TELKOMNIKA, Vol.12, No.1, March 2014, pp. 47~52
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v12i1.1976

Investigation of Wave Propagation to PV-Solar Panel Due to Lightning Induced Overvoltage

Nur Hidayu Abdul Rahim*, Zikri Abadi Baharudin, Md Nazri Othman, Zahriladha Zakaria, Mohd Shahril Ahmad Khiar, Nur Zawani Saharuddin, Azlinda Ahmad
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Karung Berkunci No.1752, 76109 Durian Tunggal, Melaka, Malaysia.
*Corresponding author, e-mail: zikri@yahoo.com

Abstract

Lightning produces extremely high voltages that generated induce overvoltage which have a high tendency to effect the electrical apparatus especially renewable energy plant that directly expose to this source. This study was performed through experimental work by investigating the effect of induce overvoltage upon the photovoltaic system. The induce voltage was performed by using lightning impulse generator. It is found that the maximum voltage of the unwanted signal is proportional with the distant of the specimen. The closer distant between solar panel material and spark discharge, the more serious effect would occur due to the induced overvoltage.

Keywords*: Photovoltaic system, Induced overvoltage and wave propagation.*

1. Introduction

Induced overvoltage is created by either direct or indirect lightning strike hit on solar panel system. A cloud to ground lightning flash generates a transient electromagnetic field which can induce overvoltage of significant magnitudes on overhead lines situated in the adjacent. Like all electrical equipment photovoltaic systems can be damaged with both direct and indirect lightning strikes and other overvoltage disturbances caused by electrical switching operations, load switching and so on. Statistics on damage due to lightning induced overvoltage from the strike point have shown that the installations between solar panel and electronic equipment up to about 1 km may be impressionable to induced or line-carried overvoltage [1]. Furthermore, to produce large amount of electricity needs a large size of solar cell but have a tendency to increase the probability to be affected by lightning strike activity.

The phenomenon of lightning has been the subject of intensive study by researchers [2,5] and its behaviour is fairly predictable in general terms, although the exact description of specific incidents is not predictable. Protection against lightning effects includes two categories: direct strike (direct effects) and indirect strike. Direct strike is concerned with the energy, heating, flash, ignition of the lightning current, and indirect strike or also known as lightning-induced overvoltage (indirect effect) which coupling between the lightning stroke and, either to the PV system or lines conductor in electrical and electronic systems. The work of lightning and surge protection of photovoltaic installations by researcher [6] have speculated about two installations of PV systems which were damaged during lightning thunderstorms, may due to direct lightning strike. The two locations were located in Vulcano Island (Italy) and Kythnos Island (Greece). Following the description of these two case studies, a discussion is presented and leading to firm conclusion when the evident is sufficient and also allowing conjectures when the evident is less then conclusive. However, the evident is insufficient to conclude that all observed damage was caused by direct lightning strike effect since it is very difficult to predict when exactly lightning strike to the specific point. Therefore further investigation of direct effect need to be done by considering the complexity, the cost, and safety issues.

Recently, the lightning simulation for PV system concerning lightning-induced overvoltage was appeared in [7]. The work of [8] calculated and analysed the induced overvoltage for PV panel arrays on the rooftop of building. They concluded that the lightning-induced overvoltage is directly proportional to the peak value of lightning current. Indeed, they claimed that the high building, soil resistivity and the distance effect were more serious factor to be exposed to the overvoltage. Furthermore, their investigations concluded that the selection of Surge Protective Devices (SPD) should be considered for all the factors mentioned above. This

Received November 27, 2013; Revised January 5, 2014; Accepted February 11, 2014

problematic matter has greatly encouraged to further study in examining and developing the proper lightning protection scheme for PV system.

The main goal for this paper is to provide the important signature of unwanted signal that coupled to the solar panel. This signature is due to the propagation effect of induced voltage created by the short spark gap from experimental work in the high voltage laboratory. In order to fulfil this goal in research, the lightning artificial discharge of 1.2/50 μs with the peak voltage of 66 kV is built by having vertical orientation layout. The solar panel is located apart from the spark gap with the initial distance of 1.0 m. The distance between solar panel and spark gap is varied in order to see the relationship of the maximum voltage of unwanted signal and the distance of the specimen.

2. Experimental Work

The experimental work is conducted to determine the breakdown probability of a spark gap under voltage impulse by generating 66 kV impulse voltages. The experiment is carried out at High Voltage Laboratory, Universiti Teknikal Malaysia Melaka. The instruments used are as below:

1. Diode (140 kV, 20 mA)
2. Smoothing and Energy Storage Capacitor (25 nF)
3. Parallel Resistor (Tail Resistor)
4. Series Resistor (Wave front Resistor)
5. Solar panel array (21 V)
6. Spark Gap
7. Measuring Capacitor
8. Impulse Voltage Configuration Circuit
9. Oscilloscope
10. Electrical copper cable 1.5mm^2 (15 m)

The experiment is set up to investigate the effect of indirect lightning strike on the output of solar panel as shown in Figure 1. The experiment is conducted using impulse generator in high voltage laboratory to produce impulse voltage. The output from solar panel in the form of waveform is read using 2-input channels oscilloscope. Impulse voltage is generated by discharging high voltage capacitors through switching onto network of resistor and capacitors as shown in Figure 2. To perform a testing for impulse voltage, double exponential impulse voltage has been utilised.

Figure 1. Impulse voltage generator configuration in high voltage laboratory to produce high voltage

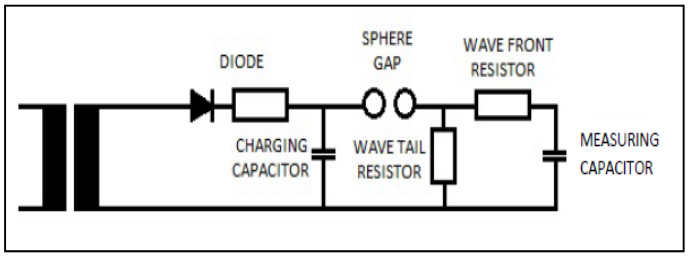

Figure 2. Circuit to generate impulse voltage using impulse voltage generator in high voltage laboratory

The next experiment is conducted to investigate the effect of the propagation of unwanted signal on solar panel with SPD. A solar panel with the rated of 21 V and 80 W is placed perpendicular apart from spark gap with the range distance of 1.0 m to 2.5 m. Furthermore, in order to see the relation between voltage of unwanted signal and the distance of solar panel is increased by the factor of 0.5 m. The 15 m length of 1.5mm^2 electrical copper cable is connected from the solar panel to the oscilloscope and the internal impedance is set to 1MΩ under full bandwidth operation. The lightning artificial voltage (1.2/50 μs) is generated up to 66 kV and the trigger is set to be 30% of input voltage. Trigger system is function to stabilize repetitive waveforms and capture single-shot waveforms. The result is saved with ASCII format and analysed by using MATLAB.

3. Experimental Result and Discussion

Figure 3 below shows the input signal before the lightning artificial voltage (1.2/50 μs) is generated to 66 kV. The distance between solar panel array and spark gap is 1.0 m. Naturally, the existence noise on solar panel array is 2 V due to the light sources in the laboratory.

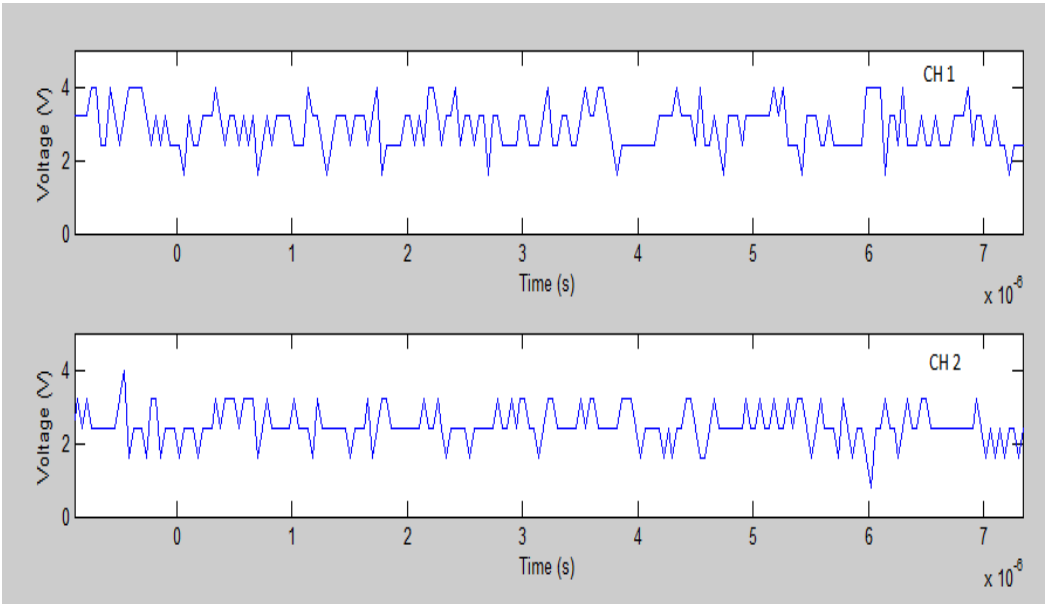

Figure 3. Profile of input signal (1.2/50μs) before inject 66 kV of impulse voltage

Figure 4 and 5 show the characteristic of unwanted signal due to induced overvoltage perform by artificial lightning generator at 1.0 m distance respectively. The induced overvoltage is labelled as input signal (CH 1) while the unwanted signal is labelled (CH 2). Figure 4 indicates

that the unwanted signal (CH 2) is appeared as train pulses which are correlated with fast front. It is found that the first pulse of pulse train exhibits the highest voltage. For example, the distance gap of 1.0 m is found to have 21 V (see Figure 4).

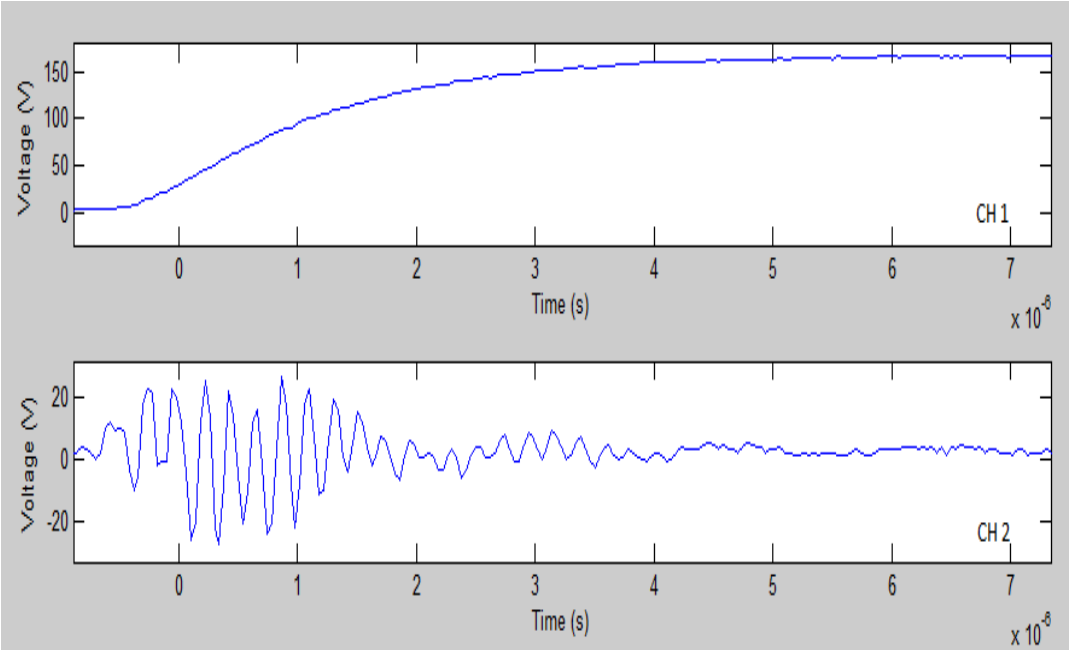

Figure 4. Profile of input signal (1.2/50μs) with the peak voltage of 66 kV and the unwanted signal of solar panel with the distance between spark gap and solar panel of 1.0 m
* Actual voltage for input signal (CH 1) = 390 x voltage oscilloscope

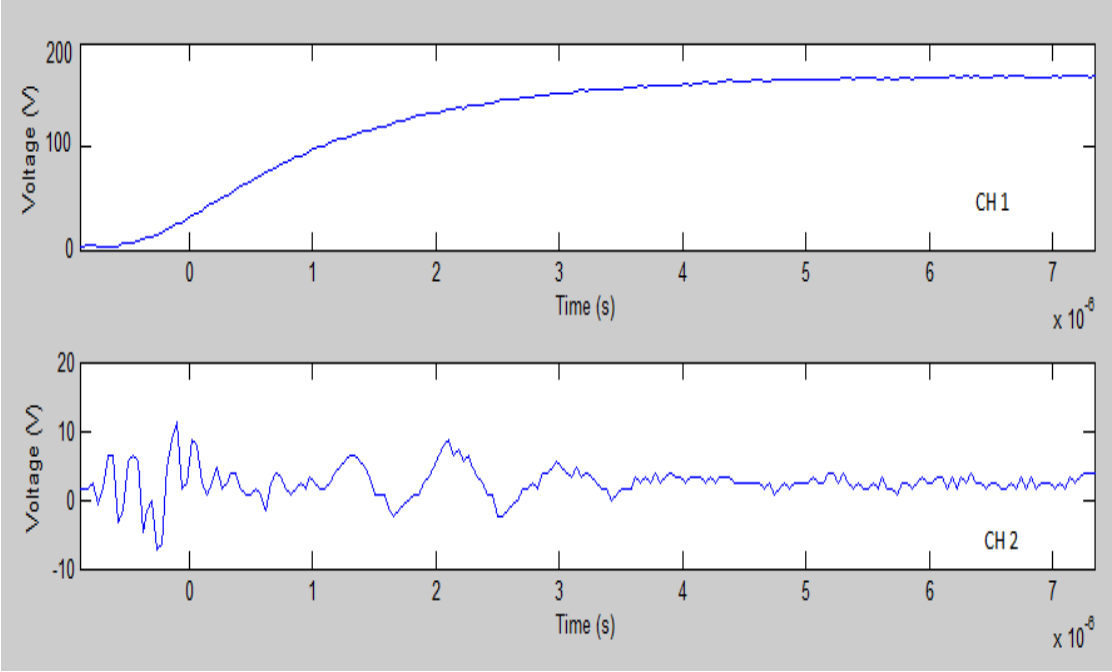

Figure 5. Profile of input signal (1.2/50 μs) with the peak voltage of 66 kV and the unwanted signal of solar panel with the distance between spark gap and solar panel of 2.5 m
* Actual voltage for input signal (CH 1) = 390 x voltage oscilloscope

Figure 5 above shows the results of the gap distance of 2.5 m with the maximum voltage of unwanted signal of 7 V. From this experiment, it is observed that the maximum voltage of unwanted signal (first pulse) decreases when the gap distance between spark gap and solar panel is increased (see Figure 5).

Table 1. Maximum voltage of unwanted signal propagation in solar panel

No.	Distant (m) and Maximum Unwanted Signal (V)			
	1.0m	1.5m	2.0m	2.5m
1	26.8 V	10.4 V	10.4 V	4.8 V
2	26 V	15.2 V	7.2 V	8 V
3	25.2 V	14.4 V	8.2 V	6.4 V
4	26 V	14.4 V	8 V	3.2 V
5	26 V	14.4 V	7.2 V	2.4 V
6	25.2 V	16.8 V	11.2 V	4 V
7	26.8 V	13.6 V	7.2 V	4 V
8	30 V	15.2 V	8.8 V	4 V
9	22.4 V	18.4 V	8 V	4 V
10	23.2 V	14.4 V	6.4 V	4 V
11	24.8 V	14.4 V	9.6 V	4 V
12	24.8 V	15.2 V	10.4 V	4 V
13	27.2 V	13.6 V	9.6 V	11 V
14	25.6 V	15.2 V	6.4 V	11.2 V
15	25.6 V	16.8 V	8.8 V	9.6 V
Mean	25.706 V	14.826 V	8.4933 V	5.64 V
Max. point	30 V	18.4 V	11.2 V	11.2 V
Min. point	22.4 V	10.4 V	6.4 V	2.4 V
Median point	25.6 V	14.4 V	8.2 V	4 V
Std. dev	3.4340	1.7854	1.5021	2.896

Statistically, the result of unwanted signal from different distance of solar panel is decreasing proportionally as shown on Table 1 above. There is a significant distinction when comparing the results of unwanted signal signature between the distance of 1.0 m and 2.5 m. At the distance of solar panel and spark gap of 1.0 m and 2.5m, the average magnitudes of unwanted signals are 25.70667 V and 5.64 V proportionally (see Figure 6). This shows that the distance between the solar panel and the indirect lightning is significantly affecting the unwanted signal values and thus can cause damage to electronic equipment.

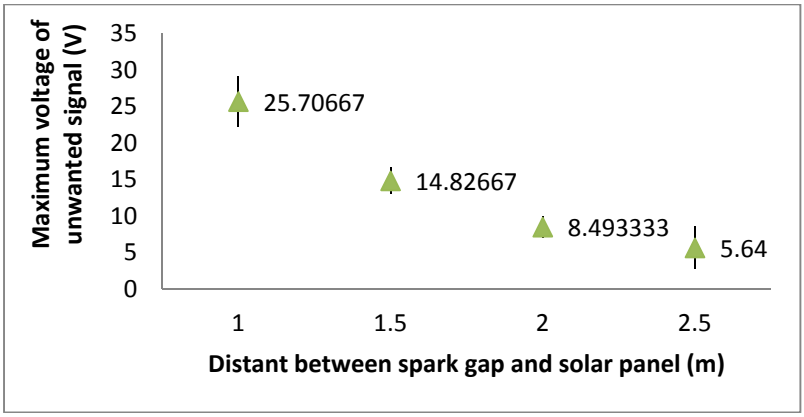

Figure 6. Gap distance of solar panel and spark gap versus maximum voltage of unwanted signal

4. Conclusion

The existence of unwanted signal due to the induced voltage with the profile of maximum voltage, duration and pulse width of unwanted signal was observed, and discussed in detail in the result and discussion sections. It is found that the maximum voltage of the unwanted signal is proportional with the distant of the specimen. The closer distant between

solar panel material and spark discharge, the more serious effect would occur due to the induced overvoltage.

Acknowledgements

The authors would like to thank the Universiti TeknikalMalaysia Melaka (UTeM) for providing the short term grant PJP/2012/FKE (5A)/S01080 for this research.

References

[1] Jesus C. Hernandez, pedro G. Vidal Francisco J. Lightning and surge protection in Photovoltaic Installation. *IEEE Transactions on power delivery*. 2008; 23(4): 1961-1971.
[2] H. –J. Stern, H. C. Karner. *Lightning Induced EMC phenomena in photovoltaic modules*. Proceedings of IEEE EMC conference. 1993: 442-446.
[3] V. A. Rakov et al. Direct lightning strikes to the lightning protective system of a residential building: Triggered lightning experiments. *IEEE Transaction Power Delivery*. 2002; 17(2): 575-586.
[4] P. Hasse. *Overvoltage protection of low voltage systems*. 2nd edition (London IEE press, Book review), ISBN 0852967180. May 1992: 192.
[5] F. A. M. Rizk. Modeling of transmission line exposure to direct lightning strokes. *IEEE Transaction of Power delivery*. 1990; 5(4): 1983–1997.
[6] F.D.Martzloff. *Lightning and surge protection of photovoltaic installations*. NISTIR 89 – 4113, Sandia National Laboratories, Albuquerque, Jun 1989.
[7] T. Youping, C. Zhang, J. Hu, S. Wang, W Sun, H. Li. *Research on lightning overvoltage of solar arrays in a rooftop photovoltaic power system*. 7th Asia Pacific International Conference on lightning. 2011; 94: 10–15.
[8] Yokoyama S., K. Miyake, H. Mitani, A. Takanishi. Simultaneous measurement of lightning induced voltages with associated stroke currents. *IEEE Transactions on Power Apparatus and System(PAS)*, 1983; 102(8): 2420-2429.
[9] Master M.J., M.A. Uman, W.H. Beasley, M. Darveniza. Lightning induced voltages on power lines: experiment. *IEEE Transaction on Power Apparatus and Systems (PAS)*. 1984; 103(9): 2519-2529.
[10] de la Rosa ; Inst. de Investigaciones Electr., Cuernavaca, Morelos, Mexico, Valdivia, R. Perez, H. ; Loza, J. Discussion about the inducing effects of lightning in an experimental power distribution line in Mexico. *IEEE Transaction on Power Delivery*. 1988; 3(3): 1080-1089.
[11] Rubinstein M., A.Y. Tzeng, M.A. Uman, P.J. Medelius, E.W. Thomson. An experimental test of a theory of lightning-induced voltages on overhead lines. *IEEE Transaction on Electromagnetic Compatibility (EMC)*. 1989; 31: 376-383.
[12] Barker P.P., T.A. Short, A. Eybert-Berard, J.B. Berlandis. Induced voltage measurements on an experimental distribution line during nearby rocket triggered lightning flashes. *IEEE Transaction on Power Delivery*. 1996; 11: 980-995.
[13] Swanson, R. M. Photovoltaic Power Up. *Science*. 2009; 324(5929): 891–2. doi:10.1126/science.1169616. PMID 19443773.
[14] Renewable Energy Policy Network for the 21st century . Renewables 2010 Global Status Report. Paris. 2010: 1–80.
[15] Antonio Luque and Steven Hegedus. *Handbook of Photovoltaic Science and Engineering*. John Wiley and Sons, ISBN 0-471-49196-9. 2003.