The 11th Asia-Pacific International Conference on Lightning
June 12-14 Hong Kong,China
APL 2019

Lightning Surge on the DC and AC Side of Solar PV System

N. H. Zaini
Centre for Electromagnetic and Lightning Protection Research (CELP),
Universiti Putra Malaysia,
Serdang, Malaysia
Institute of Power Engineering (IPE),
Universiti Tenaga Nasional, Malaysia
nurhasz@yahoo.com

M. Z. A. Ab-Kadir
Centre for Electromagnetic and Lightning Protection Research (CELP),
Universiti Putra Malaysia,
Serdang, Malaysia
Institute of Power Engineering (IPE),
Universiti Tenaga Nasional, Malaysia
mzk@upm.edu.my

M. A. M. Radzi
Centre for Advanced Power and Energy Research (CAPER),
Universiti Putra Malaysia,
Serdang, Malaysia
amranmr@upm.edu.my

N. Azis
Centre for Electromagnetic and Lightning Protection Research (CELP),
Universiti Putra Malaysia,
Serdang, Malaysia
norhafiz@upm.edu.my

N. I. Ahmad
Centre for Electromagnetic and Lightning Protection Research (CELP),
Universiti Putra Malaysia,
Institute of Power Engineering (IPE),
Universiti Tenaga Nasional, Malaysia
nizzati71@yahoo.com

M. S. M. Nasir
Universiti Pertahanan Nasional Malaysia (UPNM),
Kuala Lumpur, Malaysia
Centre for Electromagnetic and Lightning Protection Research (CELP),
Universiti Putra Malaysia,
Serdang, Malaysia
solehin@upnm.edu.my

M. Izadi
Centre for Electromagnetic and Lightning Protection Research (CELP),
Universiti Putra Malaysia,
Serdang, Malaysia
mahdi@upm.edu.my

N. F. Ab Aziz
Institute of Power Engineering (IPE),
Universiti Tenaga Nasional, Malaysia,
nfadilah@uniten.edu.my

Z. Ali
Institute of Power Engineering (IPE),
Universiti Tenaga Nasional, Malaysia,
zaipatimah@uniten.edu.my

***Abstract*—The solar PV has become an alternative solution in Malaysia to generate electricity. Unfortunately the solar PV installed in Malaysia is attracted to the lightning strike. There were two points that have high possibilities of being strike by the lightning; on the DC side between the solar PV and inverter and on the AC side, between the inverter and the substation. Therefore, this study was performed to analyse the effects of lightning strike at these two different points at the solar PV farm without any lightning protection system (LPS).**

Keywords—solar PV, lightning current, striking point, transient voltage, inverter, DC, AC

I. Introduction

The solar PV farm in Malaysia was attracted to the lightning strike since the installation is in wide open area. Malaysia located near the equator give high radiation and also high lightning densities. According to the United States National Lightning Safety Institution, Malaysia has an average thunder level of 180-260 days per year [1]. A lightning strike can cause an interruption and damage to the electronic equipments of the solar PV system like solar PV modules, string inverters, transformers, and cables. [2]. This interruption or damage can contribute to losses and affect the solar PV performance [3]. The extent of the electronics component damage depends on few characteristics like lightning peak current, lightning current waveshapes and the location of striking points. This study will analysed the impact of striking points on the DC and AC side at the solar PV farm without any LPS install. In addition, this study will give the impact if the designer ignored or underestimate the importance of installing the LPS in the solar PV farm.

II. Solar PV Farm

A solar PV farm (1 MW) was developed in the PSCAD/EMTDC simulation. This solar PV farm consists of 4032 solar PV modules of 250 W each with 42 string inverters to convert the DC output of solar PV to AC output. The illustration of the solar PV farm was shown in Fig.1.

978-1-7281-1695-2/19/$31.00 ©2019 IEEE

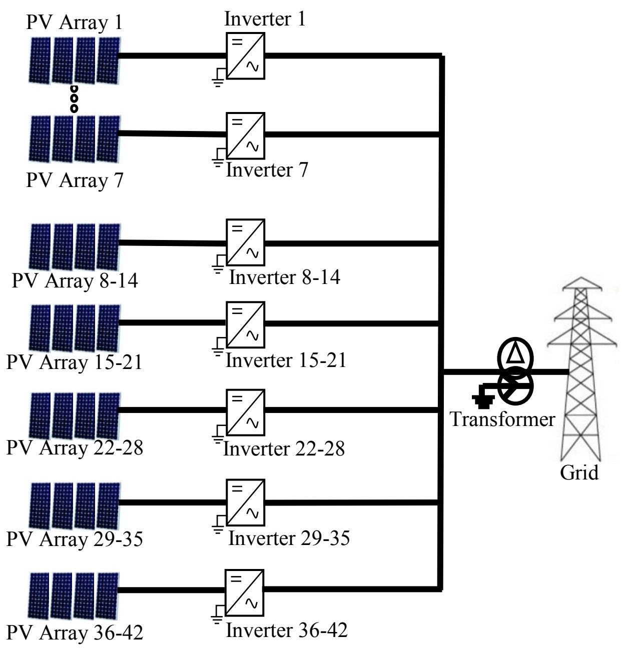

Fig. 1. Solar PV Farm

III. LIGHTNING CURRENT OF 10/350 µS

The lightning current waveshape was modeled using the Heidler function as defined in Equations 1 and 2 [4] since the Heidler function provides more realistic results and recommended by IEC 62350-1 [5].

$$i\,(t) = \frac{I_m}{\eta}\frac{(t/\tau_1)^n}{1+(t/\tau_1)^n}exp\left(-\frac{t}{\tau_2}\right) \quad (1)$$

$$\eta = \exp\left[\frac{-\tau_1}{\tau_2\left({}^{n\tau_2}/_{\tau_1}\right)^{({}^{1}/_{n+1})}}\right] \quad (2)$$

where I_m = peak current
η = correction factor of peak current
τ_1 = rise time constant
τ_2 = fall time constant
n = steepness factor

Fig.2 illustrate the 10/350 µs lightning current waveshape using the Heidler function.

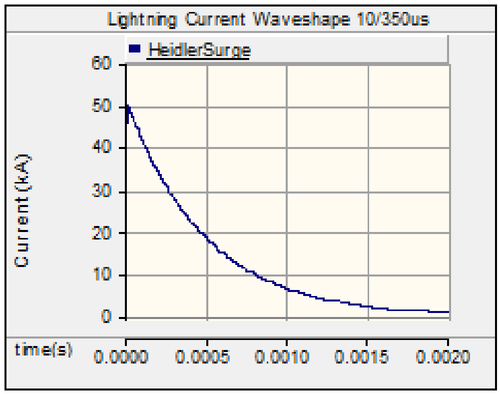

Fig. 2. Lightning Current Waveshape 10/350 µs

IV. IMPULSE WITHSTAND VOLTAGE (U_W) FOR ELECTRONIC COMPONENTS IN SOLAR PV SYSTEM

The components of solar PV system have its specific withstand voltage. Table 12 in Section 7.3.7.1.4 in the MS IEC 60664-1 tabulated the withstand voltage of the electronic components on the DC and AC side of the solar PV system as shown in Fig.3.

Column 1	2	3	4	5	6
System voltage (7.3.7.2)	Impulse withstand voltage V				Mains circuit Temporary overvoltage (peak / r.m.s.) (see note 5)
	Overvoltage category				
V	I	II	III	IV	V
50 V rms or 71 V dc	330	500	800	1 500	1 770 / 1 250
100 V rms or 141 V dc	500	800	1 500	2 500	1 840 / 1 300
150 V rms or 213 V dc	800	1 500	2 500	4 000	1 910 / 1 350
300 V rms or 424 V dc	1 500	2 500	4 000	6 000	2 120 / 1 500
600 V rms or 849 V dc	2 500	4 000	6 000	8 000	2 550 / 1 800
1 000 V rms or 1 500 V dc	4 000	6 000	8 000	12 000	3 110 / 2 200

NOTE 1 Interpolation is not permitted in mains circuits, but is permitted in other circuits.

NOTE 2 The last row only applies to single-phase systems, or to the phase-to-phase voltage in three-phase systems.

NOTE 3 Column 6, temporary overvoltages, only applies to mains circuits.

NOTE 4 PV circuits are in general OVCII with a minimum impulse voltage of 2 500 V - see 7.3.7.1.2b).

NOTE 5 These values are derived using the formula (1 200 V + system voltage) from IEC 60664-1.

Fig. 3. Impulse withstand voltage (U_W) for electronic components in solar PV farm [6]

For this solar PV farm, the impulse withstand voltage for the solar PV array and inverter for the Dc side is 6 kV. While on the AC side, the impulse withstand voltage for the inverter is 2.5 kV and 4 kV for the transformer.

V. RESULT AND DISCUSSION

The lightning strike was apply at two separate point; SP1 and SP2 that have high possibilities strike by the lightning in the solar PV farm. SP1 is on the DC side between the solar PV array and inverter and SP2 is on the AC side between inverter and substation as shown in Fig.4.

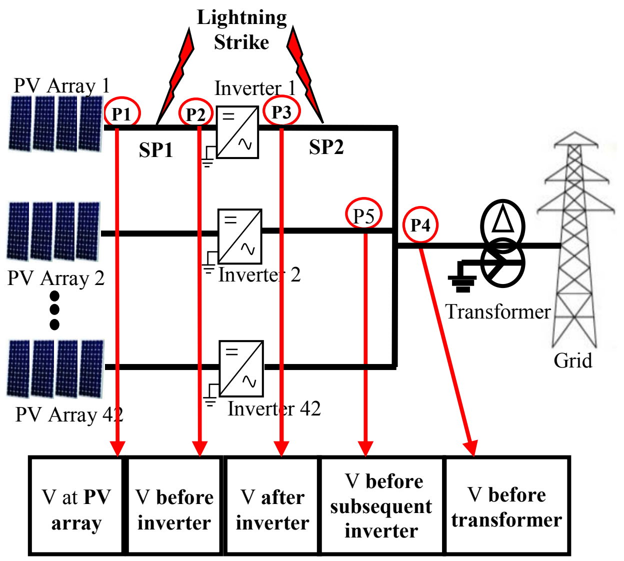

Fig. 4. Lightning strike at DC side and AC side at solar PV farm

The lightning current waveshape of 10/350µs representing a direct lightning strike since the solar PV farm was installed in open area. A 50kA lightning peak current was used for this analysis.

TABLE I. VOLTAGE MEASUREMENT AT DIFFERENT POINTS

Lightning Amplitude (kA)		SP1	SP2
P1 (PV Array)	Vpv (kV)	328.60	2.00
P2 (before Inverter)	Vinv DC (kV)	113.39	2.00
P3 (after Inverter)	Vinv AC (kV)	4.44	399.83
P4 (before Transformer)	Vtrans (kV)	0.27	354.79
P5 (before Inverter 2)	Vinv sub (kV)	0.27	354.79

When the lightning strike hit the conductor, the voltage and current were generated and travel along the conductor line at the solar PV farm. All the results were analyse by plotting in a graph based on the lightning strike at 50 kA peak current with 10/350 µs lightning current waveshape at each measured point as below.

Fig.5 illustrates 328.60 kV of transient voltage appearing at the solar PV Array 1 which exceeds the impulse withstand voltage when the lightning strike was at the SP1. A 2 kV transient voltage measured when the strike was at SP2 which does not cause a damage to the solar PV module but this voltage can cause degradation to the solar PV module, as studied in [7]. Therefore, the solar PV modules sustained damage when the lightning strike at SP1 and faced degradation if the lightning strike were to be at SP2.

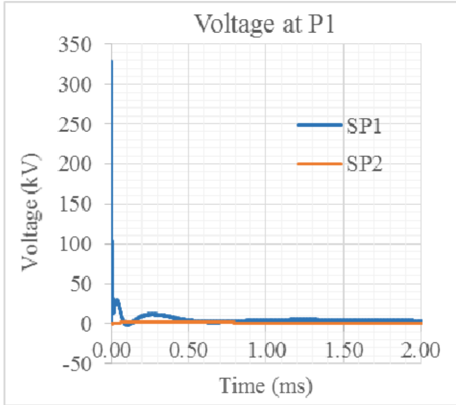

Fig. 5. Voltage measurement at P1 before solar PVat DC side

Fig.6 show the transient voltage and current detected prior to entering the inverter at DC output. The transient voltage is 113.39 kV for lightning strike at SP1 and at SP2 is similar to transient at solar PV array.

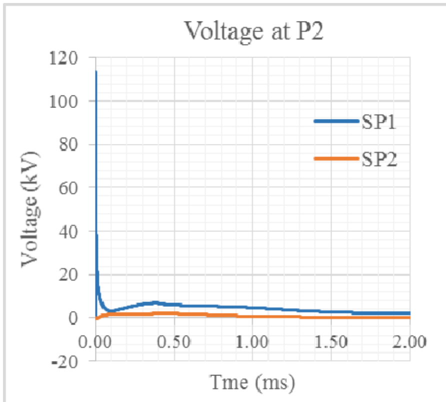

Fig. 6. Voltage measurement at P2 before inverter at DC side

Fig.7 presents the transient voltage after leaving the inverter (AC output) at P3. The AC output shows at least one phase was impacted by the lightning strike. The inverter faced a total damage from when the lightning strike at SP2 and SP1. The difference between these two points of strike were a high transient (399.83 kV) was detected at AC side when the lightning strike was at SP2 compared to that a high transient (113.39 kV) was detected at DC side when the lightning strike was at SP1. In other words, high transience occurs at the nearest point of the lightning strike.

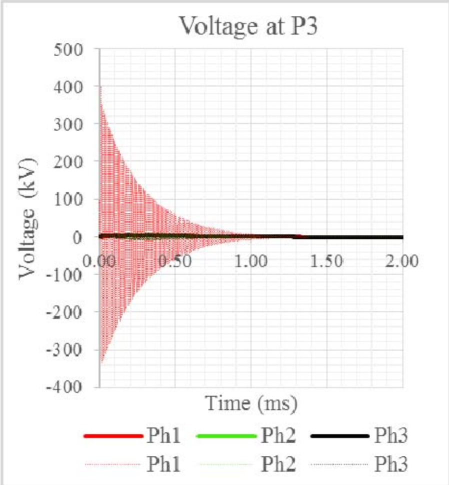

Fig. 7. Voltage measurement at P3 after inverter at AC side

Whilst Fig.8 shows a high transient voltage; 354.79 kV were measured at the transformer (at P4) when the lightning strike was at SP2, which again will damage the transformer and cause degradation when lightning strike was at SP1 [8, 9].

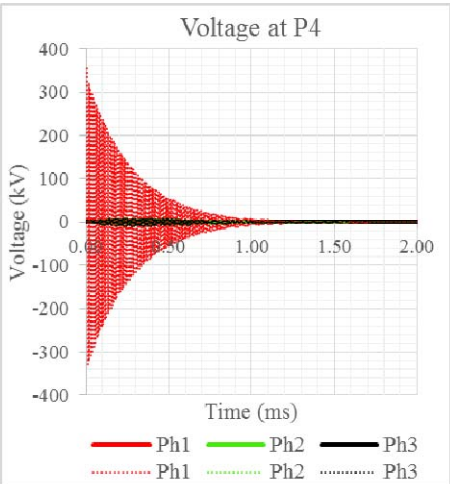

Fig. 8. Voltage measurement at P4 before transformer at AC side

Although the lightning strikes were at SP1 and SP2 in the series line of the solar PV array 1, the transient voltage also could cause damage to the other parts of the string inverter due to generated travelling waves throughout the system. Obviously, high transient voltage of 354.79 kV that damage the subsequence string inverter appears when the lightning strike is at SP2, as shown in Fig. 9.

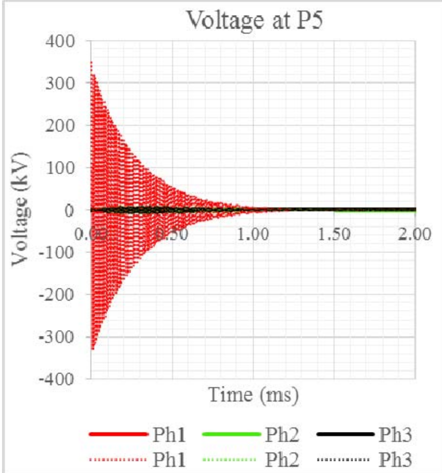

Fig. 9. Voltage measurement at P5 before subsequence inverter at AC side

VI. Conclusion

In conclusion, the electronic components near the striking points have highest possibilities of being damaged compare to the far one. The electronic parts in the long connection also will be damaged if the LPS are neglected. This is because the transient voltage and current can travel along the connected cable from the lightning striking point although the damage may not be as severe as the electronic parts near the striking point. In addition, the transient voltage also causes a degradation of the electronic parts that are not damaged directly by high voltage and current cause by the lightning strike [10]. Therefore, the installation of LPS was important to protect all the electronics components in the solar PV farm.

Acknowledgment

This work was supported by the Centre for Electromagnetic and Lightning Protection Research (CELP) and the Department of Electrical and Electronic Engineering, Universiti Putra Malaysia.

References

[1] National Lightning Safety Institute, www.lightningsafety.com/nlsi_info/world-lightning-activity.html (accessed on January 2019).

[2] A. Shahsavari, et al., "A data-driven analysis of lightning-initiated contingencies at a distribution grid with a PV farm using micro-pmu data", in proceeding of IEEE PES North American Power Symposium, Morgantown, WV, 17 September 2017..

[3] A. Ahadi, N. Ghadimi and D. Mirabbasi, "Reliability assessment for components of large scale photovoltaic systems", Journal of Power Sources, vol. 264, pp. 211-219, 15 October 2014.

[4] F. Heidler, J. Cvetic, and B. Stanic, "Calculation of lightning current parameters", *IEEE Transactions on Power Delivery*, vol. 14, no. 2, pp. 399-404, 1999..

[5] D. Lovric, S.Vujevic and T. Modric, "On the estimation of Heidler function parameters for reproduction of various standardized and recorded lightning current waveshapes", *International Transactions on Electrical Energy Systems*, vol. 23, no. 2, pp. 290-300, 2013.

[6] MS IEC 60664-1, "Insulation Coordination for Equipment Within Low-Voltage Systems - Part 1: Principles", *Malaysian Standard*, 2014

[7] T. Jiang, and S. Grzybowski. "Electrical degradation of Photovoltaic modules caused by lightning induced voltage", in *2014 IEEE*

Electrical Insulation Conference (EIC), *IEEE*, Philadelphia, Pennsylvania, USA, June 8-11, 2014.

[8] S. P. Balaji and S. Usa, "Life estimation of transformer insulation under repeated impulses", *IEEE 1st International Conference on Condition Assessment Techiques in Electrical Systems (CATCON)*, pp. 331-334, IEEE, 2013.

[9] S. P. Balaji, et al., "Effect of repeated impulses on transformer insulation", *IEEE Transaction on Dielectrics and Electrical Insulation*, vol. 18, no. 6, pp. 2069-2073, Dec 2011.

[10] H. Haeberlin, "Damages at Bypass Diodes by Induced Voltages and Currents in PV Modules Caused by Nearby Lightning Currents Damages at Bypass Diodes by Induced Voltages and Currents in PV Modules Caused by Nearby Lightning Currents", *22nd European Photovoltaic Solar Energy Conference*, Milano, Italy, September, 2008.