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Impedance Analysis and Surge Characteristics of PV Array

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ABSTRACT

Photovoltaic (PV) array, which is generally installed outside, has the possibility of being damaged by high voltage due to lightning primarily because the electrical characteristics of PV array have not been fully identified by lightning yet, there is a very important issue whether PV array should be connected with a ground or not.

In this paper, a basic model of PV array is provided considering the PV cell's barrier capacitance and ground capacitance for analysis of electrical characteristics by lightning

Keywords: Photovoltaic (PV), simulator, optimum

1. Introduction

A large photovoltaic (PV) array is easily hit by lightning due to high generation capacity However, the electrical characteristics of PV array by surge voltage are undefined For this reason, there are some countries that ground PV array, while others do not Therefore, the electrical characteristics of grounded and non-grounded PV array need to be analyzed and evaluated for safety and protection of PV system.

In this paper, the author proposes a basic model of PV array based on measured and calculated results

2. PV Array Model

2.1 Structure of PV module

Figure 1 shows a general structure of PV module

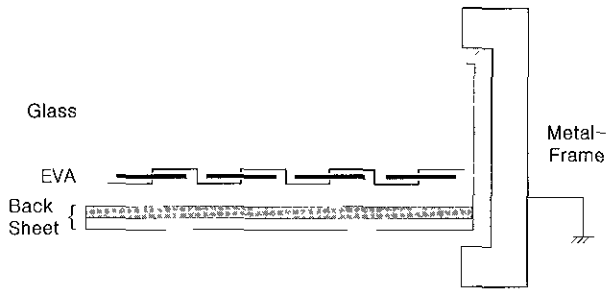

Fig 1 Structure of PV module

PV module consists of glass, ethylene vinyl acetate (EVA), solar cell, back sheet and metal-frame etc Because of metal-frame is grounded, a ground capacity exists between output terminal and metal-frame of PV module

Impedance characteristics of PV module are measured and calculated, and then a basic model of PV module is expressed using impedance characteristics results

2.2 PV cell model

PV cell consists of silicon semiconductor with p-n junction capacity In this paper, when cell is insolated and is not, the impedance of output terminal in cell is measured using LCR meter

This paper is recommended by chairperson of 2003 Power Electronics Annual Conference as one of good papers

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2.3 PV module model

Several cells of PV module are connected with series and parallel The measurement method of PV module impedance is the same as PV cell model.

2.4 The model between PV module and metal-frame

Figure 1 shows that the cell is surrounded and insulated by EVA Thus, insulation resistance and earth capacity exist between output terminal of PV module and metal-frame The insulation resistance, which is located between the output terminal and the metal-frame of the PV module is measured The measurement method of insulation resistance using LCR meter is as follows

(1) Short-circuit output terminal of PV module.

(2) Supply a voltage of 1000VDC between output terminal and metal-frame of PV module and then measures the insulation resistance

(3) Calculate a PV module model of the combined capacitance and resistance and then calculate the model parameters using time constant

(4) Calculate the model parameters to have minimal error using the method of the least squares.

The back-sheet of PV module, which is made of polyester, is used in this experiment. Table 1 shows a specification of PV module

Table 1 PV module specification

Model	SM - 50(Samsung Electronics)
Power	50W
Size	942mm×502mm×50mm
Type	Multicrystalline silicon (36 Series)

3. Measurement and Calculation

3.1 PV cell model

When the impedance is measured, it is given two conditions. One is that insolate light to the cell and the other is not The method of the second condition is applied since impedance characteristics are not affected by frequency in case of the first condition. Figure 2 shows impedance characteristics of PV cell output terminal in case that sinewave is provided varied frequency from 20 to 100kHz between each PV cell output terminal

From the results of impedance characteristics by the method of the second condition, the calculated model of PV cell is expressed in Figure 3

Figure 4 shows the measured and calculated value of output terminal impedance of PV cell The calculated parameters of PV cell model are presented in Table 2

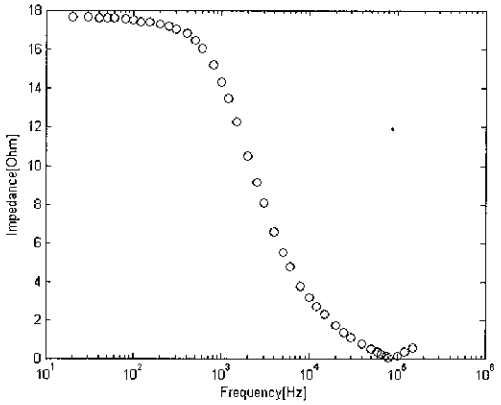

Fig 2 Impedance characteristics of PV cell output terminal at varied frequency

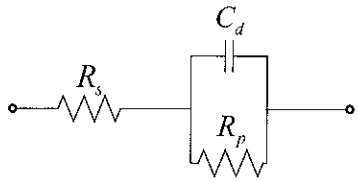

Fig 3 Estimation model of PV cell

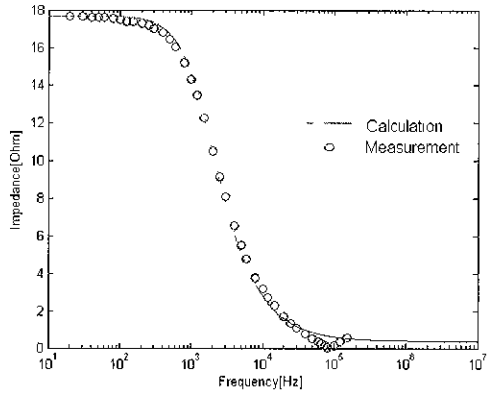

Fig 4 Comparison of measured and calculated value (Output terminal of PV cell)

Table 2 Calculation parameter (Impedance between output terminal of PV cell)

$R_s(\Omega)$	$R_p(\Omega)$	$C_d(\mu F)$
0.3452	17 34	6 39

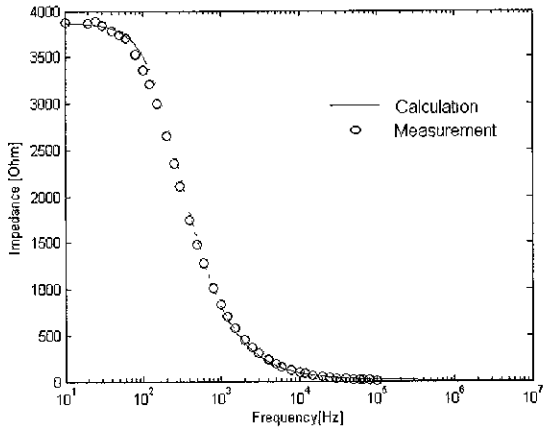

Fig 5 Measurement and calculation (Impedance between PV module output terminal)

Table 3 Calculation parameter (Impedance between output terminal of PV module)

$R_s(\Omega)$	$R_p(\Omega)$	$C_d(\mu F)$
9 2	3863.8	0.19

3.2 PV module model

The PV module model is obtained the same method as the PV cell model PV module, which is used in this experiment, consists of 36 cells in the series. As frequency is varied, the measured and calculated impedance characteristics of the PV module are shown in Figure 5 The calculated parameters of PV module model are presented in Table 3.

3.3 The model between PV module and metal-frame

After short-circuit of the PV module output terminal, the characteristics results of insulation resistance, which is existed between output terminal and metal-frame of PV module, are shown in Figure 6 From the characteristics results of PV module, the model of PV model is expressed in Equation 1 and Figure 7

$$R = \frac{R_{S1}(R_{S1}+R_{P1})}{R_{S1}+R_{P1}\cdot e^{(-t/\tau)}} \quad (1)$$

Only, $\tau = R_{S1}R_{P1}C/(R_{S1}+R_{P1})$

The calculated parameters of the model between the output terminal and the metal-frame of PV module cell model are presented in Table 4 using time constant.

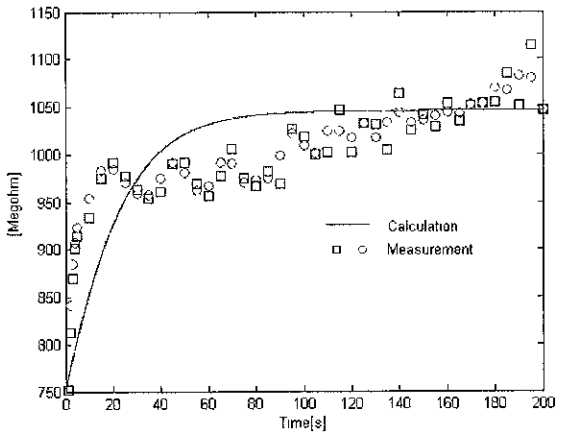

Fig 6 Impedance between output terminal and metal-frame of PV module

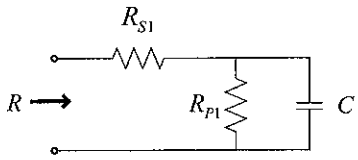

Fig 7 Model between output terminal and metal-frame.

Table 4 Calculation parameter (Between output terminal and metal-frame)

$R_{S1}(G\Omega)$	$R_{P1}(G\Omega)$	$C(\mu F)$
0.752	0.294	4.58

4. PV Array Model and Simulation

To analyze electrical characteristics of PV array when the surge current is injected to the PV array, PV array model is expressed as shown in Figure 8. This basic model of PV array consists of PV module models, and models between output terminal and metal-frame of PV module PV array model is simulated using PSCAD/EMTDC

Figure 9 shows a schematic diagram of grid-connected PV system for analyzing electrical characteristics of PV array due to surge current Figure 10 shows surge current approved Ramp input, that rising time = 1 5 μs, peak current = 25 kA, falling time = 48.5 μs [1-3]

Simulations were done with PSCAD/EMTDC for two conditions: One is whether PV array and PCS are connected or not. The other is whether the negative output

terminal is grounded or not

Figure 11 shows metal-frame characteristic of ground connection (a) and non-ground connection (b) Consequently, ground connection repress high earth potential Thus, metal-frame of PV array should be grounded

Figure 12 shows the characteristic of the PV module by using PSCAD/EMTDC And Figure 13 shows peak voltage of PV module at 40 μs PV module voltages are the nearest to the positive output terminal of PV array There are grounded and non-grounded of negative output terminal After simulating, grounded negative output terminal voltage(a) is 80 kV higher than non-grounded(b) As a results, grounded negative output terminal of PV array obtained high voltage than non-grounded negative output terminal.

After simulating, even negative output terminal of PV array grounded or non-grounded, voltages of PV module obtained very high voltage. And then, capacitor(600 μF) inserted in between positive and negative output terminal of PV array, the high voltages were controlled Figure 14 shows voltages of PV module, inserted a capacitor(600 μF) between positive and negative output terminal of PV array As a results, we know that the capacitor restricts to high voltage of PV module [4]

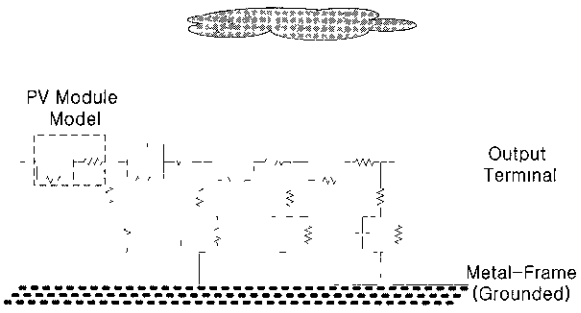

Fig 8 PV array model

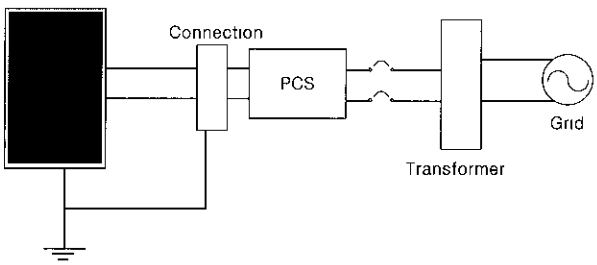

Fig 9 Grid-connected PV system

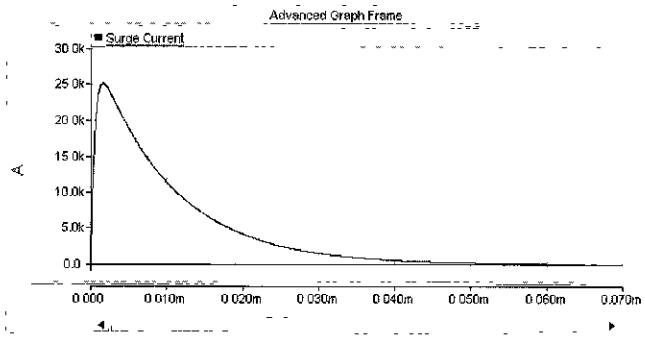

Fig 10 Surge current

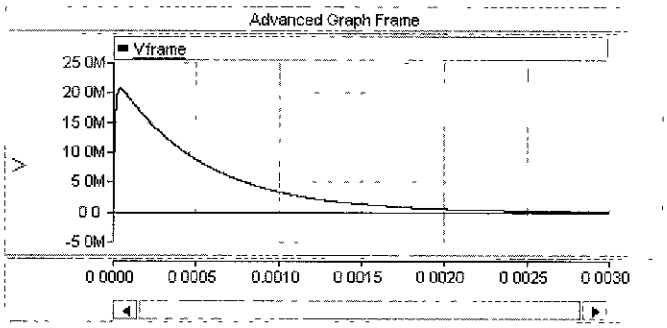

Fig 11 (a) Grounded metal-frame of PV array

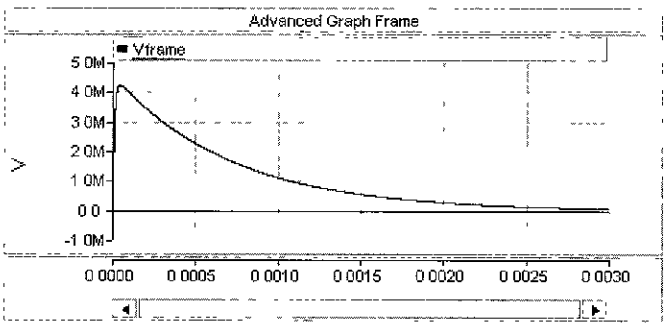

Fig 11 (b) Non-grounded metal-frame of PV array

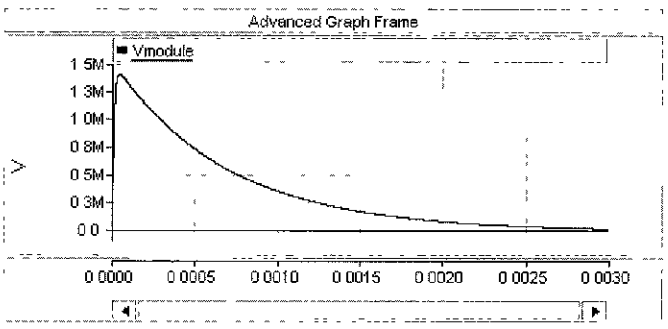

Fig 12 Voltage of PV module

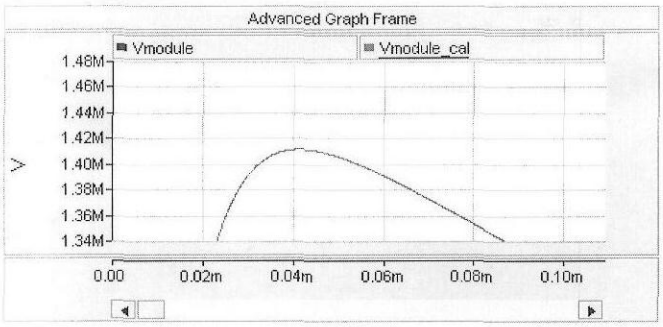

Fig. 13. (a) Grounded negative output terminal voltage of PV array.

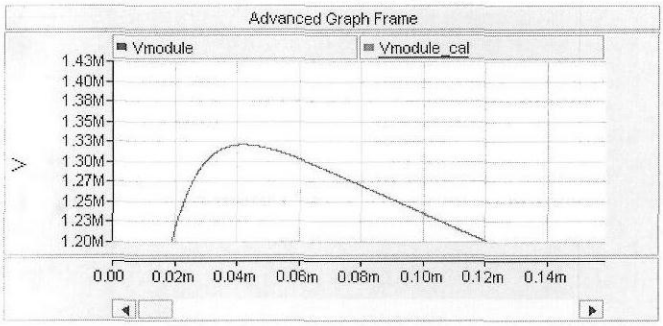

Fig. 13. (b) Non-grounded negative output terminal voltage of PV array.

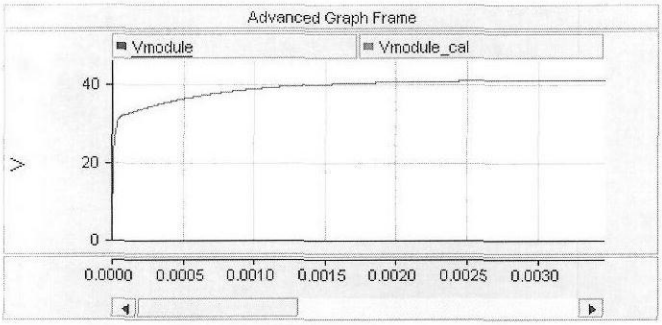

Fig. 14. (a) Grounded negative output terminal voltage of PV array with a capacitor.

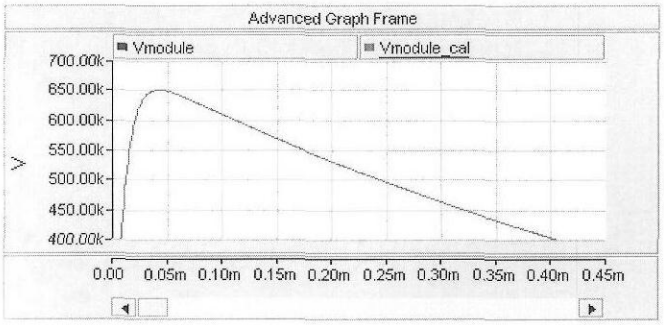

Fig. 14. (b) Non-grounded negative output terminal voltage of PV array with a capacitor.

5. Conclusions

In this paper, the author proposed a basic model of photovoltaic (PV) array for analyzing the electrical characteristics of PV array due to surge like lightning. It is a basic model of PV array consists of PV module model that is considered insulation resistance by measured and calculated.

After PV array model is analyzed, if metal-frame is grounded, the increase of ground voltage will be restricted due to surge voltage. However, if output terminal of PV array is grounded, the high voltage will be obtained. As a result, if PV system is installed, it will be an advantage for grounded metal-frame but it would be a disadvantage for grounded negative output terminal of PV array. And the inserted capacitor, which is between positive and negative output terminal of PV array, will restrict to high voltage of PV module.

In the future works, we will research that the impact of surge current both grid-connected PV system and electrical power system by injection point of surge current like lightning.

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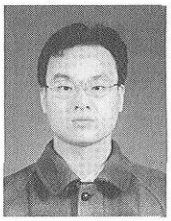

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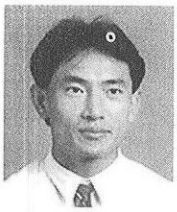

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