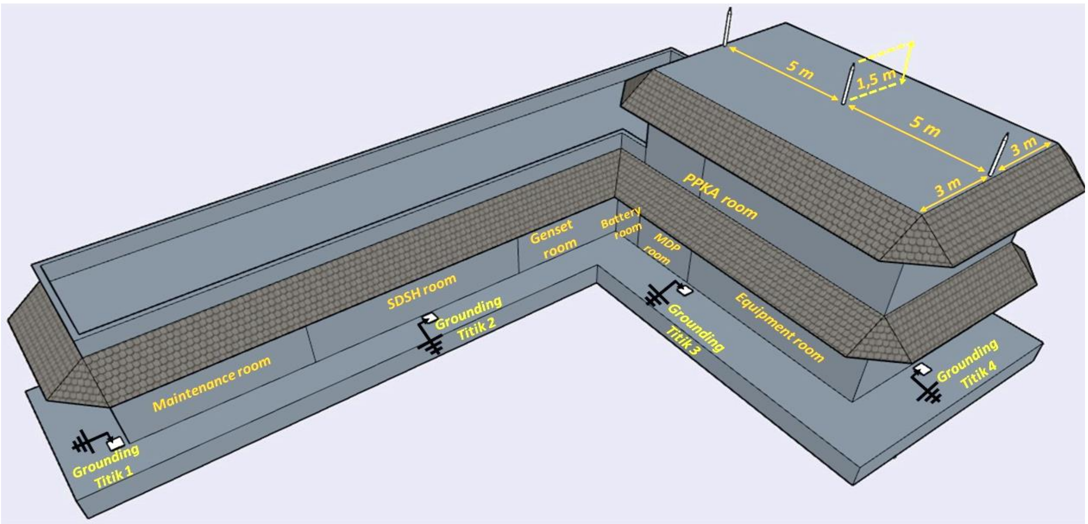

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Figure 3. Existing condition of the train dispatcher building

3. Results And Discussion

A review of building protection needs is obtained by calculating the frequency of direct lightning strikes per year (Nd). The Nd value is obtained from the density value of direct lightning strikes to the ground (N_g) and the equivalent coverage area value (A_e) which is influenced by the influence of the distance of surrounding objects (X_s). The N_g value was obtained using isocheraonic level map data issued by the Meteorological, Climatological, and Geophysical Agency (BMKG) Bogor Station. To analyze lightning strike protection, data on thunder days in the Depok area, West Java, was used. Data processing uses *Lightning Data Processing* software *Nextstorm V.11.0* , entered latitude (-6.405924 ^{o}) and longitude (106.81694 ^{o}) parameters.

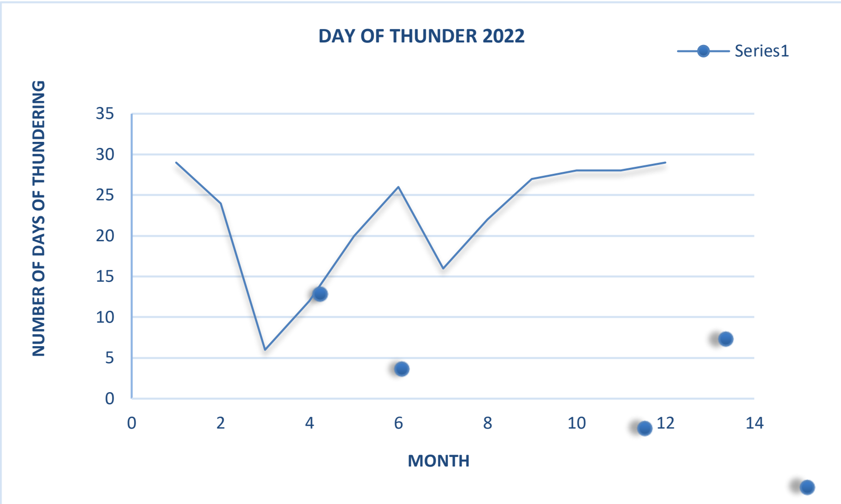

Figure 4. Thunder day Depok area

From the graph above , the value of thunder days (T_d) is 267 days, so that N_g is 43.2 km ^{2}/ years . The A_e value is obtained by carrying out calculations per building section which is calculated based on building section A (ER-MDP-PPKA) and building section B (*Battery* - Genset-SDSH- *Maintenance room*). The value of A_e is also influenced by the value of X_s .

Table 4. A_e values for PPKA building dimensions

No	Building Name	Building Dimensions (m) P	L	T(h)	Roof Dimensions (m) P(b)	L(a)	Q	A_e (m^2)
1	ER-MDP-PPKA	14,675	9,175	9.2	14.1	8.55	1.05	3762,761
2	Sintel	27,675	5,425	5.2	27.05	4.15	1.05	1947,007

Table 5. Details of objects that affect the building

No	Object	Details Distance (m) (d)	Height (m) (hs)	X_s	A_e (m^2)
1	LAA poles	2.74	11	4.07	-
2	Old ER Building	3	8.8	0.9	-
			X_s A_{total}	4.97	3757,791
1	Pole Provider Indosat	20	15	24.7	-
2	Old ER Building	2	8.8	6.4	-

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x s **B** total	31.1	1915,907
A total		**5673.7**

A $_{eTotal}$ value obtained is 5673.7 m2 and the N $_{g}$ value is 43.2 km ^{2}/year, so that the predicted N $_{d}$ value for buildings is 0.245 strikes/km2/year. Buildings need lightning protection because $Nd > Nc$ namely $0{,}245 > 0{,}1$ with an efficiency level E of 59%.

Table 6. Results of review of protection levels

No	Building Name	AeT $_{total}$ (m2) -	Ng (km ^{4}/ year)	Nd (strikes/km ^{2}/ year)	NC (km ^{4}/ year)	E (%)	Protection Level
1	PPKA building	5673.7	43.2	0.245	0.1	59	Level IV

According to the results of the review calculations in Table 6, the building requires lightning protection at protection level IV, namely 80%. According to Table 6 and based on Table 1 the system will protect 80% of all lightning strikes to the ground, while the remaining 20% is a risk.

The air termination used is a conventional lightning rod type, installed at a height of 1.5 meters from the tallest building with 3 *splitzers* , each 5 meters apart . The radius of protection for a conventional barrier can be calculated, with a building height h $_{B}$ of 9.2 m and a barrier height h $_{S}$ of 1.5 m, then we get 10.7 meters . Based on Table 3, the protection angle is 55 ^{o} with a protection radius of 15.3 meters.

Table 7. Specifications for existing air termination calculations

Building	h $_{S}$ (m)	Splitzer N (Pcs)	r(m)	α(^{O})
PPKA	1.5	3	15.3	55

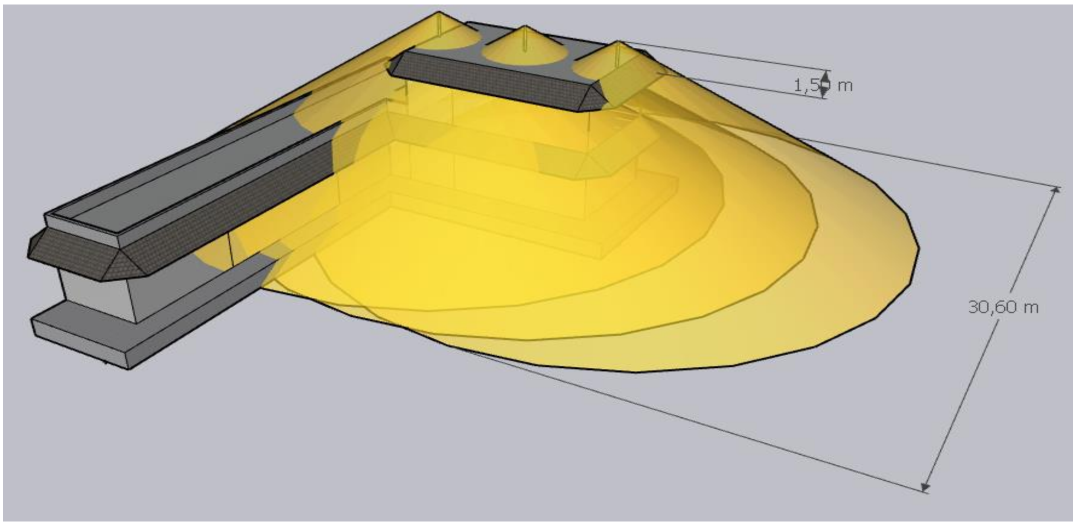

Figure 5. Projection of existing external protection system

The peak lightning current value is obtained from the largest current parameter, negative lightning in sub-tropical areas, worth 40 kA [10] , so that the minimum cross-sectional area of the A conductor used is 45.14 mm ^{2} , while the down conductor used NYA is 50 mm ^{2} copper type [15] which has a current carrying capacity of 5.75 kA and a DC electrical resistance of 0.387 Ω / km or 0.000387 Ω /m [15] . Grounding system existing equipped with *solid copper rod* diameter 19 mm. 4 electrode rods are planted 1.5 meters deep and connected using *bare copper conductor* with a cross-sectional area of 50 mm ^{2}

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and *down* protection cable *conductor* . The connection channel is planted 1 meter deep from the ground and connected parallel to all existing lightning rods. The measured *grounding* value is less than 1 Ω.

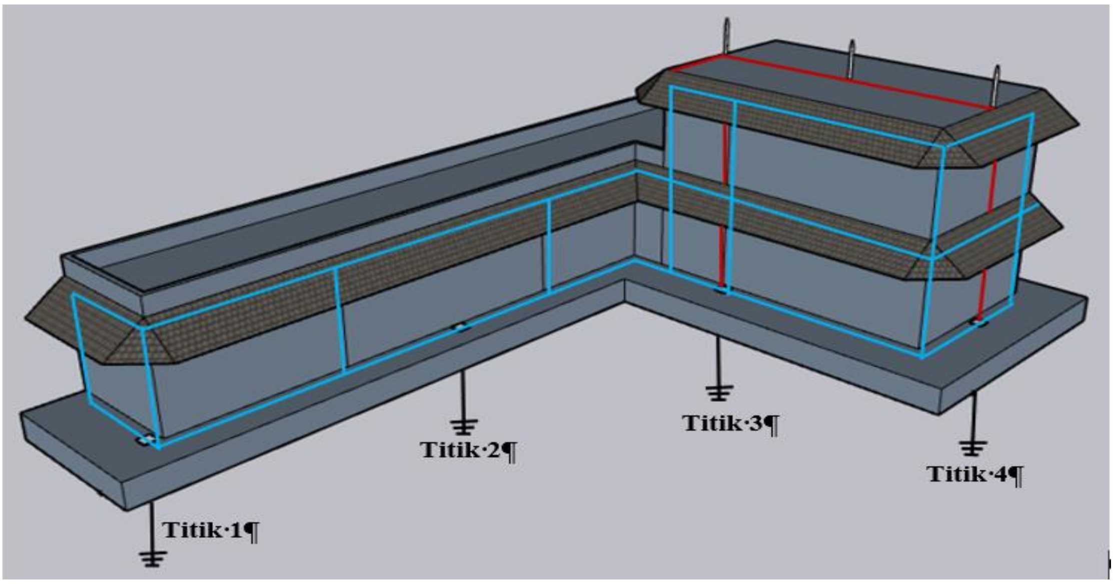

Figure 6. Relationship between protection system and earth termination

Table 8. Grounding measurement results

No	Location	Measurement Results (Ω)
1	Point 1	0.57
2	Point 2	0.20
3	Point 3	0.10
4	Point 4	0.19

For optimization Design 1 , splitzer raised from the position of the existing building as high as 9 meters from 9.2 meters , then a total barrier of 18.2 meters is obtained . The protection radius is $\tan \propto\ = \frac{r}{h}, r\ = \tan 55^{o}\ \times 18{,}2 = 26\ \text{meters}$. Design 2, splitzer raised from the position of the existing building as high as 12 meters from 9.2 meters , then a total barrier of 21.2 meters is obtained. The protection radius r is 30.27 meters. Design, splitzer raised from the existing building position as high as 9 meters and changed position diagonally. Design 4, splitzer raised from the position of the existing building as high as 12 meters and changed position diagonally.

Table 9. PPKA Building splitzer optimization design calculations

Design	Structure	Splitzer h (m)	Splitzer N (pcs)	Radius r(m)	Angle α (^{o})
1	PPKA	18.2	3	26	55
2	PPKA	21.2	3	30.27	55
3	PPKA	18.2	3	26	55
4	PPKA	19.2	3	27.42	55
5	PPKA A	18.2	2	26	55
	PPKA B	12.2	1	20.27	55
6	PPKA A	21.2	2	30.27	55
	PPKA B	17.2	1	24.56	55

Covered area protection and air termination formation for each can be shown in the following pictures.

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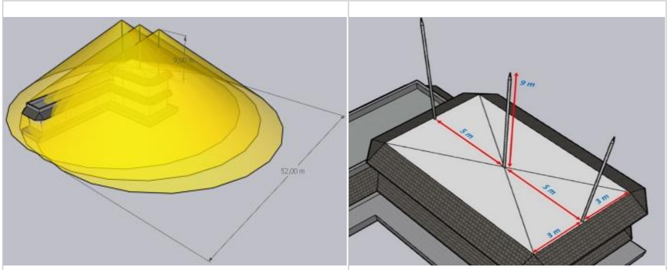
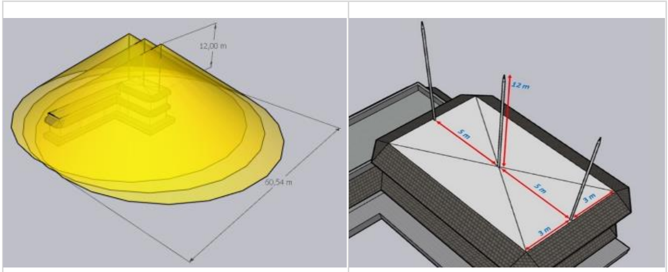


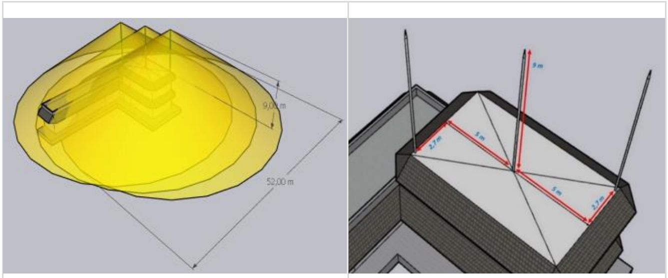
(a) (b)

Figure 7. Optimization design 1 for hight 9 meters, a) covered area protection , b) air termination formation



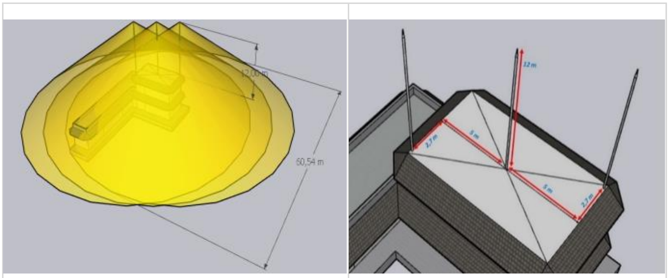
(a) (b)

Figure 8. Design optimization 2 for a height of 12 meters, a) closed area protection, b) air formation termination



(A) (B)

Figure 9. Design optimization 3 for a 9 meter high diagonal model, a) closed area protection, b) air formation termination



(A) (B)

Figure 10. Design optimization 4 for a 12 meter high diagonal model, a) closed area protection, b) air formation termination

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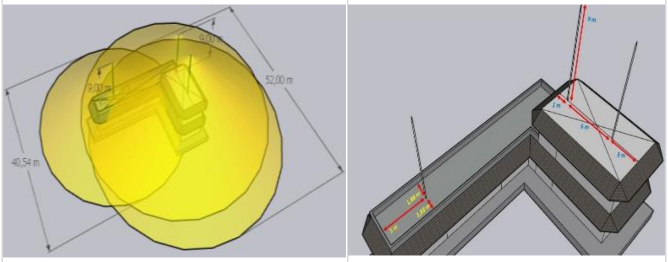
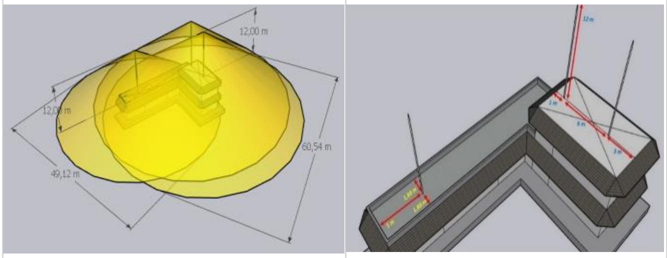
Design 5 , of the 3 splitzers raised 9 meters, 2 remain installed in building A and 1 preventer is moved to building B. So, in building section A, the total splitzer h is 18.2 meters and the radius r is 26 meters. For 1 splitzer in building section B, the total splitzer h is 14.2 meters and the radius r is 20.27 meters.



(A) (B)

Figure 11. Design optimization 5 for a height of 9 meters, a) closed area protection, b) air formation termination

Design 6 , of the 3 splitzers raised 12 meters , 2 remain in building A and 1 is moved to building B. So, in building section A, the total splitzer h is 21.2 meters and the radius r is 30.27 meters. For 1 splitzer in building section B, the total splitzer h is 17.2 meters and the radius r is 24.56 meters.



(A) (B)

Figure 12. Design optimization 6 for a height of 12 meters, a) closed area protection, b) air formation termination

The design principle of the RSM external protection system is to roll a ball with a certain radius around the building to determine the strike point and the protected area formed. From the results of calculating building protection requirements in Table 6 and Table 3, it is obtained that the radius for a PPKA building with protection level IV is 60 meters.

Prevectron3 and Viking6 lightning rods are types of early streamer emission lightning rods. Early device streamer emission is different from conventional lightning rods because it is equipped with a method to increase the efficiency of lightning attraction, thereby expanding the protection range [15]

radius is calculated via the equation; $r_{ESE}\ total = r_s + \Delta L$. The values $\Delta L = v \times \Delta T$, with $v = 1\ m/\mu s$, and values $\Delta T$are obtained from the lightning rod specifications [12] .

Table 10. Final model design calculations for PPKA structure

Plan Design	Model	Final h (m)	Completed (pcs)	r Protection (m)
1	Prevektron3 S50	6	1	110
2	Viking V6	6	1	130

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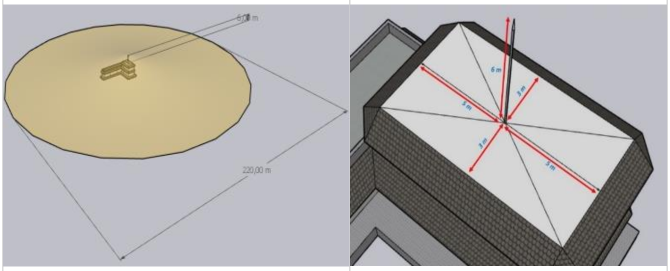
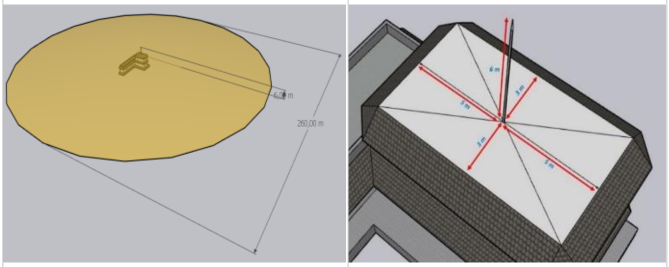
The replacement design for the lightning rod uses the Prevectron3 S50 type, so that the additional strike distance ΔL is 50 meters and the total radius of protection r $_{ESE}$ is 110 meters.



(a) (b)

Figure 13. Design plan 1 for height 6 meters with Prevectron3 S50, a) covered area protection , b) air termination formation

The design uses the Viking V6, adding a striking distance of ΔL of 70 meters and a total radius of protection rESE $_{of}$ 130 meters .



(a) (b)

Figure 14. Design plan 2 for height 6 meters with Viking V6 a) covered area protection , b) air termination formation

Table 4. 1 Comparison of optimization and planning designs

A	**Existing**	**Radius (m)**	**N (pcs)**	**Information**
Conventional barriers are installed at a height of 1.5 m from the highest point of the building		15.3	3	Not yet protected
B	**Design Optimization**	**Radius (m)**	**N (pcs)**	**Information**
1	Elevating *the splitzer* in the existing position to a height of 9 m	26	3	There are parts that are not protected
2	Elevating *the splitzer* in the existing position to a height of 12 m	30.27	3	There are parts that are not protected
3	Raising and changing the position *of the splitzer* diagonally to a height of 9 m	26	3	There are parts that are not protected
4	Raising and changing the position *of the splitzer* diagonally to a height of 12 m	27.42	3	Protected
5	Move one of the *splitzer positions* to building B and raise it to a height of 9 m	26 and 20.27	3	Protected
6	Move one of the *splitzer positions* to building B and raise it to a height of 12 m	30.6 and 24.56	3	Protected

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C	Design Plan	Radius (m)	N (pcs)	Information
1	Rolling Sphere Prevectron3 S50	110	1	Protected
2	Rolling Sphere Viking V7	130	1	Protected

Overall, both in optimization design and planning, the system is able to expand the protection radius. However, in optimization 1-3, there are still parts of the building that are not protected. Meanwhile, optimization 4-6 is able to protect the entire building. Consideration of state height selection splitzer and finial 9 and 12 meters, because increasing the height requires a *state pole* , where *Perstate* in 1 *section* has a length of 3 meters . The conductor is adjusted to the height of each optimization design. In the planning design using RSM Prevectron3 S50, A total protection radius of 110 meters is obtained with just one lightning rod installed 6 meters high from the highest point of the building. Likewise, with the RSM Viking V6, a protection radius of 130 meters is obtained with just one lightning rod installed 6 meters high from the highest point of the building. The use of early type lightning rods streamer emission with RSM Viking V6 has the widest protection radius.

4. Conclusion

The results of the review of building protection needs, with a value of Nd > Nc of 0.245 > 0.1, means that the PPKA building requires lightning protection, with an E value of 59% and is classified as protection level IV with an efficiency level of 80%. Existing conditions, 3 conventional barriers with a protection radius of 15.3 meters cannot protect the entire building. The 50 mm ^{2} conductor system and grounding with 4 19 mm diameter electrodes installed, meets the minimum requirements for a lightning protection system.The optimization design uses the protection angle method by raising *the splitzer* in the existing position , raising and changing the *splitzer* position diagonally, and moving one of the *splitzer positions* in building B, each done with *the splitzer height* set at 9 meters and 12 meters. Meanwhile, the planning design was carried out with RSM using an early type deterrent streamer emissions installed at a height of 6 meters from the highest point of the building. Using the RSM Prevectron3 S50 or Viking V6 only requires replacing one air termination, which can protect the entire building better

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