External Lightning Protection and Earthing System Design of PV Plant in Thilawa Special Economic Zone

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Abstract: *Thilawa Special Economic Zone (SEZ) is located beside the Thanlyin and Kyauktan townships, about 20 km southeast side of Yangon City. The development of solar power generation system in Myanmar is constantly increasing and the government of Myanmar has arranged to construct mega solar power generated plant. However, the knowledge of performing and installing lightning and surge protection in mega PV plants is still premature. The lightning protection of photovoltaic installations is of great importance, in order to warrant the uninterrupted operation of the system and avoid faults and damages of the equipment. The determination of the need for lightning protection and the evaluation of the performance of a risk management analysis are the first steps, in order to adopt the appropriate protective measures against lightning. This paper takes a step forward and focuses on the design principles of an external lightning protection system and earthing systems of the large-scale PV systems. These protection systems are assumed to be the product of appropriate risk assessments. In this paper, design results of Thilawa SEZ are presented by evaluated results for solar power plant including sizing of inter-row spacing, external lightning protection and earthing system. Proposed design layout diagrams are also described in this paper.*

Key Words: *Thilawa SEZ, PV Plant, Lightning Protection, Earthing System.*

1. INTRODUCTION:

The government of Myanmar has identified three Special Economic Zones as pioneer projects namely Thilawa SEZ in Yangon Region, Dawei SEZ in Taninthayi Region and KyaukPhyu SEZ in Rakhine State. Among the three SEZs, Thilawa Special Economic Zone is one of the first most successful SEZ in Myanmar. It is located beside the Thanlyin and Kyauktan townships, about 20 km southeast side of Yangon City. Due to the development of SEZ in Myanmar, utilization of renewable energy especially solar power generation becomes popular in recent years because of abundant sunshine. Potential available solar energy of Myanmar is around 51973.8 TWh/year. Intensity of irradiation is more than 5kWh/m2/day was observed during the dry seasons. The year average solar radiation of Myanmar is found to be 18.3 MJ/m^2 per day, when averaged over the country [1].

Photovoltaic (PV) systems, due to their expanded surface and their installation position in wide-open areas, are vulnerable to direct or indirect atmospheric discharges, which can cause damages and failures to the equipment and interruption of their normal operation. The layout of a typical PV installation is larger in comparison with conventional power systems, so the probability to be struck by lightning is higher. Despite the fact that PV systems face the risk of damage from lightning, many PV plants are not protected against lightning and the designers ignore or underestimate the need for surge protection. The lack of lightning protection system can cause significant destructions and damages of critical electromechanical parts of the PV installation. Moreover, an inadequate protection against lightning phenomena can increase the time of the return of investment of the PV power generating system. Therefore, it is recommended to take into consideration techno economically balanced protection measures. For these reasons, the design and the establishment of an appropriate lightning protection system (LPS) is necessary, in order to prevent the development of over voltages and restrict the repercussions of a potential lightning hit. However, only the avoidance of lightning attachment to unprotected parts of the installation is insufficient, since lightning currents passing through the LPS parts may still impact on the PV system due to inductive coupling [2].

The main objective of this paper is to present the external lightning protection and earthing system designs that may be installed mega PV plant that include in inter-row spacing sizing, external lightning protection sizing and earthing system sizing. The paper is organized as follows: Section I descripts the introduction of the study, Section II presents proposed case study area, Section III shows literature reviews of lightning protection and earthing system, Section IV presents mega PV plant design, Section V provides the design results and discussions. The paper is concluded in section VI.

2. CASE STUDY AREA:

Thilawa Special Economic Zone (SEZ) is the first Special Economic Zone that built in Myanmar, and had become commercially operated in September 2015. According to JICA report, the power load for all the tenants in the whole area of SEZ (2,400 ha including Class A and Class B) is estimated to reach approximately 800 MVA in total. To focus on the power demand, the annual volume of selling area is predicted at 20 hectare/year and assuming the load density at 0.5 MVA/hectare. For the first year of operation of the SEZ in 2015, approximately 2 MVA is estimated as the initial load. Thereafter, the load is expected to increase by 10 MVA every year, until 2037 when the sale of industrial area of Class A is completed, the load will reach a maximum of 180 MVA [3]. Case study area of Thilawa SEZ is presented in Fig 1[4]. Solar resource indicates the amount of global solar radiation that strikes earth's surface. Solar radiation for this study area was obtained from the NASA Surface Meteorology and Solar Energy website [5]. An average solar radiation of 4.699 kWh/m^2/day and a clearness index of 0.49 is obtained for the study area.

Fig. 1 Thilawa Special Economic Zone

3. LIGHTNING PROTECTION AND EARTHING SYSTEM:

A. Lightning Protection System

The necessity a PV lightning protection system shall be examined, in an effort to reduce the pre-mentioned losses ($L1$, $L2$, $L3$, $L4$). The determination of the need for lightning protection and the design of the lightning protection system is performed according to the risk management procedure. Fig. 2 shows Risk Assessment Classification for PV System. Risk management analysis determines the need of protection of the PV installation. In case that lightning protection is required, the appropriate lightning protection level (LPL) has to be defined.

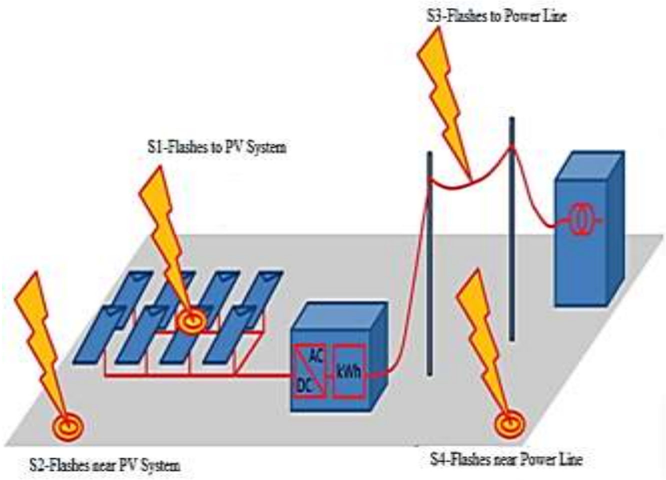

Fig. 2 Risk Assessment Classification for PV System [2]

These LPLs equate directly to classes of lightning protection system (LPS). IEC 62305-1 has defined four LPLs, based on probable minimum and maximum lightning current parameters, i.e., peak current (kA), short stroke charge (C), specific energy (MJ) and steepness (kA/µs). TABLE I shows classification of LPS. The maximum values are used to design lightning protection components, since the minimum values are used for the position of the air termination system. The LPS comprises into external and internal parts [2].

1) *External Lightning Protection*: The external LPS is intended to intercept direct lightning flashes to the PV installation and to disperse the lightning currents into the earth without causing thermal or mechanical damage, nor dangerous sparking which may cause fire or explosion. The external LPS is composed of the air termination system, the down conductor system and the earth termination system. The protection angle, the rolling sphere and the mesh method are common practices for the design of the external LPS in a way that all PV equipment to be included to the protection volume [2]. TABLE II shows class of LPS according to the respective methods and Fig 3 presents protective angle reference.

TABLE I
Classification of LPS

Lightning Protection System (LPS)	Lightning Protection Level (LPL)	Induced Voltage per Unit Length (kV/m)	Maximum Current (kA)
I	I	4	200
II	II	3	150
III	III	2	100
IV	IV	2	100

TABLE III
Class of LPS according to Respective Methods

Class of LPS	Rolling Sphere Method (r)	Mesh Size (m)	Protective Angle (α)
I	20	5 x 5	See Fig (3)
II	30	10 x 10	See Fig (3)
III	45	15 x 15	See Fig (3)
IV	60	20 x 20	See Fig (3)

Due to the high resistivity of the soil, which was not promising for an effective earthing system and in conjunction with the high ground flash density of the area, the design of the lightning and surge protection was considered of high priority. Due to the extensive area coverage of the PV park, the design of the external LPS considered both possible cases, the one for an isolated application as well as the one for a non-isolated application design, as per IEC 62305 – 3 [6]. Fig 4 shows Isolated LPS and Non-isolated LPS.

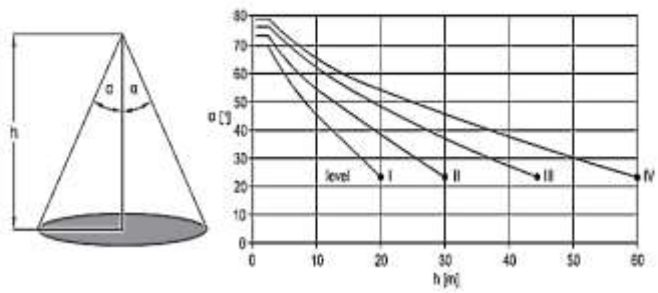

Fig. 3 Protective Angle Reference [2]

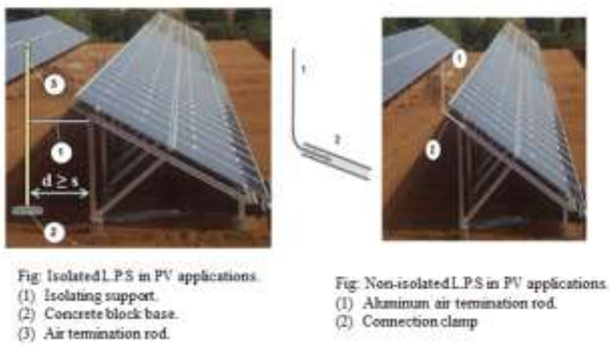

Fig. 4 Isolated LPS and Non-isolated LPS [7]

2) *Internal Lightning Protection:* The main scope of the internal LPS is to avoid the occurrence of dangerous sparking within the PV system to be protected, due to lightning current flowing in the external LPS or in other conductive parts. Internal LPS includes equipotential bonding (interconnection of the LPS with structural metal parts, metal installations, internal system, external conductive parts and lines connected to the structure) and electrical insulation between the parts (compliance with a separation distance between the air termination or the down-conductor and the metallic parts of the installation, which is depended on the class of the LPS, the length of the conductors, the insulation material and the sharing of the lightning current) [2].

B. Earthing System

The achievement of low values of grounding resistance in PV installation is of great importance, in order to minimize any potentially dangerous overvoltages. In general, a low earthing resistance (if possible lower than 10 when measured at low frequency) is recommended. The lightning current that hits the PV installation is diverted through down conductors and surge protective device (SPD) to the grounding system. There are two basic types of earth electrode arrangements apply such as type A and B arrangements.

Type A arrangement comprises horizontal or vertical earth electrodes installed outside the structure to be protected connected to each down-conductor, since Type B arrangement comprises either a ring conductor external to the structure to be protected, in contact with the soil for at least 80 % of its total length, or a foundation earth electrode. In details, in case of Type A grounding system, the total number of earth electrodes shall be not less than two. Furthermore, in Type B systems with ring conductor, when the radius of the ring electrode is less than the length specified in the Type A system, additional horizontal or vertical electrodes shall be added. In the configurations, the components the materials and the construction of the earth-termination systems are given. In any case the cost, the lifetime and the galvanic corrosion between metals of dissimilar nature are parameters that should be taken into consideration during the design and the installation of a grounding system [2].

4. MEGA PV PLANT DESIGN:

The total daily load average of Thilawa SEZ is 102.6 MWh/day. The peak load requirement decides the size of the system. The peak load consumption for industrial use of Thilawa SEZ is 6MW in day time and the least load consumption is 3.5MW in night time [8]. To meet increasing of power demand in Thilawa SEZ, 50MW dual fuel generators are already constructed in there. Because of the insufficient enough of supply gas, gas turbine generator (GT) are not operated in full efficiency. Due to the fact of future load growth and present gas turbine condition, mega solar power generation system should be considered to construct in Thilawa SEZ area. Table III shows design results and Fig 5 presents the mega solar power plant proposed design of Thilawa SEZ according to research evaluated results. Because of 4852 number of PV module string per parallel, over 4850 string inverters are required to connect the PV system. According to reduce string inverter, system required inverter may be assumed 480 numbers. In this PV plant design, there are 140 numbers of PV module per array. They are connected to one number of 50W string inverter. When there are 20 numbers of PV array per array-group, 20 numbers of 50W string inverters are connected to the PV system. Finally, there are 160 numbers of string inverter per PV sub-group and 480 numbers of string inverter per overall PV group are evaluated for PV plant design results.

TABLE III
Mega PV Plant Design

Site and Project Details		
Location	Thilawa SEZ	
Latitude	16.67 ˚N	
Longitude	96.28 ˚E	
Time Zone	GMT+6:30	
Power Plant Capacity	30	MW_p
Avg: Sun-hours per Day Whole Year	4.7	hr
Total Energy Demand per day	100	MWh
Max: Solar Radiation	4.7	$kWh/m^2/d$
Selected PV Module Specification		
Watt (W_p)	435	W
DC Voltage (V_{mp})	72.9	V
DC Current (I_{mp})	5.97	A
Open Circuit Voltage (V_{OC})	85.6	V
Short Circuit Current (I_{SC})	6.43	A
Number of PV Panel		
Total Number of PV Modules	67933	Nos
No. of Modules per String	14	Nos
No. of String in Parallel	4852	Nos
No. of PV Modules/ Array	140	Nos
No. of Modules per String of Array	14	Nos
No. of String in Parallel of Array	10	Nos
No. of PV Array per Array-Group	20	Nos
No. of Array-Group per Sub-Group	8	Nos
Number of PV Sub-Group per Group	3	Nos
Inverter Sizing		
Max PV Power	50	kW
System Voltage	$1000V_{DC}$- $400V_{AC}$	
Required Total No. of PV Inverter	485	Nos
Battery Sizing		
Nominal Capacity	2000	Ah

Voltage	2	V
Depth of Discharge (DOD)	80	%
Days of Autonomy	2	Days
Required Battery Capacity	41,666.7	kAh
Total Number of Battery	10,417,000	Nos
PV Array Area Sizing		
Array Length	15.5	m
Array Width	38.5	m
No (1) Array Area	15.5 m x 38.5 m (0.15acre)	
Group (1) Array Area	85.5m x 179 m (3.76acre)	
Sub-Group Array Area	357 m x 363m (32acre)	
Total PV Area	1221m x 373 m (112.5 acre)	

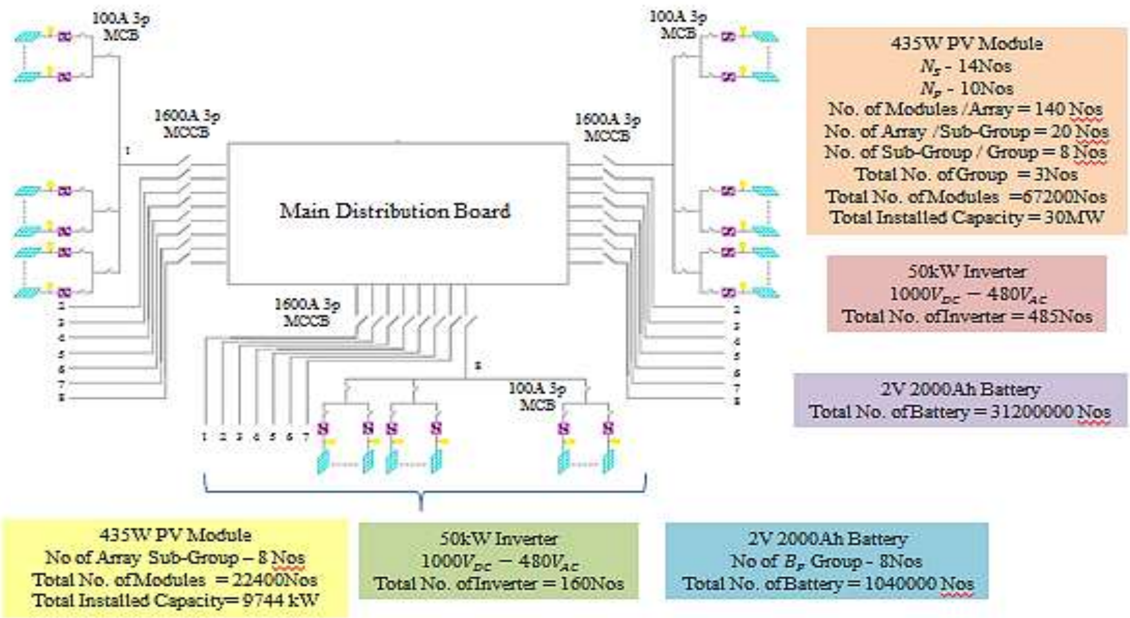

Fig.5 Proposed Mega Solar Power Plant

5. LIGHTNING PROTECTION AND EARTHING SYSTEM DESIGN RESULTS:

In this paper, design results of Thilawa SEZ are presented by two parts; evaluated results for solar power plant including inter-row spacing, external lightning protection system and earthing system sizing and proposed design layout diagram.

A. *Inter-row Spacing Sizing*

Sizing of inter-row spacing between PV modules is one of the important factor for considering the area of solar power plant design. It is also useful method to overcome shading effects of PV modules. Fig 6 shows sizing inter-row spacing for proposed design and TABLE IV presents sizing results.

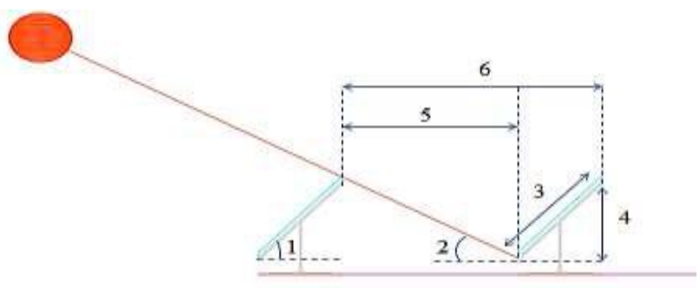

Fig.6 Inter-row Spacing between PV Modules

TABLE IV
Inter-row Spacing Sizing Results

Number	Description	Unit
1	Tilt Angle	50˚
2	Elevation Angle	29.97˚
3	Module Width	2.067m
4	Height Difference	1.6m
5	Module Row Spacing	2.8m
6	Row Width	4m

B. *Lightning Protection System Sizing*

In this paper, lighting protection level II is being considered for risk assessment of case study area. Isolated lightning protection system are being considered for system design and rolling sphere method is being chosen to estimate air termination system of mega solar power plant. Fig 7 shows side view air termination system of proposed design. Lightning protection system design of case study area is presented by Fig 8 and sizing results are descripted in Table V. Lightning protection system for PV array is shown in Fig 9. In Fig 9, red dot refers to air termination rod for proposed PV array.

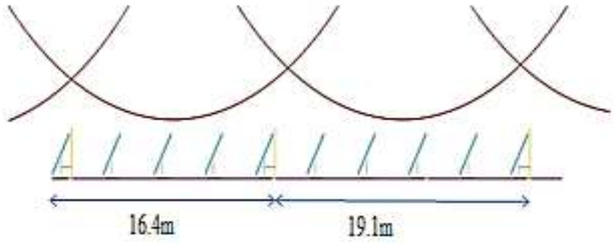

Fig.7 Air Termination System

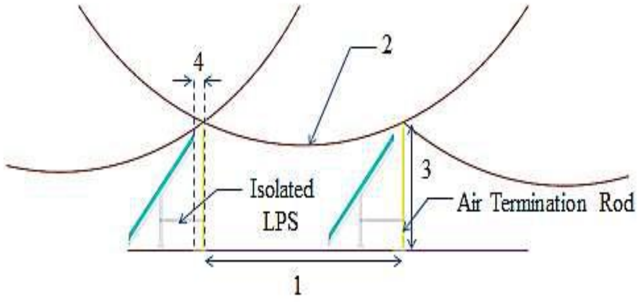

Fig.8 Lightning Protection System Design

TABLE V
Lightning Protection System Sizing Results

Number	Description	Unit
1	Distance between Two Air Termination Rod (d)	21.5m
2	Radius of Rolling Sphere (r)	30m
3	Height of Air Termination Rod (h)	2m
4	Clearness (s)	0.225m
No. of Air Termination Rod/ Array		6 Nos
Total No. of Air Termination Rod/ Plant		2880Nos

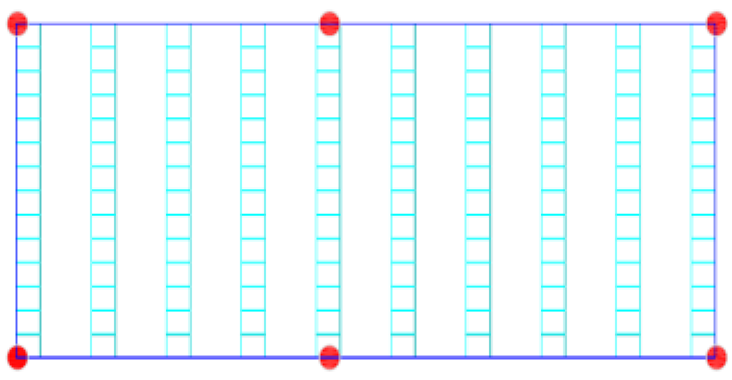

Fig.9 Lightning Protection System for PV Array

C. *Earthing System*

Proposed earthing system design is shown in Fig 10 and Fig 11. In Fig 10, red dots refers to air termination rod, green dot refers to earth rod and green line refers to earth conductor for PV array. TABLE VI and TABLE VII are presented by earthing system sizing results for PV array and earth wire description of mega solar power plant.

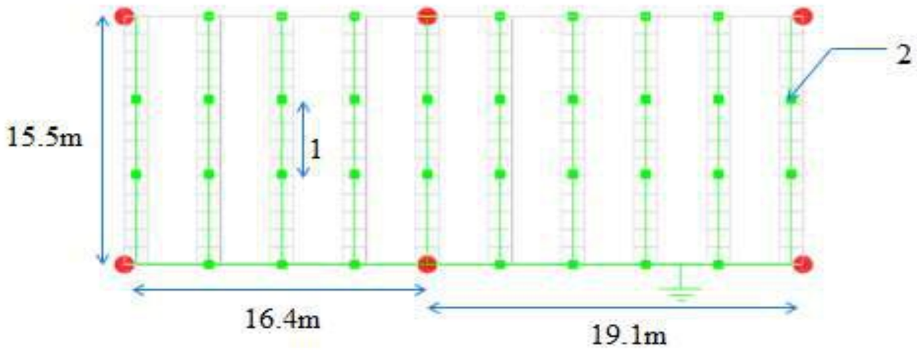

Fig.10 Earthing System of PV Array

TABLE VI
Earthing System Sizing Results

Number	Description	Unit
1	Distance between Two Earth Rod	5.17m
2	No. of Earth Rod/ Array	40 Nos
Total No. of Earth Rod/ Plant		9600 Nos

TABLE VII
Earth Wire Description

Description	Unit
Between PV String	1C 2.5mmsq Earthing Conductor
Between PV Array	1C 2.5mmsq Earthing Conductor
Between PV Group	Bare Copper 95mmsq Cable

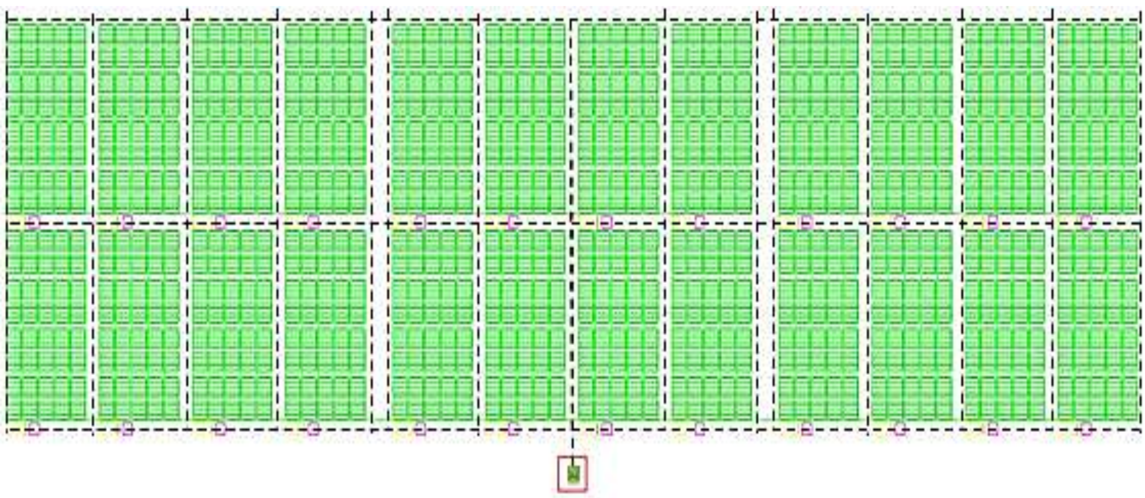

Fig.11 Earth Termination System of Mega PV Plant

6. CONCLUSIONS:

The design of a lightning protection system for large scale PV systems may depend on various factors and parameters. It is very important to take into consideration the installation arrangement and design adopted for large scale PV applications. This paper is provided design of external lightning protection and earthing system of mega PV plant in case study area. 2880 numbers of air termination rod and 9600 numbers of earth rod can be evaluated for proposed system design. Isolated LPS may be chosen to use and proposed design layout drawings are presented in this paper. To meet the best design of earthing and lightning arrester for solar PV panels, BS EN/IEC 62305 standard is preferred.

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REFERENCES:

1. Hla Myo Aung, Zaw Min Naing, and Thi Thi Soe, (2018): "*Status of Solar Energy Potential, Development and Application in Myanmar*" International Journal of Science and Engineering Applications. Volume 7. Issue 08,133-137, ISSN:-2319–7560.
2. Christos A. Christodoulou Lambros Ekonomou, Ioannis F. Gonos and Nick P. Papanikolaou, (December 2015): "*Lightning Protection of PV System*". Research Gate. Article in Energy Systems. DOI10.1007/S12667 – 015 - 0176 – 2.
3. Japan International Cooperation Agency (JICA), Nippon Koei Co., Ltd, (2014): "*Preparatory Study on Thilawa Special Economic Zone Infrastructure Development in the Republic of the Union of Myanmar: Final Report*". Thilawa SEZ Management Committee.
4. http://googleearth.com, accessed data on May 13th, 2018.
5. http://nasa.com, accessed data on February 10th, 2018.
6. Dr. Nikolaos Kokkinos, Dr. Charalambos Charalambous and Dr. Nicholas Christofides, (2012): "*Lightning Protection Practice for Large-Extended Photovoltaic Installations*". International Conference on Lightning Protection (ICLP), Vienna, Austria.
7. Charalambos A. Charalambous, Nikolaos D. Kokkinos, and Nikolas Christofides, (2013): "*External Lightning Protection and Grounding in Large-Scale Photovoltaic Applications*". IEEE Journal: 0018-9375.
8. Actual data collected from Thanlyin substation and 50MW Thilawa gas turbine in 2017.