# Impedance Analysis and Surge Characteristics of PV Array

K.O. Lee, J.H. So*, M.W. Jung*, G.J. Yu*, J.Y. Choi, and H.S. Ahn**

Kwangwoon University, *Korea Institute of Energy Research, **Kookmin University

***Abstract*** - Photovoltaic(PV) array, which is generally installed outside, has the possibility to be damaged by high voltage due to lightning. Because the surge characteristics of PV array have not been fully identified yet, there is a very important issue whether PV array should be connected with 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 surge characteristics.

## 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 grounded PV array, while do not. Therefore, the electrical characteristics of grounded and non-grounded PV array needs 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

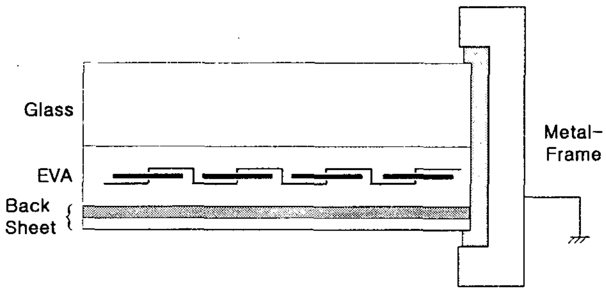


Fig. 1 . Structure of PV module

Figure 1 shows a general structure of PV module. PV module consists of glass, ethylene vinyl acetate(EVA), 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 are 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.

### 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 output terminal and metal-frame of 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 method of 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

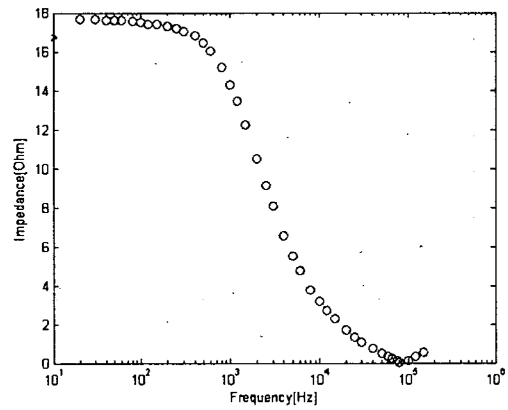


Fig. 2. Impedance characteristics of PV cell output terminal at varied frequency

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.

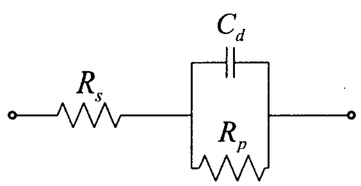


Fig. 3. Estimation model of PV cell

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

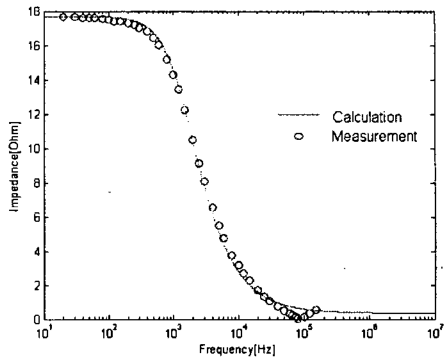


Fig. 4. Comparison of measured and calculated value (Output termianl of PV cell)

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.

Table 2. Calculation parameter (Impedance between cell output terminal)

| $R_s(\Omega)$ | $R_p(\Omega)$ | $C_d(\mu F)$ |
|---|---|---|
| 0.3452 | 17.34 | 6.39 |

### 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 series. As frequency is varied, the measured and calculated impedance characteristics of PV module are shown in Figure 5. The calculated parameters of PV module model are presented in Table 3.

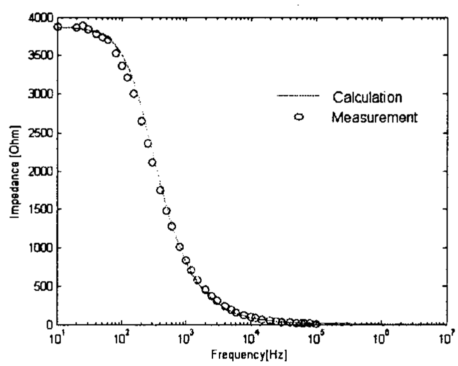


Fig. 5. Measurement and calculation (Impedance between PV module output terminal)

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

| $R_s(\Omega)$ | $R_p(\Omega)$ | $C_d(\mu F)$ |
|---|---|---|
| 9.2 | 3863.8 | 0.19 |

### 3.3 The model between PV module and metal-frame

After short-circuit of 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.

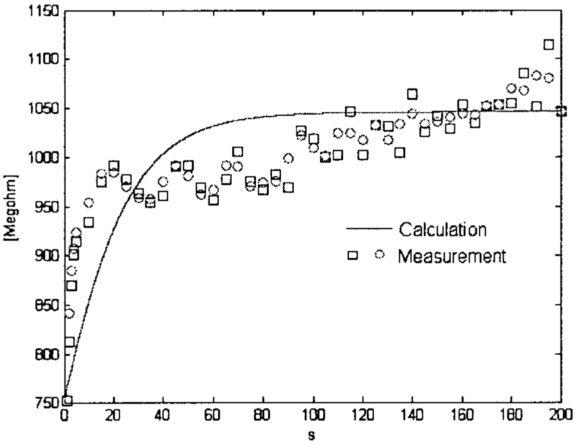


Fig. 6. Impedance between output terminal and metal-frame

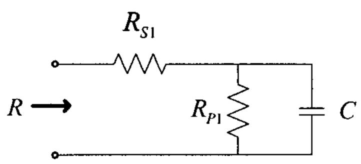


Fig. 7. Model between output yterminal and metal-frame

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

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

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

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 characteristics of PV array when surge voltage is injected to 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 powersim(PSIM).

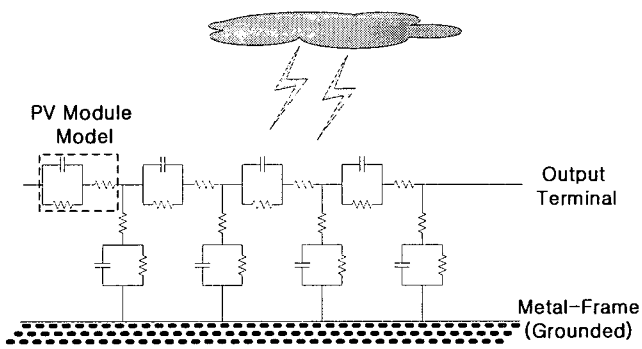


Fig. 8. PV array model

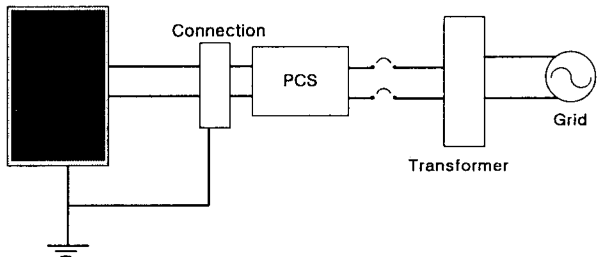


Fig. 9. Grid-connected PV system

Figure 9 shows a schematic diagram of grid-connected PV system for analyzing electrical characteristics of PV array due to surge voltage.

Surge voltage is a approved Ramp input that rising time = 1 ㎲, peak voltage = 40 ㎹, falling time = 70 ㎲.

Simulations were done with PSIM for two conditions : One is whether PV array and PCS are connected or not. The other is whether the minus output terminal voltage is grounded or not.

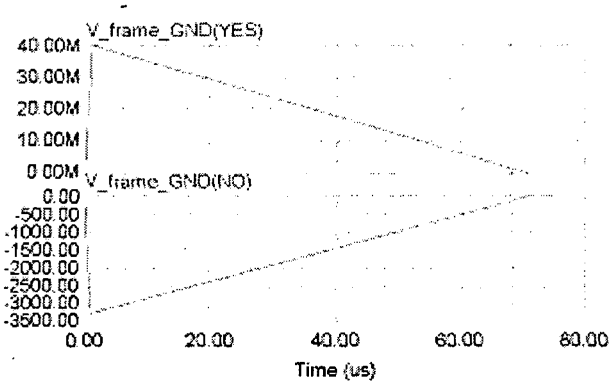


Fig. 10. Voltages of metal-frame

Figure 10 shows metal-frame characteristic of ground connection and non-ground connection. Consequently, ground connection repress high earth potential. Thus, metal-frame of PV array should be grounded.

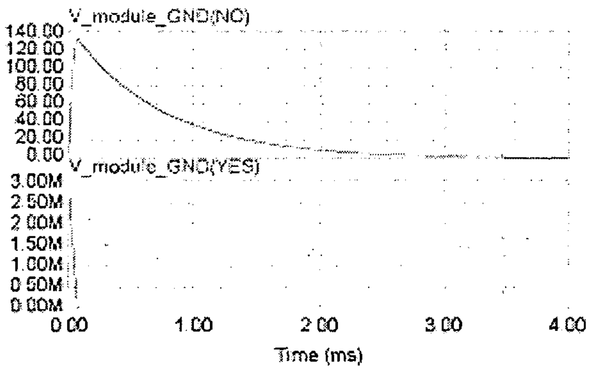


Figure 11. Voltages of PV model

Figure 11 shows the characteristic of PV module. PV module is the nearest to plus output terminal of PV array. There are grounded and non-grounded of minus output terminal. After simulating, grounded minus output terminal voltage is higher than non-grounded minus output terminal.

## 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 voltage. 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 advantage for grounded metal-frame but it will be disadvantage for grounded minus output terminal.

In the future, the author researches that the impact of surge voltage both grid-connected PV system and electrical power system.

## Acknowledgements

This work was supported by grant No. (R01-2001-00313) from the Korea Science & Engineering Foundation.

## References

[1] J.A. Gow and C.D. Manning, "Development of a Model for Photovoltaic Arrays Suitable for use in Simulation Studies of Solar Energy Conversion Systems", IEE, no. 429, 1996.

[2] C. Fenimore and F. Martzloff, "Validating surge test standards by field experience: high-energy tests and varistor performance" IEEE, vol. 2, pp. 1968~1974, 7-12 Oct 1990.

[3] M.W. Park, B.T. Kim, J.D. Lee, I.K. Yu, and K.C. Sung, "A Novel Simulation model of PV using EMTDC", KIEE, 25 Nov 2000.