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On the Effect of Lightning on a Solar Photovoltaic System

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***Abstract*—A solar PV system was modelled and the effect of lightning striking different parts of a solar PV system was studied and the results discussed appropriately. Lightning strikes of different wave shapes and different magnitudes were considered. The purpose of this research is to observe the transient current and voltage that appears in a solar PV system when struck by lightning. The results show that a transient current will appear at the nearest point to the lightning strike and the value of the transient current is same as the lightning current, while the transient voltage will appear at AC side at any point of lightning strike. This could damage the inverter which requires a high cost to repair or replace. The information of this paper can be useful to decide a suitable lightning protection system before installing a solar PV system.**

Keywords- Solar PV System; lightning strike; different points; lightning wave shape; transient voltage; transient current; PSCAD/EMTDC

I. INTRODUCTION

Nowadays, photovoltaic (PV) solar panels have moved to the forefront of public and industry awareness and have become a new sustainable electricity generation option to replace rapidly depleting fossil fuels. An increase in solar PV performance has taken place as some researchers have studied this new generating technology and have produced solar tracking systems [1] and maximum power point tracking systems [2, 3].

As we know, Malaysia is a tropical country located in Southeast Asia that lies entirely in the equatorial zone which contributes to its high potential for solar PV development. Other than this advantage, the disadvantage is that Malaysia also is highly exposed to lightning and thunderstorm activities. The United States National Lightning Safety Institution reported that Malaysia has an average thunder level within 180-260 days per year [4].

Solar PV systems are usually installing in large, open areas in unobstructed locations for efficient operation to avoid the effects of shading. However, at the same time open areas expose the solar PV panels to the threat of a lightning strike during thunderstorms. Such a lightning strike can cause damage to solar PV modules and also the sensitive electronics parts such as the inverter. This will contribute to the high cost of repair or replacement of the damage parts and also affect the solar system reliability.

When a lightning strike hits a solar PV system it will cause an induced transient current and voltage within the solar PV system wire loops [5]. These transient currents and voltages will appear at the equipment terminals and cause insulation and dielectric failures within the solar PV electrical and electronics components such as the PV panels, inverter, and control and communications equipment [6-7].

An ultra-rapid transient phenomenon will occur when there is a lightning strike and usually the transient is measured in kV/kA to MV/MA. The objective of this simulation is to obtain the value of the transient that occurs when lightning strikes at different parts of a solar PV system with different wave shapes and magnitudes of lightning impulse current. The simulation is performed using Power System Computer Aided Design (PSCAD).

The purpose of this research is to find the value of the transient current and voltage that appears when a lightning strike a solar PV system. This information can then be used to determine suitable protection to protect the solar PV system from damage. This will help to reduce the cost of replacing the expensive parts of the system.

II. SOLAR PV SYSTEM

A solar PV panel contains solar cells that convert sunlight energy to electricity. When a solar cell is exposed to sunlight, the photons with energy greater than the band-gap energy of the semiconductor are absorbed and create a number of electron-hole pairs proportional to the incident irradiation [8]. These carriers are swept along and create a photocurrent under the influence of the internal electric fields of the p-n junction which are directly proportional to the solar insolation [9].

The solar PV system in this present study was modelled in PSCAD/EMTDC as shown in Figure 1 that mainly consists of a PV array model, DC Link Capacitor, three-phase inverter using six Insulated-Gate Bipolar Transistors (IGBT), and a LCL filter. The PV array icon in the PSCAD was modelled to produce 24 kilowatts from 96 modules consisting of four parallel strings each of 24 modules in series. The irradiance was set at 1000 W/m^2 and the temperature was defined as 25 °C referring to the standard test conditions (STC) [10].

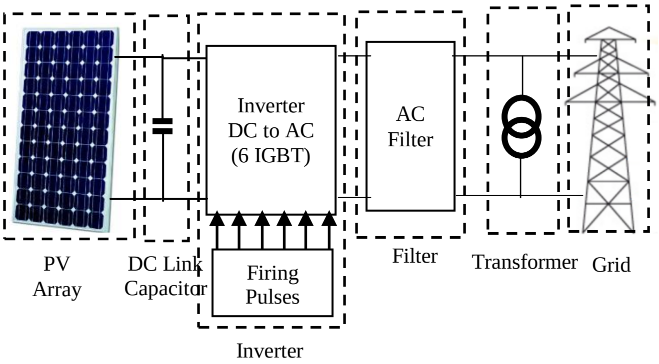
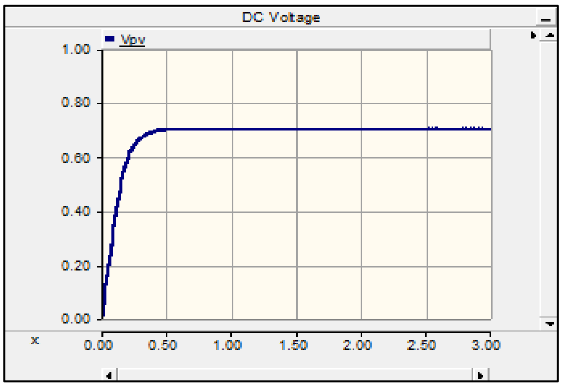


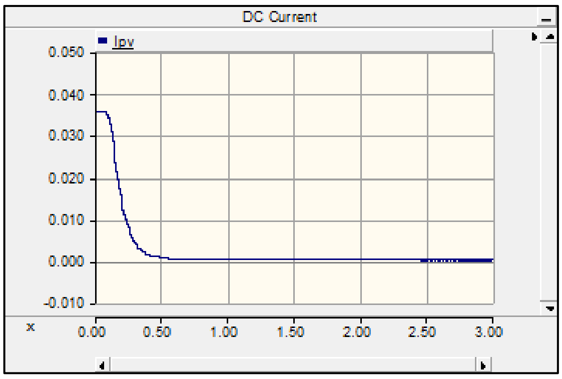
Figure 1: Solar PV System

The DC link capacitor is used to minimise the voltage ripple across the solar PV and also to act as a sink and source for every cycle to help create a balance of power on the DC bus [11].

The DC output is then converted to the AC output using six IGBT. The firing pulses of these six IGBT are generated using the Sinusoidal Pulse Width Modulation (SPWM) technique, where three sinusoidal modulating waves are compared to a triangle carrier wave [12]. The DC output of this solar system can be seen in Figure 2 and the AC output in Figure 3.

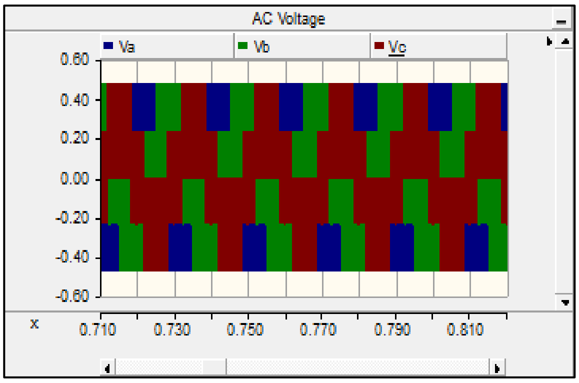


(a)

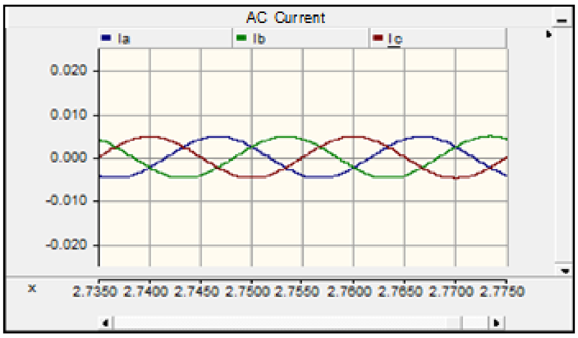


(b)

Figure 2: (a) DC Voltage of the Solar PV System and (b) DC Current of Solar PV System



(a)



(b)

Figure 3: (a) AC Voltage before LCL Filter of the Solar PV and (b) AC Current before LCL Filter of the Solar PV

III. LIGHTNING IMPULSE CURRENT

The research into lightning current waveforms was initially started in 1941 by Bruce and Golde [13-15]. Different mathematical expressions have been used since that time to describe the lightning current waveform and the double exponential expression is used as shown in Equation 1.

$$i(t) = \mathrm{I}\,[e^{\alpha t} - e^{\beta t}] \tag{1}$$

where α and β are formula constants and remain to be determined for the lightning impulse current waveform. These two important parameters will derive the tail time, t_t and front time, t_f respectively. Figure 4 shows the shape of this function.

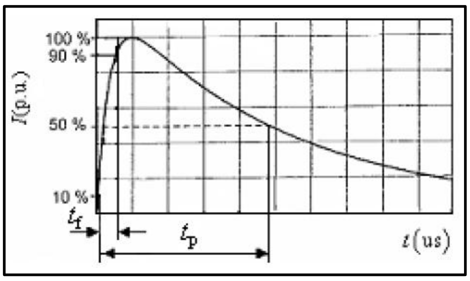


Figure 4: Double exponential lightning impulse current waveform

Referring to the IEEE standard, the suggested value for the lightning current and voltage impulses are 8/20 µs and 1.2/50 µs respectively [16]. However in this paper, only the lightning impulse current will be considered using the standard value given by the IEEE and other non-standard values such as 0.25/100 µs, and 10/350 µs. This lightning impulse current was model in the PSCAD/EMTDC as shown in Figure 5.

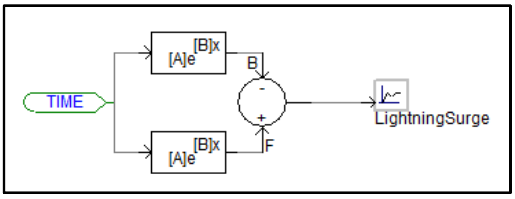


Figure 5: Lightning surge model in PSCAD

IV. RESULTS AND DISCUSSION

In this study a lightning impulse current is assumed to strike at two different points. Point A is between the solar panel and the inverter and Point B is after the inverter as shown in Figure 6. The different points of the strike will have a different effect and this effect will show a specific trend. A different wave shape and different magnitude will be used for the lightning impulse current that is applied as the lightning current source and the results will be compared and discussed accordingly.

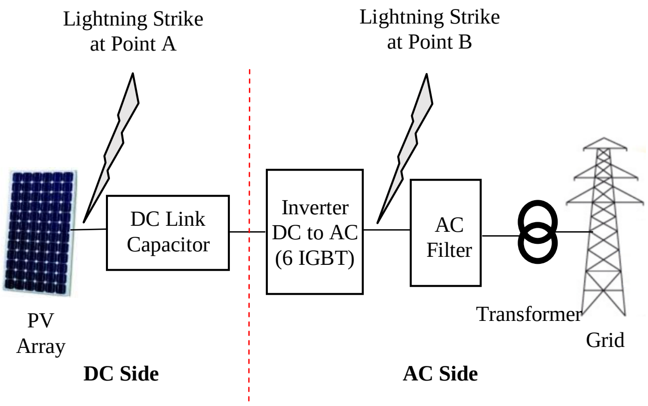


Figure 6: Lightning impulse current striking at different points

Table1 shows the current and voltage at the DC and AC side of the solar PV system under normal operation. The voltage drop at the AC side is due to the 180° conductance inverter operation.

TABLE 1: LIGHTNING IMPULSE CURRENT WAVE SHAPE 0.25/100µS

Solar PV System			
DC		***AC***	
V_{max} (V)	I_{max} (A)	V_{max} (V)	I_{max} (A)
704.42	35.64	469.64	4.17

The maximum output power of the solar system is 24 kW generated from 96 solar PV modules. The DC side attribute is that when the voltage is in time with the current it is closely equal to 24 kW. Table 2 shows the lightning impulse current for a wave shape of 0.25/100 µs with magnitude from 20 kA-100 kA.

In the simulation the lightning effect can be seen for the whole solar PV system even when the strike point is far away. When the lightning strikes at Point A the solar PV panel and the inverter will most likely be damaged. However when the lightning strikes at Point B only the inverter will be damaged. Therefore a protection device is required to protect the inverter and filter because of the expensive cost of these items.

TABLE 2: LIGHTNING IMPULSE CURRENT WAVE SHAPE 0.25/100 µS

	Lightning Impulse Current 0.25/100 µs							
I_{inject} (kA)	Strike at Point A				Strike at Point B			
	DC		***AC***		***DC***		***AC***	
	V_{max} (V)	I_{max} (kA)	V_{max} (MV)	I_{max} (kA)	V_{max} (V)	I_{max} (A)	V_{max} MV)	I_{max} (kA)
20	704.26	20.00	1.33	6.66	704.54	43.00	1.33	6.66
40	704.17	40.00	2.66	13.31	94.36	35.97	2.66	13.31
60	704.15	59.95	4.00	19.99	704.6	71.52	4.00	19.97
80	704.15	79.92	5.33	26.63	188.59	47.02	5.33	26.63
100	733.10	99.89	6.66	33.28	235.69	48.26	6.66	33.28

The high transient of current appears at the DC side when lightning strikes Point A and a high transient current appears at the AC side when lightning strikes Point B. The voltage transient is highly likely to occur at the AC side for both strike points. Table 3 compiles the results of the lightning impulse current for a wave shape 8/20 µs with magnitude from 20 kA-100 kA.

TABLE 3: LIGHTNING IMPULSE CURRENT WAVE SHAPE 8/20 µS

	Lightning Impulse Current 8/20 µs							
I_{inject} (kA)	Strike at Point A				Strike at Point B			
	DC		***AC***		***DC***		***AC***	
	V_{max} (V)	I_{max} (kA)	V_{max} (MV)	I_{max} (kA)	V_{max} (V)	I_{max} (A)	V_{max} (MV)	I_{max} (kA)
20	704.33	19.97	1.24	6.65	705.31	37.03	1.22	6.65
40	704.26	39.91	2.48	13.29	1.24k	41.11	2.45	13.29
60	704.23	59.85	3.71	19.94	1.85k	38.16	3.67	19.94
80	704.18	79.79	4.95	26.58	2.45k	40.85	4.89	26.59
100	704.16	99.73	6.19	33.23	3.06k	35.67	6.11	33.25

The value of the voltage and current transient; V_{max} and I_{max} that appeared for a wave shape of 8/20 µs is the similar value for the 0.25/100 µs wave shape. Table 4 is the result of a lightning impulse current for a wave shape of 10/350 µs with magnitude from 20kA-100kA. As can be seen, the wave shape for 10/350 µs also has the same behaviour as the wave shape 0.25/100 µs and 8/20 µs.

TABLE 4: LIGHTNING IMPULSE CURRENT WAVEFORM 10/350 µS

Lightning Impulse Current 10/350 µs								
I_{inject} (kA)	Strike at Point A				Strike at Point B			
	DC		AC		DC		AC	
	V_{max} (V)	I_{max} (kA)	V_{max} (MV)	I_{max} (kA)	V_{max} (V)	I_{max} (A)	V_{max} (MV)	I_{max} (kA)
20	704.15	19.96	3.34	6.64	704.90	38.87	3.34	6.67
40	827.10	39.88	6.68	13.28	1.00k	40.83	6.69	13.34
60	1.23k	59.8	1.00	19.92	1.49k	46.82	1.00	20.01
80	1.63k	79.72	1.33	26.56	1.98k	35.64	1.33	26.68
100	2.03k	99.65	1.67	33.20	2.46k	35.64	1.67	33.35

From the results, it shows that the transient current appears at the lightning strike point and the transient voltage is high at the AC side. However the values of the transients are mostly high at the AC side. The reason for this behaviour occurring is because in a solar PV system, the inverter behaves as a current source, so it tries to draw a balance between the three sinusoidal currents.

If lightning strikes with the same magnitude as a previous strike, the values of the transient current and voltage are almost similar. However the value of the high transient is based on the long duration of the tail time. The longer the tail time of the lightning strike, the higher the transient that will occur.

V. CONCLUSION

In conclusion, the transient behaviour of a solar PV system was obtained for different wave shapes with different magnitudes. The results show that when lightning strikes, a transient current will appear at the nearest point to the strike and the value of the transient current will follow the lightning current. For a solar PV system, a high voltage transient appears at the AC side at the inverter, thus causing damage to the inverter. The result of this paper can be use in order to determine the suitable protection level for the solar PV system.

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REFERENCES

[1] Poulek, V. and Libra, M. 1998. "New solar tracker". *Solar energy materials and solar cells* 51.2: 113-120.

[2] Enslin, J. H. R. November, 1990. "Maximum power point tracking: a cost saving necessity in solar energy systems". In *Industrial Electronics Society. IECON'90. 16th Annual Conference of IEEE.* 1073-1077

[3] M.Z.A. Ab Kadir, Y. Rafeeu, and N.M. Adam, "Prospective scenarios for the full solar energy development in Malaysia". *Renewable and Sustainable Energy Reviews*, 2010, *14*(9), pp.3023-3031.

[4] M.K. Hassan, A. Che Soh, A. Kadir, M.Z Abidin, A. Rahman, and R. Zafira, "Lightning strike mapping for peninsular Malaysia using artificial intelligence techniques", *Journal of Theoretical and Applied Information Technology*, 2011, *34*(2), pp.202-214

[5] P. Vangala, M. Ropp, K.D. Haggerty, K. Lynn, and W. Wilson, "Field measurements of lightning-induced voltage transients in PV arrays", In*Photovoltaic Specialists Conference, 2008. PVSC'08. 33rd IEEE*, pp. 1-4.

[6] M.A. Hossain, and M.R. Ahmed, "Analysis of Indirect Lightning Phenomena on Solar Power System", 2014, *21*(4), pp.127-133.

[7] Hernández, Y. M., Ioannidis, D., Ferlas, G., Tsovilis, E. G. T., Politis, Z., & Samaras, K., "An experimental approach of the transient effects of lightning currents on the overvoltage protection system in MW-class photovoltaic plants", In *Lightning Protection (ICLP), 2014 International Conference o*, IEEE, pp. 1972-1977, October , 2014.

[8] G. Bhuvaneswari and R. Annamalai, "Development of a solar cell model in Matlab for PV based generation system," India Conference (INDICON) Annual IEEE, pp. 1-5, 2011.

[9] H.L. Tsai, C.S. Tu, and Y.J. Su, "Development of generalized photovoltaic model using Matlab/Simulink", Proceedings of the world congress on Engineering and computer science, vol. 2008, pp. 1-6, October 2008.

[10] International Electrotechnical Commission, "Standard IEC 60904-3: photovoltaic devices", Part 3: measurement principal for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data, 1987.

[11] A. Kalbat, "PSCAD simulation of grid-tied photovoltaic systems and Total Harmonic Distortion analysis", In *Electric Power and Energy Conversion Systems (EPECS), 2013 3rd International Conference on*, IEEE, 2013, pp. 1-6.

[12] B.A. Johnson, "Modelling and Analysis of a PV Gried-Tied Smart Inverter's Support Functions", (Doctoral dissertation, California State University), 2013.

[13] C.E.R. Bruce and R.H. Golde, "The lightning discharge", *Journal of the Institution of Electrical Engineers-Part II: Power Engineering*, 1941, *88*(6), pp.487-505.

[14] W. Jia, and Z. Xiaoqing, "Double-exponential expression of lightning current waveforms", In *Environmental Electromagnetics, The 2006 4th Asia-Pacific Conference on*, IEEE, 2006, pp. 320-323.

[15] M. Izadi, M.Z.A. Ab Kadir, C. Gomes, and W.F. Ahmad, "Numerical expressions in time domain for electromagnetic fields due to lightning channels", *International Journal of Applied Electromagnetics and Mechanics*, 2011, *37*(4), pp.275-289.

[16] MS International Electrotechnical Commission, "Standard MS IEC 61000-4-5: Electromagnetic Compatibility (EMC)," Part 4-5: Testing and measurement techniques – Surge immunity test, 2007.