symmetry

Article

Five-Year Performance of an ESE Lightning Protection System for a Large Scale PV Power Plant in Thailand

Rungphet Kongnok, Thanakorn Pummaitong and Boonyang Plangklang *

Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, 39 Moo 1, Klong 6, Khlong Luang, Pathum Thani 12110, Thailand; rungphet_k@mail.rmutt.ac.th (R.K.); thanakorn_p@mail.rmutt.ac.th (T.P.)
* Correspondence: boonyang.p@en.rmutt.ac.th; Tel.: +66-2-549-3420

Abstract: This article presents a five-year performance review of an early streamer emission (ESE) air terminal lightning protection system for a large scale PV power plant in Thailand. The comparison effect of a Franklin lightning protection system and the ESE lightning protection system was analyzed for the PV power plant. The ESE lightning protection system was selected to be implemented in the PV power plant. The capacity of the PV power plant studied was 8 MWp on an area of 150,000 square meters in the Nong Ya Plong district, Phetchaburi province, Western Thailand. A Franklin lightning rod type was also designed to be implemented in this PV power plant. The Franklin lightning rod type comprised 122 pieces but the ESE lightning rod type consisted of only 11 pieces. The conceptual design of the Franklin rod type followed the standard of the Council of Engineers, Thailand, and the ESE lightning rod type followed the NFC17102 standard of France. The estimated cost of installation was a key comparison to select the lightning protection system; the total installation cost of the Franklin lightning rod type was USD 197,363.80 and the ESE lightning rod type was USD 44,338.06. The lightning system was applied to the lightning arrester in the power plant to provide good protection, in which the balance of the pole to the mounting position is required to optimize the system performance. The result of the simulation also showed that the shading effects of the Franklin rod type were greater than the ESE rod type. The installation cost of the Franklin lightning rod type was 4.45 times more expensive than the ESE lightning rod type. Therefore, the ESE lightning protection system was selected to be implemented in the PV power plant. From the recorded data of the five-year performance of the ESE lightning protection system (2016–2020), there were three occurrences of a lightning strike on the PV power plant. The ESE lightning protection system effectively protected and prevented the lightning strike to the PV power plant. This study can help and support with the selection of a lightning system for the protection of large scale PV power plants in the future.

Keywords: Franklin lightning protection; ESE lightning protection; PV power plant

Citation: Kongnok, R.; Pummaitong, T.; Plangklang, B. Five-Year Performance of an ESE Lightning Protection System for a Large Scale PV Power Plant in Thailand. *Symmetry* **2021**, *13*, 2106. https://doi.org/10.3390/sym13112106

Academic Editor: Mihai Postolache

Received: 14 September 2021
Accepted: 25 October 2021
Published: 6 November 2021

1. Introduction

A solar system is a system that converts energy from sunlight and is widely used today because the cost per unit is reduced. Moreover, the technology makes the performance of the device higher. However, the blocking of light to the solar panel reduces the efficiency taken into account. Therefore, an installation design must avoid the incident light to the solar panel installed. Currently, PV applications include ground-mounted and roof-mounted installations. Building areas for solar panel installation have also been installed in the sea or large water reservoirs for maximum benefit. One thing to consider when installing a PV system is the prevention of lightning strikes on the solar panels, which cause damage to the installed solar power system. Lightning protection is required for the installed solar system of open spaces or high-rise rooves such as outdoor installations. A lightning protection system will cause lightning to come down to the protection system instead of cutting to the installed power system. It is necessary to design a lightning protection system that is suitable for each application. Currently, the lightning protection systems consist of the Franklin air terminal lightning protection system and the streamer emission air terminal protection system. The difference between these two systems is the radius of protection at the same height, in which the ESE system uses a smaller number in the same area. Using this smaller number, the grounding system of the two systems differs accordingly, resulting in the overall installation cost of the lightning arrester. The protection level of the Franklin air terminal lightning protection system at a pole height of 10 m has a protection radius of 21.4 m. An ESE system with a height of 10 m has a protection radius of 109 m. This difference, if installed in the same area, will result in a different grounding system. Lightning is a natural phenomenon that affects people, property and the environment and causes enormous damage such as explosions, fire or death. Therefore, there are various studies to protect against lightning effects. Generally, the damage forms of the lightning strike can be divided into three parts comprising electrical, thermal and mechanical damage. Many researchers have studied the effects of lightning, from which the designs for photovoltaic (PV) power plants and property protection have been proposed [1–6]. Research has been conducted to compare the installation cost of PV power plants [7,8] where the studies included the two types of lightning protection system [9]. There have been studies on the difference between two points of the lightning effects on the PV rooftop [10]. One of the works used a vector modulation technique of equivalence circuits for analyzing the transient generated from the lightning strikes in a PV power plant [11]. There was a study on the structural effects of lightning [12] where a grid ground protection system for supporting lightning strikes was implemented but at a high cost of installation [13]. The effects of lightning have been studied on the change in soil resistivity where lightning affected the reduction of the ground resistance value [14]. The repeating impact of impulse voltage on the panel caused the panel power to decrease accordingly [15]. A study on the risks of installing a PV rooftop system was to ensure that the installation of this system was successful by assessing the risks of various structural systems related to the type of installation on the roof [16]. In [17], the impact of lightning-induced overvoltage on a hybrid solar system using Electro-Magnetic Transient Program-Restructured Version (EMTP-RV) software was presented. This software was developed by investigating the effect of lightning-induced overvoltage by using indirect lightning strikes near to the system. It was found that the induced effects on the system and on the impulse withstanding the voltage of DC and AC systems should be eliminated.

Due to the above information, this paper examines the effects of light obscuring and the initial installation cost of both data systems to determine the installation cost of the lightning protection system of the studied power plants.

2. Theoretical Background

Lightning is caused by transferring electric charges between clouds and the ground. They are: (1) negative from the cloud to earth; (2) positive from the cloud to earth; (3) negative from earth to the cloud; and (4) positive from earth to the cloud. The striking distance or lightning return stroke is defined by the current magnitude of the lightning strike with the rolling sphere as of Equation (1) [4] as follows:

$$i(0,t) = \frac{i_0}{\eta} \times \frac{\left(\frac{t}{t_1}\right)^n}{1+\left(\frac{t}{t_1}\right)^n} \exp\left(\frac{-t}{t_2}\right) \tag{1}$$

where i_0 is the current magnitude of the lightning strike, t_1 is the front time of the lightning strike, t_2 is the decay time of the lightning strike and n is the exponent value (2–10), which can be expressed by Equation (2) [18]:

$$\eta = \exp\left[-\left(\frac{t_1}{t_2}\right)\times\left(n\times\frac{t_2}{t_1}\right)^{\frac{1}{n}}\right]. \tag{2}$$

The design concept of external lightning is defined by using two systems for a design process related to the conventional and ESE system. Therefore, the lightning protection design consists of an air termination system and separator distance. The down conductors, earth termination and lightning equipotential bonding are not focused on in this design.

(A) The conventional system is defined by using IEC/EN 32305 for a design reference related to three methods for protecting the PV power plant.

1. The protective angle method is defined by using the height level of the lightning rod and the angle under shade concept. Therefore, the height level may impact the PV power plant and needs to be defined as the separation distance clearance.
2. The rolling sphere method is a so-called electro-geometric model that is used to exemplify by a radian from Equation (3) [19] to find the air terminator rod position for installation and is applied by using the protective angle method for the PV power plant protection. It has four lightning protection classes related by the calculation of value r. Value r was also used to calculate the position of the lightning rod given in Table 1.

$$r = 10\times I^{0.65} \tag{3}$$

where r is the rolling sphere radian and I is the current magnitude of the current strike.

Table 1. IEC/EN 32305 class of the protection level.

Class of Lighting Protection Zone (LPS)	Radius of the Rolling Sphere (r)
I	20 m
II	30 m
III	45 m
IV	60 m

3. The mesh method is used to design the lightning protection on the flat and complex shape of the building or infrastructure. The mesh method is defined by the dimension of the mesh, which is related to the lightning protection level.

(B) The ESE system is defined by using the French NFC17102 standard on the ESE rods. This method is designed using the rolling sphere concept but is different from the rolling sphere radius dimension that still uses a rolling sphere plus the upward streamer. Therefore, the protection radius of the ESE is presented to the height relative to the surface or area. It is shown in Table 2 that the protective zone is computed as follows:

$$R_p(h) = \begin{cases} \sqrt{2rh - h^2 + \Delta(2r+\Delta)} & ;\in h \geq 5\ m. \\ h\times R_p(5)/5 & ;\in 2m. \leq h \leq 5\ m \end{cases} \tag{4}$$

where $R_p(h)$ is the rolling sphere radian at a given height (h), h is the height of the ESE over the protection zone, r is the radius of the rolling sphere (Table 2) and Δ is the earlier upward streamer with a simple rod by the addition of ΔT that equals $\Delta = \Delta T \times 10^6$.

Table 2. Calculation of the lightning radius protection.

Lightning Radius Protection			
Lightning Protection Level, h (m)	**1 (D = 20 m)**	**2 (D = 45 m)**	**3 (D = 60 m)**
2	32	39	43
3	48	59	65
4	64	78	86
5	79	97	107
10	79	99	109
15	80	101	111
20	80	102	113
45	80	105	119
60	80	105	120

(C) The separation distance of the lightning protection is computed using Equation (5) [19] and is related to the distance between the lightning protection pole or rod and the PV structure as shown in Figure 1. It can be expressed as follows:

$$S = \frac{k_i \times k_c}{k_m} \times l \quad (5)$$

where S is the separation distance, k_i depends on the selected class of the lightning protection zone (LPS), k_c is the lightning current flowing through the down conductor, k_m is the material of the electrical insulation and l is the length along with the air terminal system or the down conductor from the point of the separation distance.

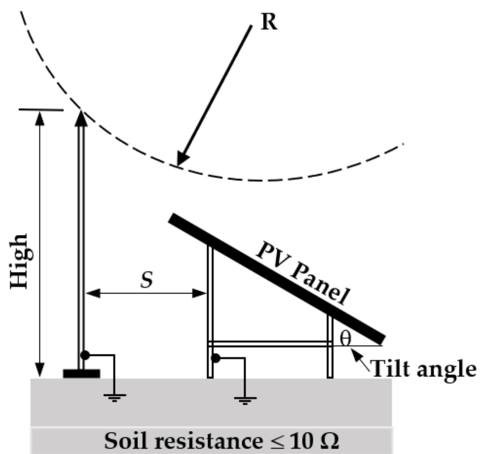

Figure 1. Separation distance of the lightning protection system [20].

(D) The lightning strike frequency (LSF) is used to determine the LPS. The LSF is computed using the lightning flash density and the equivalent area for protection. It can be expressed as follows [9]:

$$N_d = N_g \times A_e \times C_1 \times 10^{-6} \quad (6)$$

where N_g is the yearly average flash density in the region where the structure is located or positioned to protect, as shown in Figure 2, and A_e is the equivalent area of the structure. It can be computed by the sizing of the structure in a wide (W), long (L) and height level (H) by using Equation (7) [9]:

$$\left(LW + 6H(L+W) + \pi 9H^2\right). \tag{7}$$

C_1 is the environmental coefficient.

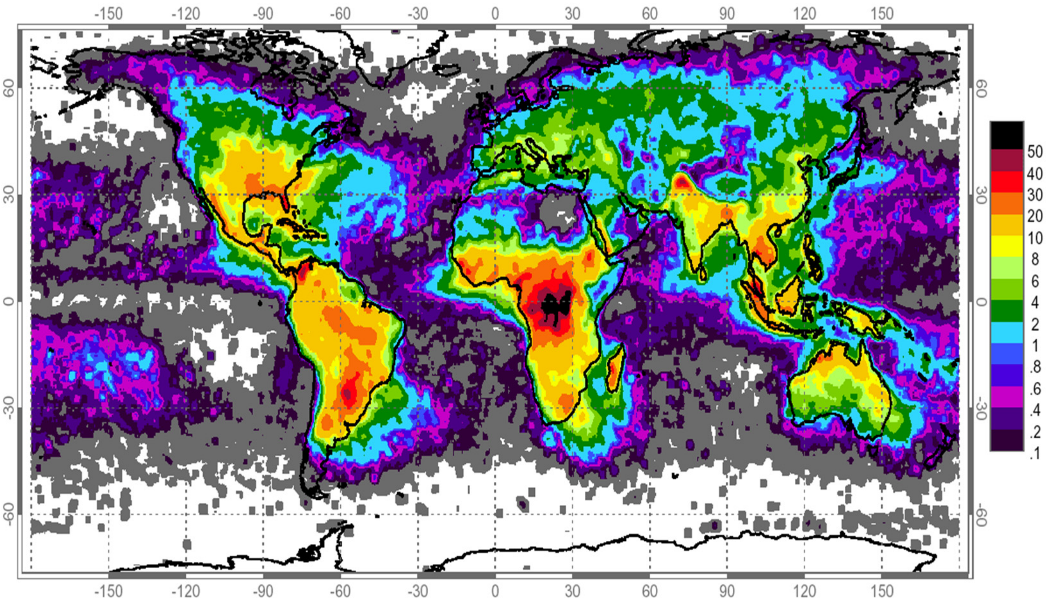

Figure 2. Yearly average flash density of the world [21].

The occurrence of lightning in the world is recorded as a statistic as shown in Figure 2. Thailand has approximately 30 lightning strikes/square kilometer/year. Therefore, to prevent the damage to the PV power plant, it is necessary to correctly design the effective lightning protection systems.

3. The External Lightning Protection Design for the PV Power Plant

This paper needs to be presented by using the field installation that is related to the economic and performance ratio (PR) of the PV power plant. The impact of the LPS is related to the shading in the daytime. It is directly affected by the power generation of the PV power plant. The number of lightning rods of the conventional type and ESE is needed to be studied to evaluate the optimal conditions and capital costs. The location of the PV power plant in this study is in the Nong Ya Plong district, Phetchaburi province, Thailand. The area of the PV power plant is 150,000 square meters on a latitude of 13.108121° N and a longitude of 99.700025°, as shown in Figure 3. The PV power plant lightning design used the ESE lightning NFC17102 standard of France. The PV power plant lightning protection was designed by a polling sphere method within the PV power plant area. The properties around are 5 m tall so the highest pole of the lightning protection of the PV power plant is 9 m for the general protection of the building and surrounding properties. Figure 4 is the ESE lightning rod type. The radius of the lightning protection is 107 m, as shown in Figure 5. Therefore, the performance ratio (PR) and the shading effect used by the PVsyst program simulation were used for the analysis of the effect on power generation of the PV power plant. Figure 5 also shows the position of the ESE lightning rod type in the PV power plant. There are 11 ESE lightning rods in total for the PV power plant. Figure 6 is the Franklin lightning rod type. Figure 7 shows the position of the Franklin lightning rod type as installed in the PV power plant.

Figure 3. Location of the implementation of the PV power plant [22].

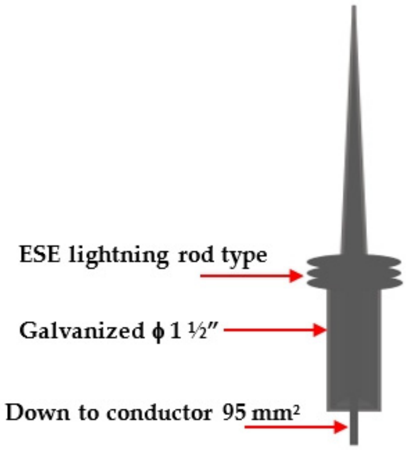

Figure 4. ESE lightning protection rod type.

The ESE lightning protection rod type was used in the selected PV power plant. The ESE lightning protection rod was designed according to the reference of the standard.

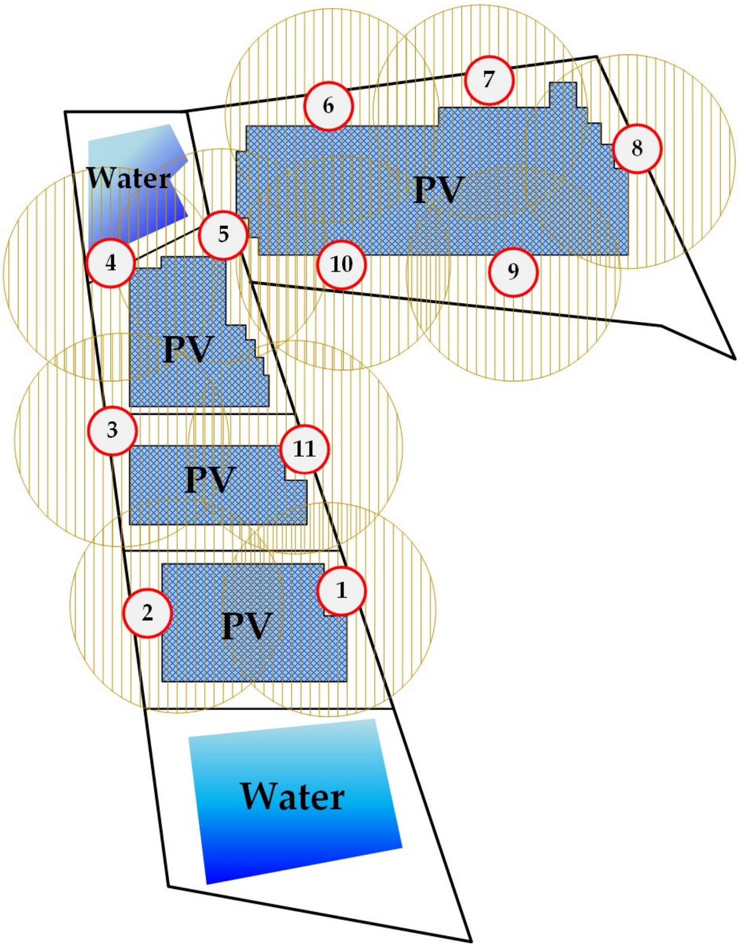

Figure 5. Design of the ESE rod system in the PV power plant.

The positioning design of the ESE lightning protection rod type was used in the PV power plant. The distance pole of the ESE lightning protection rod has a radius of lightning protection is 107 m.

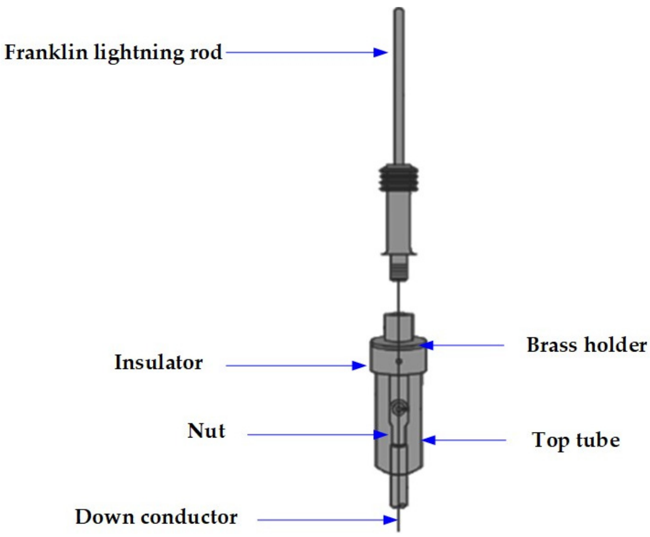

Figure 6. Franklin lightning rod type.

Figure 6 is the Franklin lightning protection rod type, which was used for the simulation in the PV power plant. The Franklin lightning protection rod was designed according to the reference of the standard.

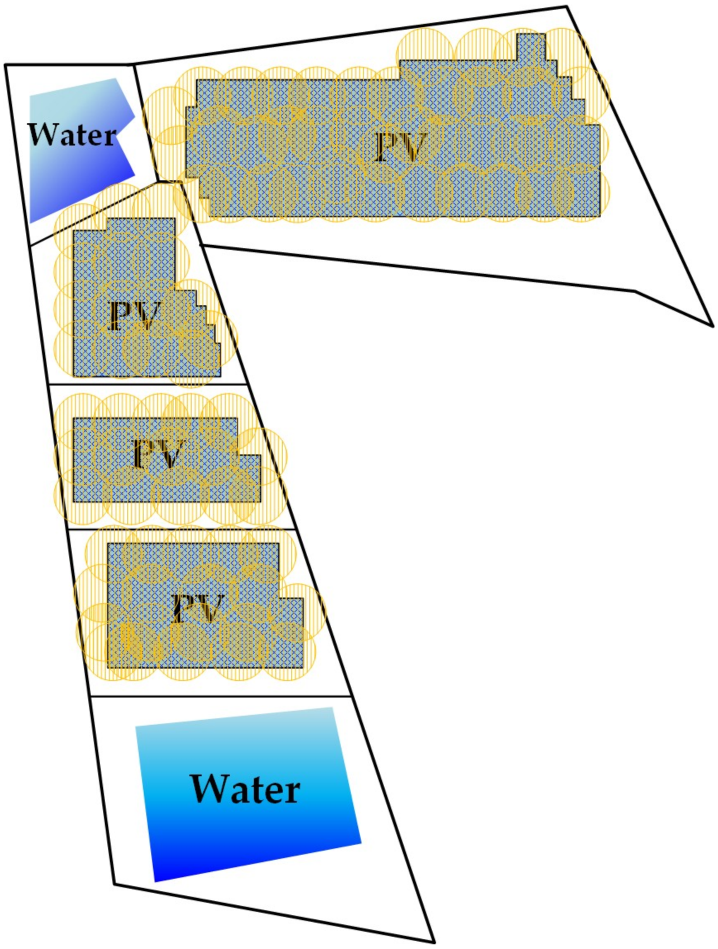

Figure 7. Design of the Franklin rod system in the PV power plant.

The positioning distance of the Franklin lightning protection rod type simulation was designed for comparison to the ESE lightning protection rod.

Figure 8 is the lightning counter for counting the lightning events at the PV power plant.

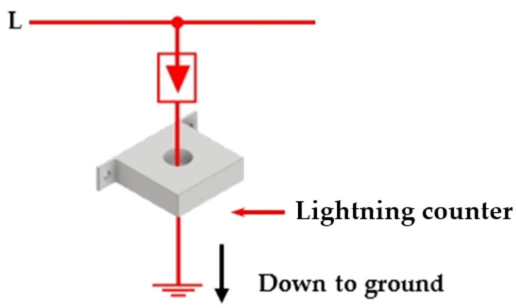

Figure 8. The lightning counter.

4. Results

A computer program simulation was used to simulate the effects of shading on the PV power plants. In this study, the simulation was based on two types of lightning protection in an 8 MWp PV power plant. The simulation consisted of the ESE lightning protection type and the Franklin lightning protection type. The ESE lightning protection simulation used 11 rods with a height of 9 m. The design was based on level 3 for protection and NFC17102 standard; the distance length of the ESE lightning type was about 107 m, as shown in Figure 9. The Franklin lightning protection simulation used 122 rods with a height of 10 m and the design was based on level 4 for protection of the standard of the Council of Engineers, Thailand. The distance length of the ESE lightning type was about 21.4 m, as shown in Figure 10. The simulation result of the PVsyst program showed that the shading of the PV power plant with the ESE lightning protection could produce energy of 13,107,000 kWh/year. Therefore, the PR of the PV power plant was 78.9% and the effect of shading on the PV power plant was 0.72%. The PV power plant with the Franklin lightning protection could produce energy of 13,096,000 kWh/year. The PR of the PV power plant was 78.8% and the effect of shading on the PV power plant was 0.80%. The installation cost was the key issue for the investment cost to allow for the best payback period. This section shows the investment cost comparison between the ESE lightning protection and the Franklin lightning system, as shown in Tables 3 and 4. Table 3 shows the installation cost, which revealed that the total cost of the ESE lightning was USD 41,500.00 and the total cost of the Franklin lightning was USD 79,363.10. The cost of the ESE lightning system was lower than the Franklin lighting system by about 2.346 times. Table 4 shows the installation cost, which found that the total cost of the ESE lightning grounding system was USD 2838.06 and the total cost of the Franklin lightning grounding system was USD 100,000.70. It was found that the ESE lightning system was lower than the Franklin lighting system by 35.24 times. Table 5 shows the installation cost, which found that the total cost of the ESE lightning was USD 44,338.06 and the total cost of the Franklin lightning was USD 179,363.80. It was found that the total costs of the ESE lightning system were lower than the Franklin lighting system by 4.451 times. The ESE lightning protection was used because of the best result of the simulation and the lower installation costs. The data record showed that there were only three occasions of a lightning strike on the PV power plant in the previous five years, as shown in Table 6. From the Table 6 result in 2017 there were two lightning strikes at poles 4 and 5 and one in 2018 with lightning strikes at pole 5. From the obtained results, the lightning strikes within the PV power plant and the ESE lightning protection could protect from the lightning strikes effectively.

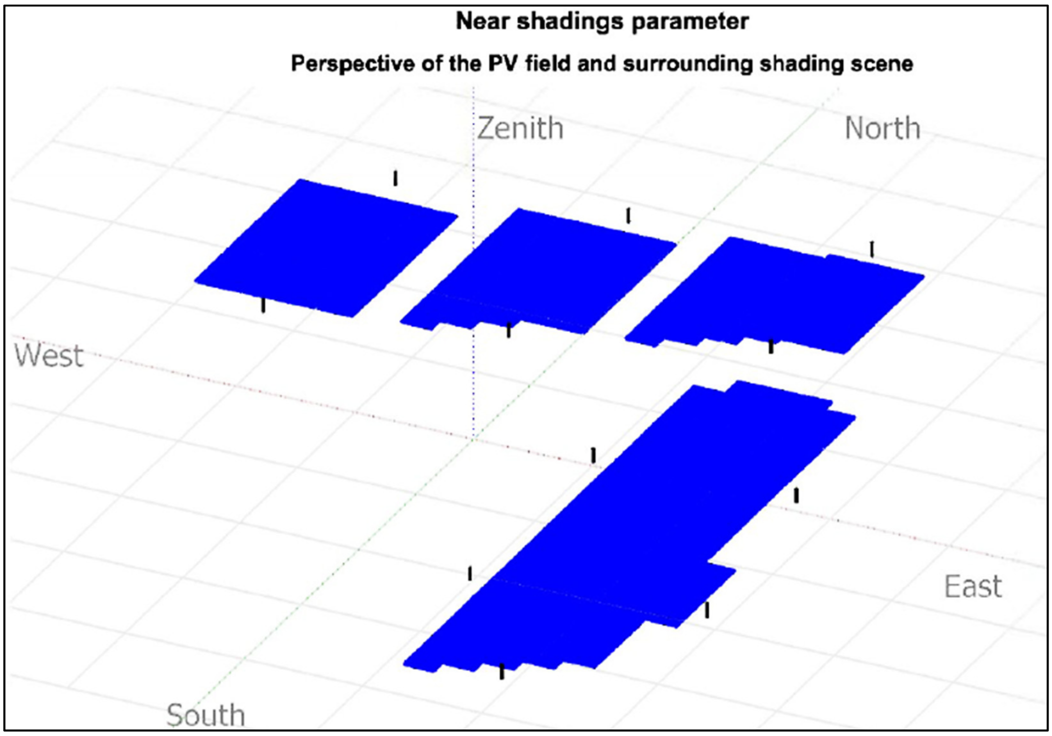

Figure 9. ESE lightning protection shading simulation [23].

Figure 9 is the lightning simulation design by the PVsyst program following the position distance of the ESE lightning poles in the PV power plant.

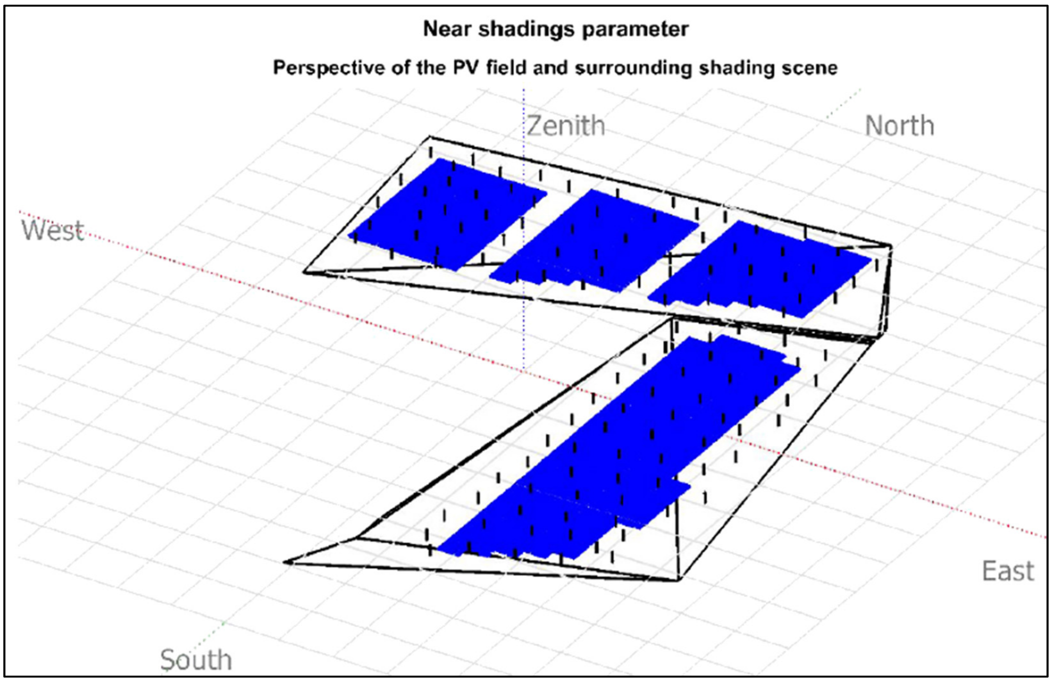

Figure 10. Franklin lightning protection shading simulation [23].

Figure 10 is the lightning simulation design by the PVsyst program following the position distance of the Franklin lightning poles in the PV power plant.

Figure 11 is the ESE lightning rod type installation at the PV power plant. The ESE lightning pole was installed as the design in the PV power plant.

Table 3. Comparison of the investment costs of the lightning system.

Details	ESE Lightning System (USD)	Franklin Lightning System (USD)
Lightning rods	36,666.67	7393.64
Copper cable # 95 mm2	3333.33	36,363.36
Lightning counters	833.33	9242.42
Galvanized mast height 9 m	2333.33	25,878.78
Installation cost	1666.67	18,484,85
Total costs	44,833.33	78,878.20

Table 4. Comparison of the investment costs of the grounding system.

Details	Units	ESE Lightning System (USD)	Franklin Lightning System (USD)
Copper cable # 95 mm2	1 m	1000.00	44,363.64
Copper rod 5/8″ × 10 ft	1 set	1350.00	44,918.18
Installation accessories	1 set	235.00	897.88
Installation cost	1 work	253.06	9821.00
Total costs		2838.06	100,000.70

Table 5. Comparison of the total investment costs of the lightning protection system.

Details	ESE Lightning System (USD)	Franklin Lightning System (USD)
Lightning rods	44,833.33	78,878.20
Ground systems	2838.06	100,000.70
Total costs	47,671.39	178,878.90

Figure 11. ESE lightning installed at the PV power plant.

Table 6. Lightning event at the PV power plant.

Year	Lightning Protection Poles										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2016	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	**1**	**1**	0	0	0	0	0	0
2018	0	0	0	0	**1**	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0

Table 6 is the 5 years record of lightning events at the monitored PV power plant. In the past 5 years, there have been 3 lightning incidents as follows: in 2017 on pole number 4, 5 and in 2018 at pole 5. The ESE lightning protection system can protect the PV power plant effectively.

5. Discussion and Conclusions

The article studied the comparison simulation and analysis result of the lightning effects at a PV power plant. The simulation program showed that the shade effects of the PV power generation as the simulation of the ESE lightning protection system was about 0.72% [23] and the Franklin lightning protection system was about 0.80% [23]. We designed and tested the lightning protection system to achieve the secure protection of the coverage of the solar plant area. It was a small area that did not use a lot of protective heads. The rod positions required a symmetrical installation to ensure effective lightning protection at the solar power plants. The symmetrical lightning rod positioning allowed for lightning protection across the entire solar power plant. The installation location of both the ESE lightning rods and the Franklin lightning rods required a balanced position of the lightning rod to optimize the performance of the lightning rod. However, the distance of the shielding radius must be properly overlapped to effectively protect the solar power plant. This depends on the maximum protection radius of the chosen lightning arrester. For example, the protected distance must overlap in a balance, as shown in Figures 7 and 9. It can be seen that the radius of the two protection balance systems overlapped each other to provide the maximum protection performance of the system. The installation costs of the ESE lightning protection system were less than the Franklin lightning protection system by 4.45 times, in which the loss was lower than the shadow one. The installation costs of the PV power plant were used in the application of the ESE lightning protection system. The lightning in the study was measured over five years and found that lightning occurred at poles 4 and 5 in 2017 and pole 5 in 2018. The ISI lightning system could prevent the damage of the power plants and other electrical equipment. It can be concluded that choosing an ESE can protect the lightning system and the installation costs were reduced as well. The studies can help support a lightning arrester system chosen for property protection. The lightning protection of the 8 MWp PV power plant area was 150,000 square meters in the Nong Ya Plong district, Phetchaburi province. The lightning protection consisted of 122 pieces with the Franklin rod type and 11 pieces with the ESE rod type. These were simulated with the Franklin rod type following the Council of Engineers, Thailand, standard and the ESE lightning rod type following the NFC17102 standard of France. The estimated costs of installation were used for a comparison and found that the total costs of the installed Franklin rod type used USD 178,878.90 and the ESE rod type used USD 47,671.39. The information obtained from this study can be used by investors to make decision for choosing a low-cost lightning protection system for PV power plants in the future.

Author Contributions: R.K.: conceptualization, methodology, software, writing original draft preparation, formal analysis; T.P.: investigation, validation, writing review; B.P.: conceptualization, editing, visualization, supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. KernF, A.; Krichel, F.; Mueller, K. Lightning Protection Design of a Renewable Energy Hybrid-System Without Power Mains Connection. *Soc. Automot. Eng.* **2001**, *1*, 2932.
2. Kokkinos, N.; Christofides, N.; Charalambous, C. Lightning Protection Practice for Large-Extended Photovoltaic Installations. In Proceedings of the 2012 International Conference on Lightning Protection (ICLP), Vienna, Austria, 2–7 September 2012.
3. Yamamoto, K.; Takami, J.; Okabe, N. Overvoltages on DC Side of Power Conditioning System Caused by Lightning Stroke to Structure Anchoring Photovoltaic Panels. *Electr. Eng. Jpn.* **2014**, *187*, 29–41.
4. Zaini, N.H.; Ab-Kadir, M.Z.A.; Izadi, M.; Ahmad, N.I.; Radzi, M.A.M.; Azis, N.; Hasan, W.Z.W. On the effect of lightning on a solar photovoltaic system. In Proceedings of the 2016 33rd International Conference on Lightning Protection (ICLP), Estoril, Portugal, 25–30 September 2016; pp. 1–4.
5. Zaini, N.H.; Ab-Kadir, M.Z.A.; Radzi, M.A.M.; Izadi, M.; Azis, N.; Ahmad, N.I.; Nasir, M.S.M. Lightning Surge Analysis on a Large Scale Grid-Connected Solar Photovoltaic System. *Energies* **2017**, *10*, 2149.
6. Karim, M.R.; Ahmed, M.R. Lightning Effect on a Large-Scale Solar Power Plant with Protection System. In Proceedings of the 2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), Dhaka, Bangladesh, 3–5 May 2019.
7. Tan, P.H.; Gan, C.K. Methods of Lightning Protection for the PV Power Plant. In Proceedings of the 2013 IEEE Student Conference on Research and Development, Putrajaya, Malaysia, 16–17 December 2013; pp. 221–226.
8. Hunt, H.; Nixon, K.; Naudé, J. Using lightning location system stroke reports to evaluate the probability that an area of interest was struck by lightning. *Electr. Power Syst. Res.* **2017**, *153*, 32–37. https://doi.org/10.1016/j.epsr.2016.12.010.
9. Lee, S.W.; Roh, M.S. Application of Early Streamer Emission (ESE) Air terminal in Lightning Systems of NPP. In Proceedings of the Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, 24–25 October 2013.
10. Nasir, M.S.M.; Ab-Kadir, M.Z.A.; Radzi, M.A.M.; Izadi, M.; Ahmad, N.I.; Zaini, N.H. Lightning performance analysis of a rooftop grid-connected solar photovoltaic without external light-ning protection system. *PLoS ONE* **2019**, *14*, e0219326.
11. Zhang, Y.; Chen, H.; Du, Y. Lightning protection design of solar photovoltaic systems: Methodology and guidelines. *Electr. Power Syst. Res.* **2019**, *174*, 105877.
12. Damianaki, K.; Christodoulou, C.A.; Kokalis, C.C.A.; Kyritsis, A.; Ellinas, E.D.; Vita, V.; Gonos, I.F. Lightning Protection of Photovoltaic Systems: Computation of the Developed Potentials. *Appl. Sci.* **2021**, *11*, 337.
13. Zhang, Y.; Li, B.; Du, Y.; Ding, Y.; Cao, J.; Lv, J. Effective Grounding of the Photovoltaic Power Plant Protected by Lightning Rods. *IEEE Trans. Electromagn. Compat.* **2021**, *63*, 1128–1136.
14. Hu, W.; Yu, S.; Cheng, R.; He, J. A testing research on the effect of conductive backfill on reducing grounding resistance under lightning. In Proceedings of the 2012 International Conference on Lightning Protection (ICLP), Vienna, Austria, 2–7 September 2012; pp. 1–4.
15. Jiang, T.; Grzybowski, S. Impact of lightning impulse voltage on polycrystalline silicon photovoltaic modules. In Proceedings of the 2013 International Symposium on Lightning Protection (XII SIPDA), Belo Horizonte, Brazil, 7–11 October, 2013; pp. 287–290.
16. Holland, I.; Doorsamy, W.; Nixon, K. Computational Methodology for Lightning Risk Assessment of Small-Scale Rooftop Photovoltaic Systems. In Proceedings of the 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Palermo, Italy, 12–15 June 2018; pp. 1–6.
17. Ahmad, N.; Ali, Z.; Kadir, M.A.; Osman, M.; Zaini, N.; Roslan, M. Impacts of Lightning-Induced Overvoltage on a Hybrid Solar PV–Battery Energy Storage System. *Appl. Sci.* **2021**, *11*, 3633. https://doi.org/10.3390/app11083633.
18. Izadi, M.; Ab Kadir, M.Z.A.; Hajikhani, M.; Rameli, N. Effects of Lightning Current and Ground Conductivity on the Values of Vertical Electric Fields. *J. Teknol.* **2013**, page 33-36.~~*64*~~. https://doi.org/10.11113/jt.v64.2097.
19. DEHN. *Lightning Protection Guide*; DEHN: United Kingdom,UK, 2021.
20. Charalambous, C.A.; Kokkinos, N.D.; Christofides, N. External Lightning Protection and Grounding in Large-Scale Photovoltaic Applications. *IEEE Trans. Electromagn. Compat.* **2013**, *56*, 427–434. https://doi.org/10.1109/TEMC.2013.2280027.
21. The Lightning Map. Available online: https://earthobservatory.nasa.gov/images/2002/where-lightning-strikes (accessed on 10 March 2021).

22. The Implementation PV Power Plant. Available online: https://www.google.com/maps/place/13°06′28.8″N+99o42′00.0″E (accessed on 5 March 2021).
23. PVsyst 7 Professional Licenses, V7-626d26b3859a13b58fa910bab3f1dd7f, 5/05/2021 to 15/05/2022.