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Photovoltaic Generation System Simulation using Real Field Weather Conditions

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Abstract

Actual system apparatuses are necessary in order to verify the efficiency and stability of photovoltaic(PV) generation systems considering the size of solar panel, the sort of converter type, and the load conditions and so on. Moreover, it is hardly possible to compare a certain MPPT control scheme with others under the exactly same weather and load conditions as well. For the purpose of solving above mentioned difficulties in a laboratory basis, a transient simulation of PV generation system using real field weather conditions is indispensable.

A straightforward simulation scheme with cost effective hardware structures under real weather conditions is proposed in this paper using EMTDC type of transient analysis simulators. Firstly, a solar cell has been modeled with VI characteristic equations, and then the real field data of weather conditions are interfaced to the EMTDC through Fortran program interface method. As a result, the stability and the efficiency analysis of PV generation systems according to various hardware structures and MPPT controls are easily possible under the exactly same weather conditions.

Keywords : EMTDC, Photovoltaic generation system, MPPT, Simulation

I. Introduction

The solar energy, the wind energy and the fuel cell have been highly interested among researchers as the promising sources of energy for the future. The implementation of ambitious programs pertaining to the PV generation systems, in particular, has strongly been driven worldwide and will require practical technologies in which the following aspects should be considered.

a) the power output is directly affected by the weather conditions

b) the cost of the device is still too expensive

c) power conversion by an inverter is necessary in most cases

d) MPPT control is indispensable.

As a matter of fact, researches for the PV generation system technologies are mainly focused on the evaluation of the system stability or reliability and the expected efficiency by the characteristic analysis of the solar cell, the scale, and the inverters and MPPT controls. It is, however, very difficult to consider the real field weather conditions in laboratory basis. Especially, stability of the MPPT type of control methods is one of very important topics, and the

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comparative study is indispensable to clarify the effectiveness of proposed methods. If the comparison study is performed by an experiment under the same weather conditions, it is necessary to prepare two or more devices for the simultaneous operational purpose. There have been released many simulation methods[1, 2] so far, but those are not hand-friendly and the real time concept of simulation has not been achieved yet.

The authors propose a novel simulation method in which the real weather conditions can easily be utilized and the scale of PV generation systems is able to be changed readily, and the kind of solar cells are also flexibly exchangeable by the characteristic equations of the solar cell in the simulation. The control methods will be changed in simple manner as well. The PSCAD/EMTDC[3] has been used as a simulation tool. The PV generation system analysis, which includes the influence by the sort of system and the change of real field weather conditions, is performed more conveniently and accurately by the proposed simulation method.

The simulation results demonstrate not only the effectiveness of the proposed straightforward simulation scheme but also the stability and the efficiency analysis of PV generation systems according to various hardware structures and MPPT controls are easily possible under the exactly same weather conditions.

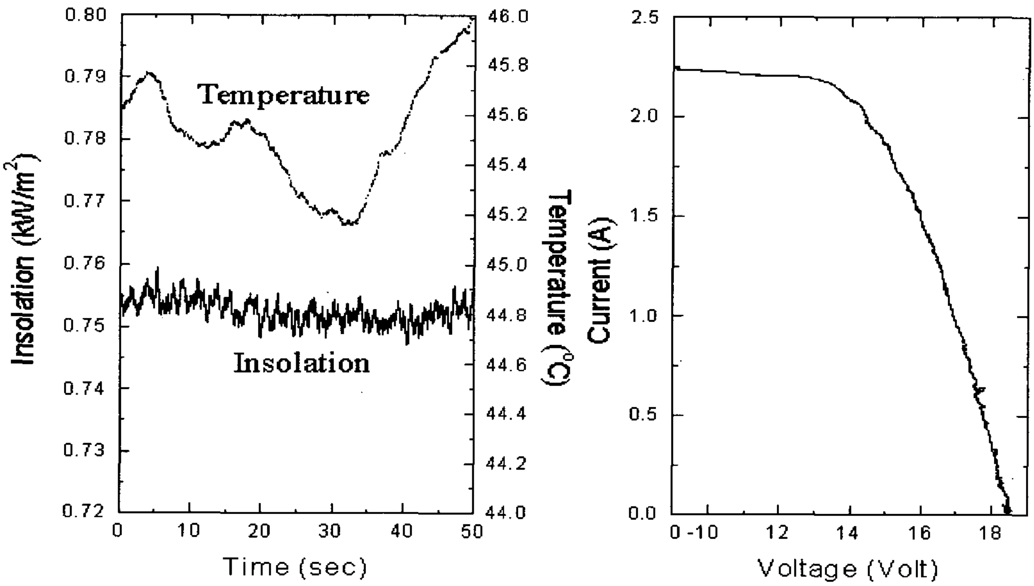
II. Modeling of solar module

2.1 The V-I characteristics equation

Equation (1) shows the VI characteristics equation of a solar cell [4, 5] and (2) expresses an empirical formula of the saturation current.

$$I = I_{sc} - I_{os}\left[\exp\left(\frac{q}{n \cdot k \cdot T} \cdot V\right) - 1\right] \quad (1)$$

$$I_{os} = AT^{\gamma} \exp\left(\frac{-E_g}{n \cdot k \cdot T}\right) \quad (2)$$



(a) Weather conditions (b) VI characteristics under (a)

Fig. 1 Experimented data from a PV panel

List of symbols;

- I = current flowing into load [A]
- Isc = short-circuit current [A]
- Ios = saturation current [A]
- s = insolation [kW/m2]
- q = electron charge, 1.6e-19[C]
- k = Boltzman constant, 1.38e-23 [J/K]
- T = PN junction temperature [。K], t [。C]
- n = junction constant
- A = temperature constant
- γ = temperature dependency exponent
- Eg = energy gap [eV]
- V = across voltage of solar cell [Volt]
- Voc = open-circuit voltage of solar cell [Volt]
- P = output power of solar cell [W]
- Vop = optimal voltage of solar cell [Volt]
- Varray-op = optimal voltage of PV array [Volt]
- Rs = series parasitic resistance [Ω]
- Rsh = shunt parasitic resistance [Ω]

For the purpose of close matching of (1) to reality, the constant values of (1) and (2), Isc, n, A, and Eg are manipulated using experimental data of a PV panel which is composed of 36 cells in series. Fig. 1(a) shows the weather conditions under which the various resistor was changed to obtain its VI characteristics including the open voltage and the short-circuit current of PV panel for 50 seconds. Fig. 1(b) illustrates the VI characteristics of the PV panel under the same weather conditions of Fig. 1(a).

With considering the parasitic resistance, Rs and Rsh, the solar cell characteristic of the PV panel can be expressed as in (3). And the constant values are determined by (3) at 25℃ of module surface temperature, (4) and Table 1 which obtained from various VI characteristics curve under the various weather conditions.

Table 1 Constant values of the solar cell

N	1.5		3	A	9.0e-2	Eg	1.103eV
Rs		0.028		Rsh			1k
Voc at 25C		0.58 Volt		Isc at 1.0kW/m2			3.0 A

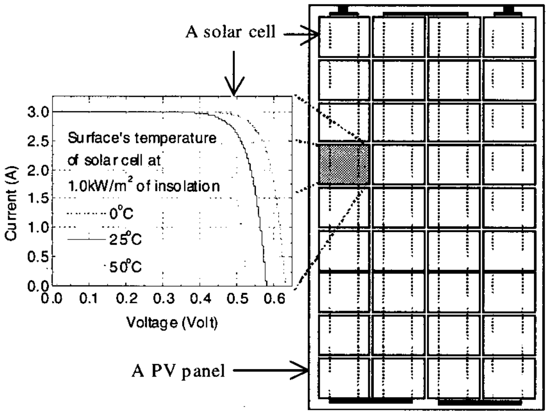


Fig. 2 VI characteristics of a solar cell

$$I = I_{sc} - I_{os}\left\{\exp\left[\frac{q\cdot(V + I\cdot R_s)}{n\cdot k\cdot T}\right] - 1\right\} - \frac{V + I\cdot R_s}{R_{sh}} \quad (3)$$

$$I_{sc} = 3.0\cdot s \quad (4)$$

It is possible to draw the VI characteristics curve of a solar cell close to a practical cell using (3) and Table 1 as shown in Fig. 2. Equation (1) to (4) and Table 1 are treated as the mathematical basis in this paper.

2.2 Modeling of solar module the EMTDC

The schematic diagram of simulation for a solar cell in the PSCAD/EMTDC is given in Fig. 3. In this paper, the output current Id of ideal solar cell and the real field data of insolation and surface temperature are substituted to the ideal non-linear VI characteristics equation, and the obtained voltage of Ed is treated as a voltage source. Due to the parameters including Id are input at every sampling time, the output voltage is delayed by one sampling time. Comparing to the circuit response, however, the delay time is short enough to disregard its influence on the simulation, it does not causes any problem. Consequently, the voltage V and current I of (3) can be substituted to the terminal of Fig. 3.

2.3 Interface of the real field weather conditions

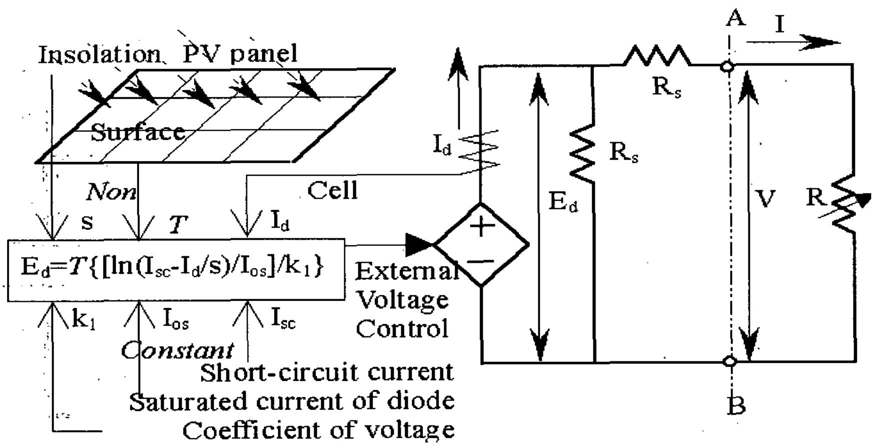


Fig. 3 Schematic diagram of the proposed simulation

It is hardly possible to imitate real weather conditions in the simulation of the PV generation systems with a transient phenomenon digital simulation tool for the electric power systems such as PSCAD/EMTDC. Therefore, the reliability is not guaranteed in the simulation for which external parameters of the weather conditions are necessary. However, the simulation of the PV generation system under the real field weather conditions is able to be achieved by introducing the interface method of non-linear external parameters and FORTRAN using PSCAD/EMTDC in this paper.

Fig. 4 shows the flow chart of the proposed simulation method considering the non-linear external parameters by the PSCAD/EMTDC. The measured data of insolation and the module surface temperature are interfaced to the simulation through the interface method with FORTRAN. And, the simulation analysis, which uses real data of insolation and temperature, becomes possible by doing so.

2.4 Reformation of the insolation data

The measured insolation data must be distorted due

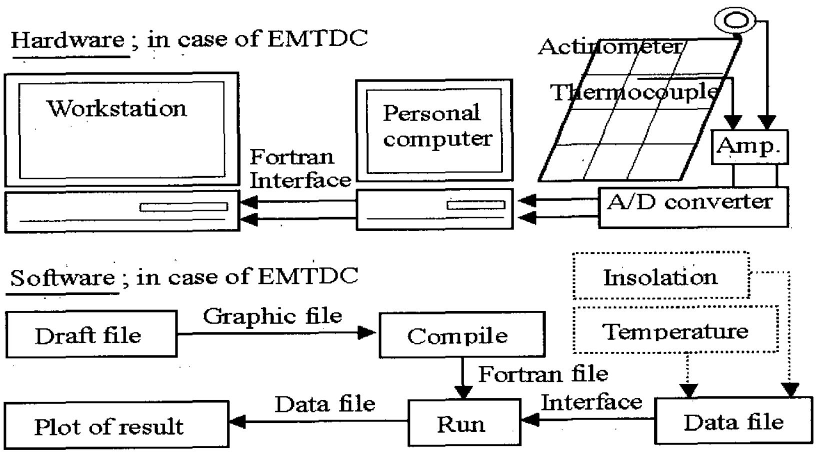


Fig. 4. Simulation diagram on EMTDC/PSCAD using real weather condition

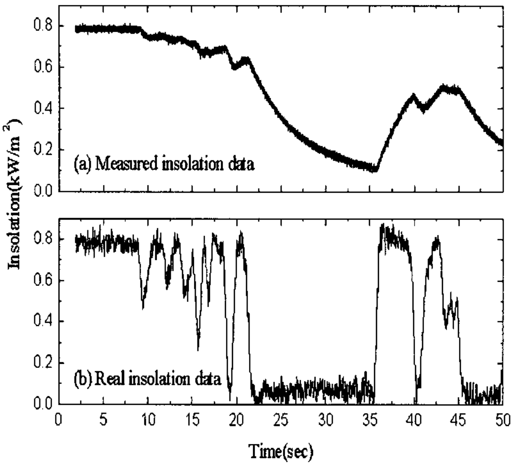


Fig. 5 Conversion of the insolation data

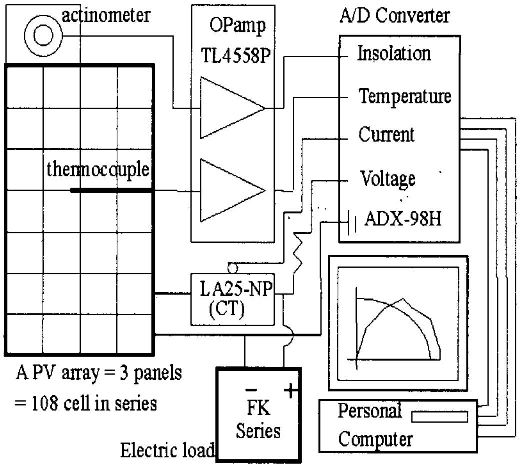


Fig. 6 Concept of the experiment apparatus

to the response speed of actinometer as described in (5).

$$RI(s)\frac{G}{1+sT} = MI(s) \qquad (5)$$

where, RI(s) is the real insolation data, G=1.0, T=5.67 for the actinometer used in the simulation, and MI(s) is the measured insolation data. The real insolation data illustrated in Fig. 5(b) is calculated by (5) using the measured insolation data of Fig. 5(a), where the actinometer is artificially covered and shined frequently in order to confirm (5) in this paper.

III. Analysis of solar module

3.1 Solar module and experiment apparatus

The measurement apparatus shown in Fig. 6 is used in the simulation in order to measure the output characteristics of PV array and the weather conditions. A PV array described in Table 2 is set up for the comparison of the results obtained from the proposed simulation.

Table 2 Size of the PV array

A panel = 36 cells in series	Voc-array	118Volt	Isc-array	6A
Array = 6 panels in shunt and 2 panels in series	Fill Factor	62.9%	Rated power	445 W

3.2 Output variations of the PV array

It is necessary to compare the output voltage and current by the result of the proposed simulation with those from the actual PV array in order to confirm the validity of the simulation method. The electric load is connected to the output terminal of the PV array and the load is varied for 50 seconds as shown in Fig. 7. The output voltage and the current are stored in the personal computer.

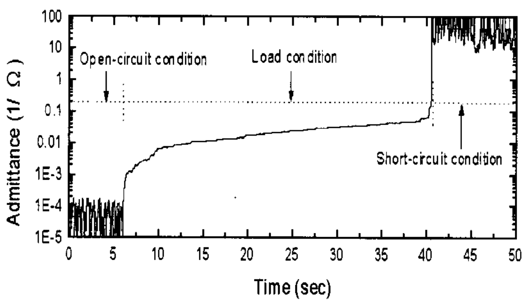


Fig. 7 Variation of the load admittance for 50 seconds

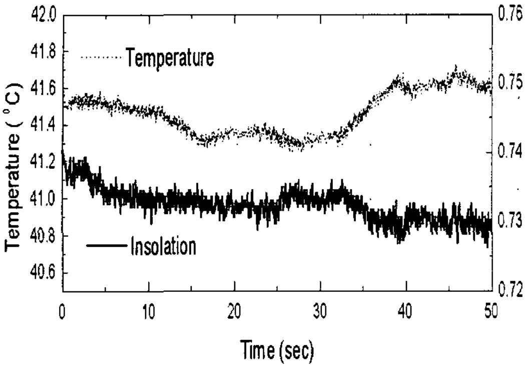


Fig. 8 Real field weather conditions for 50 seconds

The insolation data and the module surface temperature of PV array are measured at the same time and the results are depicted in Fig. 8.

3.3 Simulation results

The obtained real data of insolation and the surfaces temperature are substituted into (3), and the load variations of Fig. 7 are also interfaced as the admittance of external load R of Fig. 3, then the simulation is performed for 50 seconds. The simulation sampling time is 40 seconds, and the data input sampling cycle is 100Hz. The simulation circuit built in the PSCAD/EMTDC is given in Fig. 9.

Fig. 10 shows an actual measurement result and the simulation results. The VI characteristics obtained from the measurement result and the simulation result is depicted in Fig. 11, respectively. As can be seen from those figures, both the measurement result and the simulation result are corresponding well, so that the validity of the proposed simulation method is confirmed. A lot of comparative studies for various conditions are performed and all of results show the same configurations, however, only limited results are presented in this paper due to lack of space.

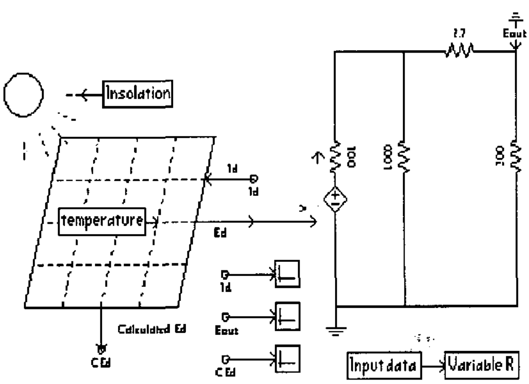


Fig. 9 Simulation circuit diagram of the PSCAD/EMTDC

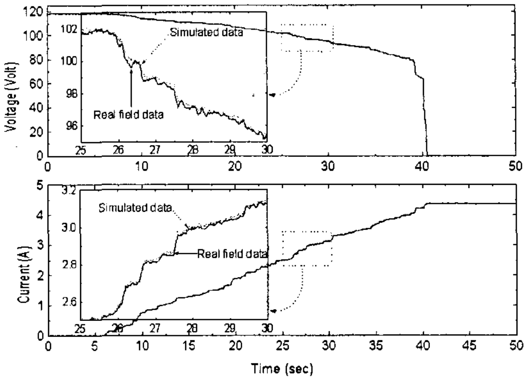


Fig. 10 Comparison of voltage and current curves

IV. Conclusions

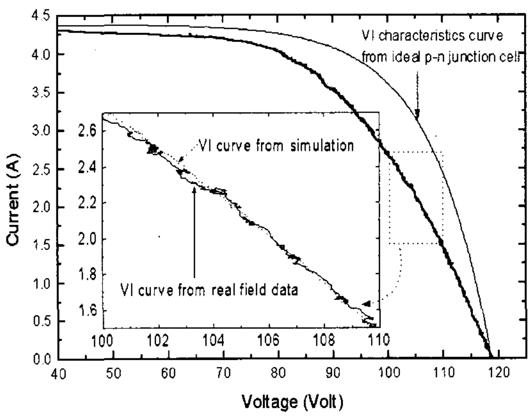


Fig. 11 Comparison of voltage-current characteristics curves

A novel simulation method of PV generation systems under the real field weather conditions is proposed in this paper. The simulation results obtained by the proposed method is compared with the real output data of the same PV array and both numerical values of them are matched well, which means that the validity of the proposed simulation method has been confirmed.

It is also possible to simulate of any type or size of PV generation systems by the proposed cost effective and straightforward simulation scheme in a laboratory basis. The simulation results demonstrate not only the effectiveness of the proposed simulation scheme but also the stability and the efficiency analysis of PV generation systems according to various hardware structures and MPPT controls are easily possible under the exactly same weather conditions.

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Minwon Park was born in Masan, Korea in 1970 and received a bachelor degree in Electrical Engineering from Changwon National University (Korea) in 1997 and a master degree in Electrical Engineering, Osaka University in 2000 where he is presently a Ph.D. student. His research mainly deals with the dispersed generation system and the control theory of it. And, he is also interested in the high-frequency AC link DC-AC converter and the development of the simulation model of power conversion equipment and renewable energy source using EMTP type simulators.

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