Model and Experiment for study and analysis of Photovoltaic lightning Effects

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***Abstract*--This paper will present the proposed model and experiment of effects from lightning impulse on photovoltaic. The study will show results of effect from lightning impulse indirect striking on Photovoltaic. As the increasing of photovoltaic applications worldwide, there are varieties of photovoltaic applications around the world have been installed. From the records and reports of photovoltaic applications, there are many serious cases that photovoltaic applications were damaged by thunder lightning strikes on photovoltaic module or its components. When lightning impulse strikes to the area of PV system, the effects cause a failure of PV system therefore it is really necessary to study this problem in order to find the appropriated method to protect the PV system. The paper proposes a simulation model to study phenomena and characteristic from lightning impulse on PV system by Matlab/Simulink. The PV experimental platform is also constructed for the implementation in the High volt laboratory of Rajamangala University of Technology Thunyaburi (RMUTT). The experimental platform is tested by lightning impulse generated from 100 – 800 kV. The results from the laboratory will be investigated comparing to the simulation results. Moreover the method of protecting PV system from the Lighting Impulse will be introduced.**

I. INTRODUCTION

Normally the installation of Photovoltaic system is installed in the free area or on the roof of building. Thus the installation areas have the risk from the lightning strike on the photovoltaic module or its components. From the reports, the lightning impact is very severe for PV if we don't have the appropriated protection system. Normally, the PV system has already lightning protection by using a typical air terminal. However, after lightning storm, the reported photovoltaic system is still defected especially its components, thus it has a high cost for replacing the defected equipments and short of power deliver to consumers. For this reason, it is necessary to study and investigate the effects of lightning on PV. We set up a model an experiment for study of the effect. The Matlab/Simulink is used for the model simulation. The model is used to investigate the characteristic of the PV for understanding when the impulse occurs. The PV equivalent circuit as shown in Fig. 1 is considered for model of photovoltaic simulation.

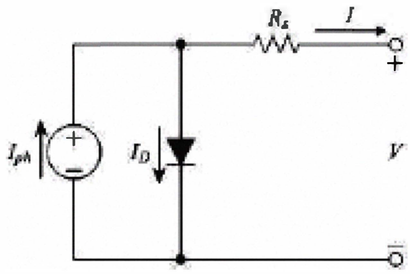

Fig.1: PV Equivalent circuit

From the Equivalent circuit, we obtained as;

$$I = I_{ph} - I_D = I_{ph} - I_{sat}\left[e\frac{V + IR_s}{V_t} - 1 \right] \qquad (1)$$

when I_{ph} = Photovoltaic current
V_t = Thermal Voltage
I_{sat} = Saturated diode current

As the short circuit we obtained as;

$$I_{ph}(G_a, T) = I_{scs}\frac{G_a}{G_{as}}\left[1 + \Delta I_{sc}(T - T_s)\right] \qquad (2)$$

when Ga = Irradiation
T = Absolute Temperature
Iscs = Standard of short circuit current
Gas = Standard of irradiation 1000 W/m^2
ΔI_{sc} = Coefficient temperature of Short circuit current
Ts = standard of temperature 298 K

And open circuit voltage as;

$$V_{oc}(T) = V_{ocs} + \Delta V_{oc}(T - T_s) \qquad (2)$$

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V_{ocs} = standard voltage when open circuit test

ΔV_{oc} = Coefficient temperature of Open circuit Voltage

The photovoltaic current obtained as;

$$I_{ph}(G_a,T) = I_D(G_a,T) \qquad (4)$$

The diode current obtained as;

$$I_D = I_{sat} \times \left[e^{\frac{V_{oc}}{V_t}} - 1 \right] \qquad (5)$$

The terminal photovoltaic voltage as;

$$V_t = \frac{AkT}{q} \qquad (6)$$

A = Ideality Factor

q = 1.602 x 10-19 culomb

k = Boltzman constant 1.38 x 10-23 J/K

So we find saturated current of diode from ;

$$I_{sat} = \frac{I_{ph}}{e^{\frac{V_{oc}}{V_t}} - 1} \qquad (7)$$

Then we can have the simulation PV model from mentioned equations. Another consideration is the model of lightning impulse. We can define the standard lightning impulse as Fig. 2 which has the wave time of 1.2/50 µs. The following equation is for the lightning impulse.

$$U(t) = k_u \times U_{max} \times (\exp\times(-\frac{t}{\tau_2}) - \exp\times(-\frac{t}{\tau_1})) \qquad (8)$$

When k_u = Factor of maximum voltage increase

U_{max} = Maximum value of voltage surge

τ_1 = Time constant of transient wave front

τ_2 = Time constant of transient wave tail

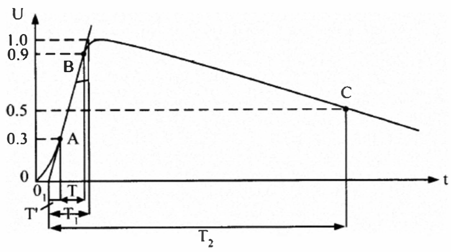


Fig. 2: Standard lightning impulse waveform

II. MODEL OF PV AND LIGHTNING IMPULSE

The model of PV module and lightning impulse are constructed by Matlab/Simulink accordingly to the mentioned equations. The PV model can be done as shown in Fig.3.

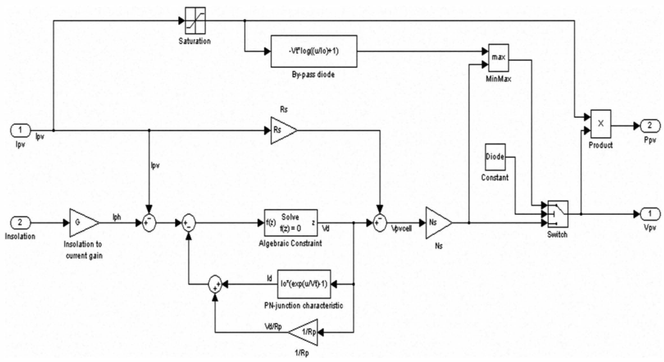


Fig. 3: Block of the constructed PV model

Then from the constructed PV model as Fig.3, we can create as a symbol for proposed PV model as shown in Fig. 4.

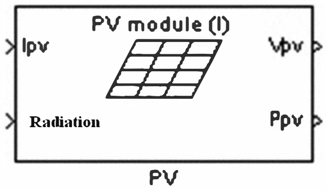


Fig. 4: Proposed PV Model

To simulate, the diagram is constructed as in Fig.5. We can enter radiation for simulation and the I-V curve output form the simulation is shown in Fig. 6 which can confirm that the model is correctly constructed.

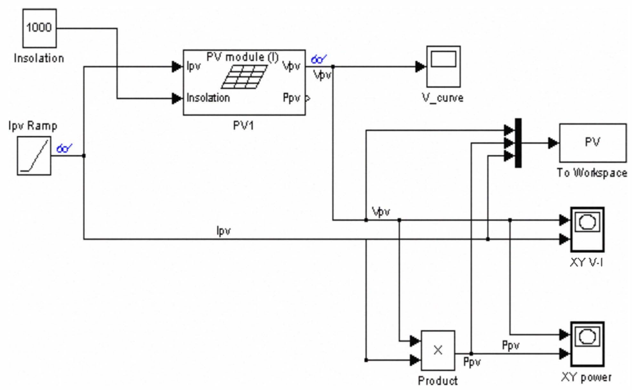


Fig 5. Block diagram simulation PV Module

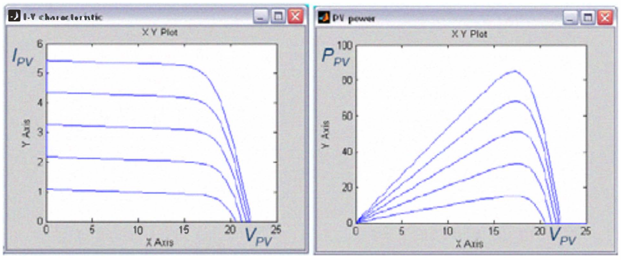


Fig. 6: I-V curve of constructed PV model

For the lightning impulse, we can construct from the math equation as in Fig. 7 and the output of lightning model confirms that the constructed model is correctly done as in Figure 8 which has 12/50 µs as the standard.

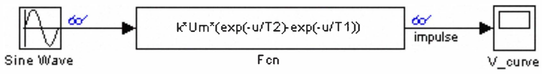


Fig. 7: The constructed lightning impulse model

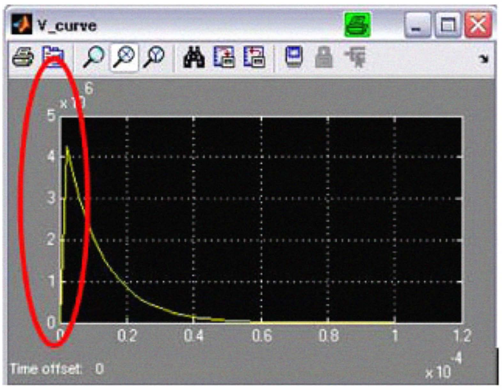


Fig. 10 Output of the constructed lightning model

After the construction of PV and lightning model, the combination between PV and lightning is investigated. It is hard to find out where the impulse should be in the PV model. Therefore the real experiment must be implemented in order to investigate the PV lightning effects.

III. Experiment Set Up

The Experiment is set up at Rajamangala University of Technology Thanyaburi for testing of the lightning impulse on photovoltaic module. The experiment consists of a PV module, lightning impulse generator, and system measuring equipments. The impulse generator is used the standard circuit of the basic lightning impulse shown in Fig.11 and Fig.12 is the laboratory Impulse generator for the experiment.

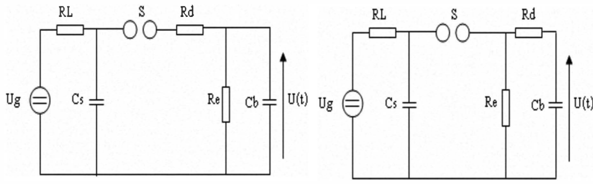


Fig.11: Equivalent circuit of lightning impulse

Fig.12: Lightning Impulse generator 800 kV

The measuring devices are set up at the control room accordingly to the standard. Fig. 13 is the control room and measuring devices.

Fig. 13: Control and measurement devices

The PV module which is used for the experiment is constructed in a single stand. The PV module is designed as its installation which has suitable tilt angle up to the installation area, for this study we can adjust the tilt angle for suitable angle in Thailand as 15-30 degree. The stand is Metal which can be connected to ground. Fig. 14 shows the PV module for the experiment. The design module is connected to ground rod in the laboratory which normally in the site-installation we connected the flame of the PV to ground. The output of PV module is connected to the oscilloscope in the control room for measuring via standard coaxial cable. Fig. 15 is the construction of experiment.

Fig. 14: Construction of Laboratory PV module

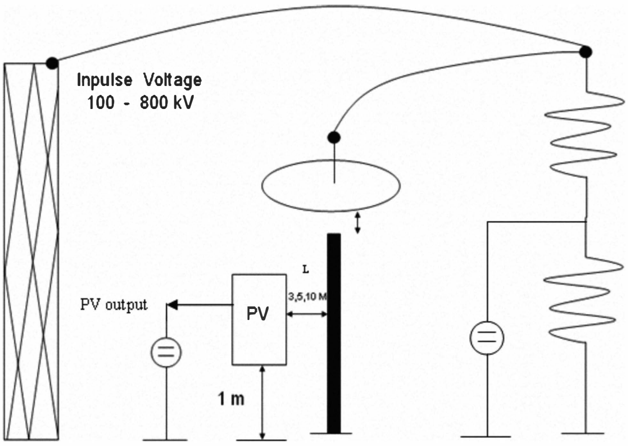


Fig.15: Diagram of constructed Experiment

The measuring devices for the Impulse and the oscilloscope of the PV module are set in the control room. The impulse is set to strike to the rod near by the PV module which is selected a distance (L) of 3,5,10 m for the study. The impulse voltage is selected at 200 kV and 400 kV for this study.

IV. Experimental Results

As mentioned, the experiment is used the impulse generator, the output of impulse wave form which is used for the experiment is shown in Fig. 16 which is chopped of 200 kV. The output of PV module is up to the radiation. At the rated voltage is 24V however the rated voltage of PV is not consider in this study, we will consider for the PV output signal after lightning impulse.

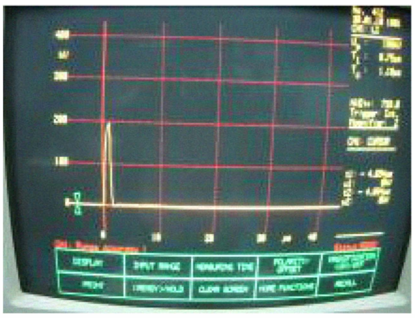
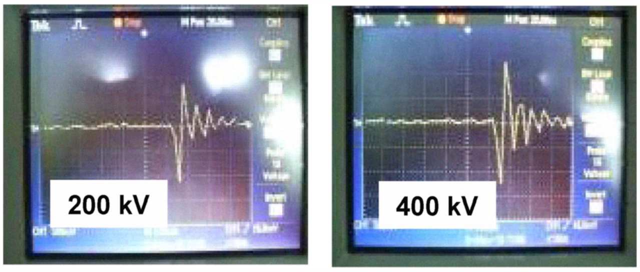


Fig. 16: Lightning impulse 200 kV

After lightning impulse by the distance (L) is 5 meters, the oscilloscope can measure the signal from the PV module as in Fig. 17. This can be seen that the outputs of PV module before and after lightning impulse are different. The effect from lightning impulse creates a signal to the PV output even we already connected the flame of PV module to ground. From the experiment results, it is obvious that we can not protect PV module by only ground system. When we increase the voltage to 400 kV, the output has similar wave form but has higher voltage this can be sure that the effect of the lightning impulse is from the same direction and the output is correct.

a) Before Lightning Impulse



b) After Lightning Impulse

Fig.17: Output of PV module before lightning impulse and after with 200 kV and 400 kV

From the results, at the lighting impulse voltage 200 kV, the output voltage is 400 Vp and at 400 kV, the output voltage is 625 Vp. With this level voltage, the system components which connected to PV can be destroyed this is very important to protect PV system components from this effect. However, from the experiment the PV module is not broken therefore we investigate the direction of effect from lightning impulse. We investigate from the model of PV and impulse and found that the effect should come into the output of PV as the simulation in Fig. 18.

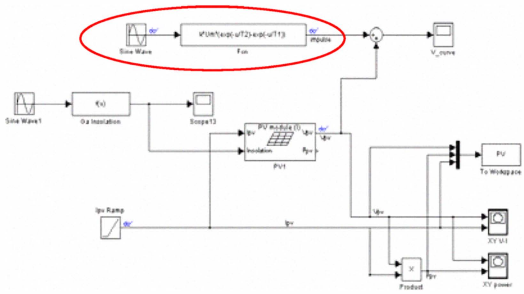


Fig. 18: Simulation of PV with lightning impulse

The output effect must come from induced electromagnetic into the output of PV, however the proposed simulation has output which is only in Positive waveform (as Fig. 10) so that this study must continue in future. From the experiment we can see that even we have ground system however the lightning impulse can have effect to the PV output

V. CONCLUSIONS

In this paper, we constructed a PV and Impulse model for study of PV impulse effects. The experiment is also implemented for the study. The experiment is set up accordingly to standards. In the experiment, we measure the output from PV module. After the test, the output voltage of photovoltaic has the lightning impulse signal combining together with PV output even we have a grounding system. The main effect is from the magnetic field intensity. It occurs from lightning impulse current. The magnetic field intensity is a main factor to induce voltage on output of photovoltaic. This induce voltage can damage to PV cell, converter, and other equipments in the PV system. From the study, the results indicate that the level of induced voltage will depends also on the level of impulse voltage. To protect this effect, The PV system must have a protecting zone from lightning impulse and also must have lightning protection device at the output of PV to protect the induced voltage from magnetic field. From the simulations, the output of proposed combination model is different from experimental results, this must study more in future. From the experiment, the effect from lightning is from the electromagnetic field.

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