Study of the Effectiveness of Lightning Protection System on 1 MWp Bangli Solar Power Plant

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Keywords: Early Streamer Emission, Lightning Protection System, Solar Power Plant, Franklin Rod.

Abstract: Protection against the danger of lightning strikes is a crucial thing to consider for a large-scale solar power plant. In this paper, a study of Franklin rod type for lightning rods is carried out, installed at the height of 15 meters to protect solar power plants with a land area of 1.8 ha. Franklin rod type lightning rod has cone-shaped protection with 112^{o} protection used as the basis for studying the effectiveness of protection. This research aim is to find area of existing protection and propose recommendations for a protection system against lightning hazards using an early streamer emission (ESE) system with a radius-shaped protection system. Using an ESE radius of 150 meters, a study of its effectiveness found that it propounds in protecting the solar power plant in Bangli from the influence of lightning surges. this existing LPS is not enough to protect all areas of the plan. For grounding system, it is recommended to install two electrodes with a length of 3 meters and a diameter of 5/8 inch.

1 INTRODUCTION

Lightning Protection Systems (LPS) is an indispensable tool in protecting buildings and electrical systems from the dangers of lightning strikes. Lightning strikes also affect the solar module (Moor, 1999), other equipment such as inverters (Smith, 1998), and the operator. So it is crucial to applies this LPS to the Bangli Solar Power Plant (BSPP) located in Kayubihi Village, Bangli District, Bangli Regency. This on-grid BSPL has no battery and occupies 1.8 ha, where 80% of its area is for solar module installation. There are 278 PV arrays, using 5005 monocrystalline solar modules with a maximum power of 200 watts per module. Another part of the BSPP is module buffers with a slope of 13-150, 50 units of inverter type SG20KTL with a capacity of 20 kVA, array protection panels, distribution panels, step-up transformers, and lightning protection. BSPP is always in an open area without being blocked by trees and buildings so that solar radiation as a source of BSPP energy can directly hit the surface of the solar panels. With conditions like this, the existence of BSPP, especially large-scale ones, is very vulnerable to the danger of lightning strikes. As a tropical country, Indonesia has a high evaporation rate, with 200 lightning strikes per year per km2 or the thunderstorm days or the number of or IKL (Iso Crounic level). The magnitude of this IKL indicates the possibility of losses incurred in each strike. In BSPP, these losses can damage buildings, equipment (solar panels, inverters) (Moore, 1999), data networks and even threaten the lives of living things.

Some equipment such as inverters in BSPP has a protection part for over or low voltage problems, anti-islanding, overheating, and lightning protection. The preliminary study found the damage of 30 units of inverter due to a lightning problem. There is only a conventional lightning rod with a Rods system or rod-type by placing a lightning receiving conductor rod in a tower covering the entire BSPP area, which is quite

Figure 1: Layout of the Solar Energy Plant.

Sugirinta, I., Saputra, I., Mudiana, I. and Ta, K.
Study of the Effectiveness of Lightning Protection System on 1 MWp Bangli Solar Power Plant.
DOI: 10.5220/0010950500003260
In *Proceedings of the 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2021)*, pages 650-656
ISBN: 978-989-758-615-6; ISSN: 2975-8246

large. The damage to the inverter, solar module, and the installation in this plant might be due to the condition of external lightning protection, so it is necessary to evaluate the effectiveness of the existing LPS in BSPP.

2 LIGHTNING PROTECTION SYSTEM

2.1 Lightning Strikes Problems

Lightning strikes can cause damage and result in a loss effect for objects, including:

2.2.1 Direct Lightning Strike against Buildings

Lightning strikes directly hit the structure of houses, offices, and facilities. This lightning is very dangerous for the construction and its contents because it may cause fire, damage to electrical/ electronic devices, or even fatalities. Therefore, every building is required to install a lightning rod installation. The way to handle it is by installing a lightning strike receiving terminal and other supporting facilities following predetermined standards. Moreover, if a lightning strike directly hits a human, it can result in injury or disability and even cause death. There are so many incidents of direct lightning strikes that hit humans and usually occur in open areas.

2.2.2 Lightning Strikes through the Electricity Network

The danger of this strike is when it hits something outside the building area but impacts the electricity network inside the building. The electrical system's striking effect occurs when the electricity distribution network system uses open-air cables located at a high place. If lightning strikes this open cable, the high current will flow to consumer devices directly. The way to handle it is by installing an arrester device as an overvoltage safety device. The installation of this electric surge arrester must be connected to a grounding system.

2.2.3 Strikethrough Telecommunication Network

The danger of this type of lightning strike is almost the same as the second one but impacts telecommunications equipment, such as telephones and PABX. Installing a special arrester for the PABX network with a grounding system can eliminate the lightning strike. If the building to be protected has an internet network via a telephone network, this tool can also preserve the internet network.

2.2 Effects of Lightning Strike

Lightning strikes can cause various effects on the struck object, namely:

a. Electric Effect

When a lightning current passes through a conductor) to the resistance of the earth electrode of a lightning rod installation, it will cause a resistive voltage drop, which can immediately increase the voltage of the protection system to a high value compared to the earth voltage. This lightning current also creates a high voltage gradient around the electrode's earth, which is very dangerous for living things. Applying the inductance of the protection system can reduce the steepness of the lightning pulse waveform. Thus, the voltage drop in the lightning protection system is the arithmetic sum of the resistive and inductive voltage components.

b. Translucent – Side Effects

Lightning strike points in lightning protection systems can have higher voltages against nearby metallic elements. Therefore, there will be a risk of breakdown voltage from the lightning protection system that has been installed to other metal structures. If this breakdown voltage occurs, some of the lightning currents will propagate through the internal parts of metal structures such as iron pipes and wires. This breakdown voltage can cause a hazardous risk for the contents and framework of the building structure to be protected.

c. Thermal Effects

In the case of lightning protection systems, the thermal effect of a lightning discharge is limited to the rise of the conductor's temperature through which the lightning current passes. Although the current is large quickly, its impact on the lightning protection system is usually negligible. In general, the cross-sectional area of the lightning rod installation conductor is chosen primarily to meet the mechanical quality requirements, which means it is large enough to limit the temperature rise to 1 degree Celsius.

d. Mechanical Effects

If the lightning current passes through the parallel supply cable (conductors) that are close together or on a conductor with a sharp bend will cause a large enough mechanical force. Therefore, a sufficiently mechanical solid bond is required. Another mechanical effect of a lightning strike is caused by a sudden rise in air temperature to 30,000 K and causing an explosive expansion of air around the moving charge path. This effect is because if the conductivity of an electric arc replaces the conductivity of the metal, the energy generated will increase hundreds of times, and this energy can cause damage to the protected building structure.

e. Fire Effect Due to Direct Strike

There are two leading causes of flammable material fires due to lightning strikes, firstly due to direct strikes on flammable materials storage facilities. These volatile materials may be directly affected by the heating effect of the lightning strike or the path of the lightning strike. Both secondary effects are the cause of oil fires. It consists of confined charges, electrostatic and electromagnetic pulses, and ground currents.

f. Stuck Load Effects

The cloud storm induces this static charge as opposed to other loading processes. Suppose the charge neutralization process ends and the strike path is neutral again. In that case, the trapped charge will be left on objects isolated from direct electrical contact with the earth and on non-conducting materials such as combustible materials. Non-conducting materials cannot transfer charge in a short time when there is a path of strike.

2.3 Lightning Protection System

2.3.1 External LPS

External Lightning Protection System avoids the direct danger of a lightning strike in installations, equipment installed outside the building, in towers, and exterior parts of the building. This type of protection includes the protection of people outside the building. The External Lightning Protection System consists of:

2.3.2 Air Termination

Air termination is part of an external lightning protection system devoted to capturing lightning strikes in metal electrodes mounted vertically or horizontally. Terminal air is an area or zone that is specifically for capturing lightning at a certain radius. Lightning arresters can catch all lightning strikes without hitting the building, building, or protected area (protection zone).

2.3.3 Lightning Current Conductor (Down Conductor)

The down conductor distributes lightning current that hits the air termination (air terminal) and is forwarded to earth/grounding (Smith, 1998 and Mendez, 2014). The choice of the number and position of the supply conductors should consider the fact that, if the lightning current is divided into several supply conductors, the risk of side-stepping and electromagnetic interference within the building should be considered is reduced. Based on the 2014 SNI 7015 standard that each down conductor installed on a down conductor is installed on the shortest possible route and does not cause a side-flash hazard to humans/equipment and induction hazards, especially for sensitive equipment. Down conductors in installations with sensitive equipment must be equipped with a lightning strike monitoring device and a current recording device. Designing the down conductors with small resistance is essential to direct the lightning current to the ground.

In the ATP/EMTP software, the down conductor has a replacement circuit that is a component of resistance and inductance. Down conductor models are generally modeled in terms of resistance and inductance connected in series. The magnitude of the resistance value in the down conductor can be calculated using the following equation. Meanwhile, to calculate the radius of the conductor using equation (1)

2.3.4 Earthing (Grounding)

Grounding is planting one/several electrodes into the ground in a certain way to get the desired grounding resistance (Zaini, 2016). The grounding electrode makes direct contact with the earth. A non-insulated earth conductor embedded in the earth is considered part of the earth electrode.

2.3.5 Internal IDIC

Implementing the concept of an internal lightning rod is an effort to avoid potential differences at all points in installing protected equipment inside the building (Smith, 1998; Moore, 1999; Jiang, 2013; Zaini, 2016; Mendez, 2016).

The steps that can be taken are integrating potential equalizer facilities, installing voltage and current arrestors, shielding, and filters. The investment costs required for the procurement of internal lightning rods are considerable. These costs due to various mechanisms can cause potential differences in the protected equipment, which can be in the form of overvoltage propagation through the line, telephone, antenna, electric power supply, grounding, and various electromagnetic induction. Some efforts to minimize costs are by defining the zoning area of protection and reducing to a minimum all lightning impulse currents or voltages that propagate into buildings and installations. This method reduces the risk of internal damage in electrical equipment such as over-voltage and induced voltage which is detrimental to the equipment. Experience shows that maximum effort in improving external lightning rods and applying to shield can reduce the cost of internal lightning rods. Specifically for the procurement of lightning protection systems for explosive installations, three main things must be considered as follows:

a. Aspects of external influence, which is the aspect of the occurrence of lightning strikes. Security measures must be taken care of to prevent electric arc sparks, near the roof of the building, inside the protected building, and in the grounding system. The method that can be applied is to justify the finial arrangement, distribution of lightning current and grounding, and its connection and prevent the "Faraday Hole" mechanism.
b. The operational aspect, which involves the problem of a mixture of gaseous materials, dramatically determines the temperature, voltage, and ignition energy.
c. Internal Capability Aspect, which is an effort to improve the installation's internal capability and can eliminate the consequences that occur if it turns out that there is a failure from the efforts of the two aspects above.

3 DISCUSSIONS

3.1 Existing Condition

There is a conventional type LPS installed in Bangli Solar Power Plant on top of an iron tower with a height of 17.335 mm to protect the BSPP area of 1.8 ha.

3.1.1 Air Terminal

The installed type of LPS air terminal/receiver is franklin rod type. The franklin type LPS can protect the form of an inverted cone (dome), with a maximum protection angle of 112º. For a protection angle of 112, the protective area will be in a radius of 2 x tan 112º, which is 25,700 mm. While the farthest distance from the LPS to the PV position is 199.382 mm, meaning that only 13% of the area is protected.

3.1.2 Down Conductor

The down conductor used is 50 mm^2 BC wire tied along with the LPS tower and then planted at a depth of 50 cm in the ground, stretched for 12 meters. Then the ends are connected to grounding rods.

3.1.3 Grounding

There is no ground rod for thiss PLS the grounding system uses a bare conductor (BC) that is planted at a distance of 8 meters from the LPS tower. Total of the length of the BC is 10 meters under ground. The result of the measurement of the grounding value (earth) is 5.6 Ohms. This value is greater than the specified minimum standard of 5 Ohms.

3.2 System Redesign

By looking at the condition of the existing LPS, which is not effective in providing comprehensive protection for BSPP, it is necessary to re-plan the existing LPS to provide more effective protection for the entire BSPP area.

3.2.1 Determination of Protection Level

The selection of the level of protection aims to reduce the risk of damage, below the maximum tolerance level, by a direct lightning strike to the building or space being protected.

3.2.2 Lightning Strike Density (Ng)

Lightning strike density is calculated by equation-(1)

$$Ng = 0{,}04xTd^{1{,}26} \quad (1)$$

where

Td = average number of lightning annually for Bali = 61, so:

$$Ng = 0{,}04x61^{1{,}26} = 7{,}105$$

3.2.3 Frequency of Strikes

The calculation of the frequency of lightning strikes (Nd) uses equation (2).

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

Where *Ae* is the protection coverage area (m2), which is calculated by equation (3)

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

Where,
a = length of protected area (260 m)
b = width of protected area (137 m)
h = building height (5 meters)

So that the area of protection coverage is obtained with the following calculations:

$Ae = 260.137 + 65\,(260 + 137) + 9\,(3.14)\,(5)^2$
$= 135{,}843$ m2

So the strike frequency (Nd) can be calculated as follows:

Nd $= 7{,}105 \times 135{,}843 \times 10^{-6}$
$= 0.965$ strikes / km2/year

3.2.4 Protection System Requirements

Determination of protection needs is determined based on the calculation of the lightning strike frequency (Nd) and the permissible lightning strike frequency (Nc) regarding the following conditions:

a. If Nd Nc, there is no need for a lightning protection system.
b. If Nd Nc, a lightning protection system is required.

The allowable local annual lightning strike frequency (Nc) is 10-1, while Nd = 0.965, then Nd is greater than Nc, so a protection system is needed.

3.2.5 Lightning Strike Efficiency

With the need for a protection system, it is necessary to calculate the efficiency of the system that needs to be installed properly using equation (4):

$$E \geq 1 - \frac{Nc}{Nd} \qquad (4)$$
$$\geq 1 - \frac{0{,}1}{0{,}965}$$
$$\geq 0{,}896\ (89{,}6\%)$$

The system's efficiency is 89,6%, and it is at level III of the protection level.

Table 1: Protection level and their efficiency.

Protection level	Efisiensi LPS
I	0,98
II	0,95
III	0,90
IV	0,80

(SNI 03-7015-2004)

3.2.6 Determination of Air Terminal and Location

The Bangli solar plan requires an LPS with level III protection. Considering that there is not much need for a lightning protection system, as an alternative, the Early streamer emission (ESE) type LPS is chosen, which has radius type protection. By knowing the outside of the protection area calculated above, which is 135,843 m^2, the required LPS radius can be calculated using equation (5) that is denoted as follows:

$$A = \pi r^2 \qquad (5)$$
$$135.842 = 3{,}14 \,.\, r^2$$
$$r = 210 \text{ m}$$

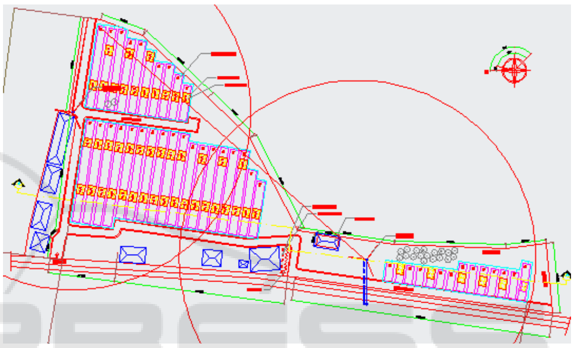

Figure 2: Area of protection of 2 LPS R100.

3.2.7 Down Conductor

LPS with a radius of 210 meters are not available in the market. As an alternative, two LPS with r = 100 meters are chosen with the placements shown in Figure 2. LPS-1 is placed at the Existing LPS position while LPS-2 is placed at the far right of the area. Figure 2 shows that two radius type of LPS protects the entire BSPP area with r is 100 meters. The installation height is 15 meters, the same as the existing condition.

3.2.8 Grounding Electrode

The LPS grounding resistance value at BSPP is designed to have a maximum value of 4 ohms, with the following conditions:

1) embedded BCC length is 10 meters
2) The length of the electrode is 3 meters
3) electrode radius is 0.0079375 meters (D 5/8 inch = 0.015875 m)
4) ground resistance is 100 ohm.m

The value of the grounding resistance calculation uses equation (6).

$$R=\frac{\rho}{2\ \Pi\ l}\ .\left(ln\frac{4l}{\alpha}-1\right) \quad (6)$$

Where
ρ : earth resistance (100 ohm/m)
l : length of grounding electrode (3m + 10m)
α : radius of grounding electrode (0,0079375 m)

The calculation result is:

$$R=\frac{100}{2.3{,}14.(3+10)}\ .\left(ln.\frac{4.(3+10)}{0{,}0079375}-1\right)$$
$$= 8 \text{ ohm}$$

It is known that the Bangli PLTS requires an LPS with level III protection. Considering that there is not much need for a lightning protection system, as an alternative, the Early streamer emission (ESE) type LPS is chosen, which has radius type protection. By knowing the outside of the protection area calculated above, which is 135,843 m^2, the required LPS radius can be calculated using equation (7). By using this equation, a number of electrodes can be found.

$$Rn = \frac{R}{n}\ x\ F \quad (7)$$

where
Rn : resistansi parallel sn (ohm)
n : number of resistors in parallel
F : multiply factor
so:

$$4 = \frac{8}{n}\ x\ 1$$
$$n = 2$$

So, it recommends installing two electrodes with a length of 3 meters and a diameter of 5/8 inch.

These two electrodes are installed in parallel, so the resistance value becomes 4 ohms.

3.3 Comparison Results

Table 2 shows the comparation between existing PLS and the proposed one. Number of air terminal is doubled to protect all area or 100% area protection. The down conductors for these conditions are BC 50 mm^2 but the length of the proposed PLS is 2m shorted.

In existing PLS there is no ground rod, but 2 ground rods are needed for proposed system with 3 m length and 5/8 inches diameter. The earth resistance value for the new proposed PLS is less than the existing ones and meet to the standard value.

Table 2: Existing vs Proposed PLS.

No	Item	Existing	Proposed
1	**Air Terminal**		
	type	Franklin rod	ESE
	number	1	2
	max angle	112^o	-
	radius	25.7 m	100 m each
	area protection	40.349 m^2	2 x 135.842 m^2
	% area	13%	100%
	heigh	15 m	15 m
2	**Down Conductor**		
	type	BC 50 mm^2	BC 50 mm^2
	length	12 m	10 m
	depth	50 cm	50 cm
3	**Grounding**		
	ground rod	-	2
	earth resistant	6 Ohms	4 Ohms
	length	-	3 m
	diameter	-	5/8 inch

4 CONCLUSIONS

This study of the effectiveness of the lightning protection at Solar plan Bangli found that the existing protection uses a Franklin rod type for its air terminal with 15m high. It only has a 13% protection area. In addition, the measurement of the grounding system of this LPS is 5.6 ohm, or it does not meet the standard value of ground resistance. So, this existing LPS is not enough to protect all areas of the plan. It is recommended to install two electrodes with a length of 3 meters and a diameter of 5/8 inch.

ACKNOWLEDGEMENTS

The author thanks the Center of Research and Community Service Polteknik Negeri Bali.

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