A Novel Simulation Scheme for Grid Connected Photovoltaic Generation Systems

Minwon Park, Bong-Tae Kim and In-Keun Yu

Abstract - A novel simulation scheme of transient phenomenon for the photovoltaic(PV) generation system under the real weather conditions has been proposed in this paper. A grid connected PV array is simulated using PSCAD/EMTDC. The transient changes of the output current of PV array under the real weather conditions is described and the output current of DC/AC converter flowing through the utility power network is also analyzed with the PWM switching width. Moreover, the MPPT control of PV generation system is combined to the system during the simulation for the comparison purposes of the control schemes. The outcome of the simulation demonstrates the effectiveness of the proposed simulation scheme. The result shows that the cost effective verifying for the efficiency or availability and stability of PV generation systems and the comparison researches of various control schemes like MPPT under the same real weather conditions are eventually possible.
Keywords - PSCAD/EMTDC, Photovoltaic, Real Weather Simulation, MPPT

1. Introduction

The PV generation system, a promising source of energy for the future, is evolving rapidly, and the implementation of ambitious programs pertaining to the solar energy will require some sort of practical technologies. Due to the cost down of PV generation systems, in particular, grid connected systems are becoming more economically viable recently. A rapid expansion of PV systems showing an industrial growth of approximately 40% per year in worldwide and solar cell and systems technology are improved, new markets become increasingly accessible [1]. This has resulted in an increased demand for researches of the PV devices and systems. From the system operational technology and effectiveness point of view, several topics can be pointed out. The power output of PV system is directly affected by the weather conditions, and when AC power supply is needed, power conversion by an inverter and a MPPT control are necessary.

Those topics lead an increased demand for the simulation scheme and operational technologies of grid connected PV devices and systems. The simulation schemes that can be applied to the grid connected PV generation systems readily and cheaply under various conditions considering the sort of solar cell, the capacity of systems and the converter system as well are strongly expected and emphasized among researchers.

A geid connected PV generation system is simulated using SPRW(Simulation method for PV generation systems using Real Weather condition) [2] in this paper. Fig. 1 shows the conceptual diagram of the SPRW. There are four keywords, which have been demanded by the researchers related with work of PV generation systems, in the SPRW as follows.

a) hand-friendly method from the user point of view
b) applicability to grid connected or hybrid systems
c) precise simulation model of solar module
d) using the real field weather conditions

As shown in Fig. 1, the SPRW could be an unique simulation method to realize the above mentioned requirements.

In this paper, the modeling method of solar module in the transient simulation tools; EMTP/ATP[3], EMTDC/PSCAD[4], RTDS[5], and the interface method of the real field weather conditions are briefly mentioned. In order to confirm the availability of the SPRW, a substantial PV generation system including a DC-DC converter connecting up to a PV array is facilitated, and the output results of the substantial experiment and those of simulation are compared. Mainly, a grid connected PV generation system is simulated using the SPRW method. The transient characteristics of the output current of the PV array under the real weather conditions is described and the input and output terminals of power converters are analyzed with the PWM switching width variations.

Moreover, the MPPT control of PV generation system

This work has been supported in part by Electrical Engineering & Science Research Institute grant, 00-040, which is funded by Korea Electric Power Co and the Korea Science and Engineering Foundation (KOSEF) through the Machine Tool Research Center at Changwon National University.

Manuscript received: June 20, 2001 accepted: Nov. 23, 2001.
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is combined to the system during the simulation for the comparison purposes of the control schemes. The outcome of the simulation shows the effectiveness of the proposed simulation scheme and that the cost effective verifying for the efficiency or availability and stability of PV generation systems and the comparison researches of various control schemes like MPPT under the same real weather conditions are eventually possible.

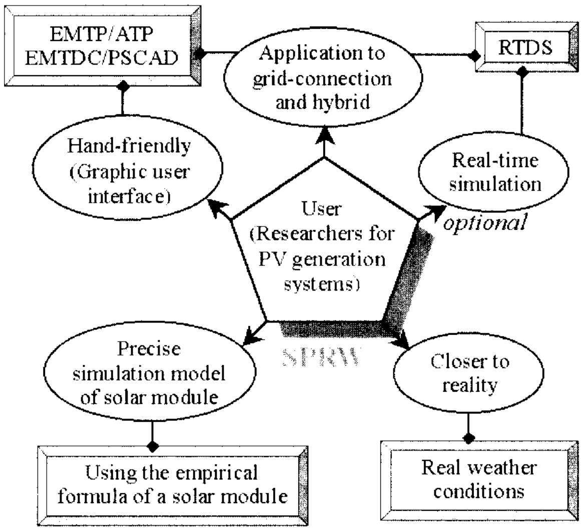

Fig. 1 Conceptual diagram of the SPRW

2. Simulation Using Real Weather Conditions

2.1 Modeling of solar module

Equation (1) shows the VI characteristics equation of a solar cell [6, 7], and (2), (3) express the short-circuit current equation and the saturation current equation, respectively.

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]
Ed = output voltage of ideal solar cell [Volt]
Id = output current of ideal solar cell [A]
Rs = series parasitic resistance [Ω]
Rsh = shunt parasitic resistance [Ω]

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

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

$$I_{sc} = 3.0\cdot s \quad (3)$$

The schematic simulation diagram of a solar cell in EMTP/ATP and EMTDC/PSCAD is given in Fig. 2. In this paper, the output current(Id) of ideal solar cell and the real field data of insolation and surface temperature are inserted to the ideal non-linear VI characteristics equation, and the obtained voltage(Ed) is treated as a voltage source. Because the parameters including Id are input at every sampling time, the output voltage is delayed for one sampling time. However, because the delay time is very short compared with the circuit response, the influence can be disregarded. Consequently, the voltage V and current I of (1) can be substituted to terminal A-B of Fig. 2.

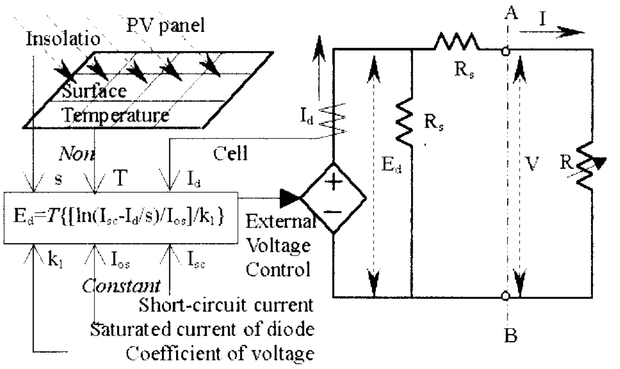

Fig. 2 Schematic simulation diagram of a solar cell

2.2 Interface of the real weather conditions

It is impossible to imitate an actual weather condition in the simulation of the PV generation systems with transient phenomenon digital simulation tool for the electric power systems such as EMTP/ATP and PSCAD/EMTDC. Therefore, the reliability is not guaranteed in the simulation for which an external parameter of the weather conditions is necessary. However, the simulation of the PV generation system using the real weather conditions is able to be implemented by introducing the interface method of a non-linear external parameter and FORTRAN using PSCAD/EMTDC in this paper.

Fig. 3 shows the simulation process of the proposed method considering the nonlinear external parameter using PSCAD/EMTDC. The measured data of insolation and the module surface temperature are interfaced to the simulation using the interface method with FORTRAN. And, the simulation analysis, which uses the real data of insolation and temperature, becomes possible by doing so.

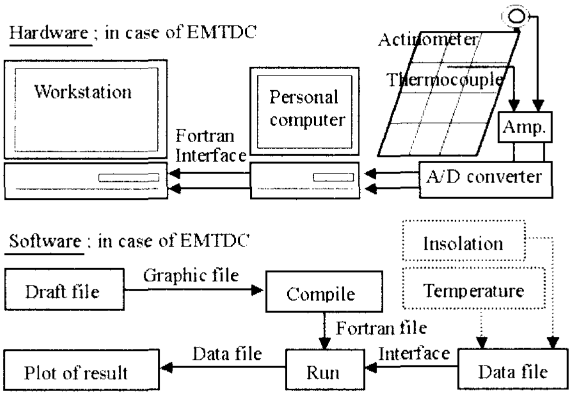

Fig. 3 Simulation process on PSCAD/EMTDC using real weather conditions

3. Analysis of DC-DC Converter Connected to the PV Array

In order to confirm the availability of the proposed SPRW method, a substantial PV generation system to which a DC-DC converter connected and supplying electric power to a pure resistance load is facilitated, and the output results are compared with those of simulation.

3.1 PV generation system using DC-DC converter

The PV generation system with DC-DC converter is illustrated in Fig. 4. Table 1 describes the size of the established PV array and Table 2 shows the circuit parameters and control conditions of Fig. 4, respectively.

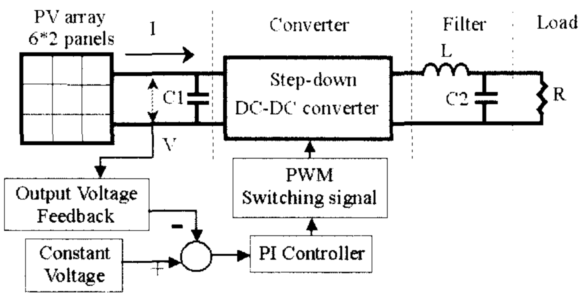

Fig. 4 PV generation system with DC-DC converter

Table 1 Dimension of the PV array

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

In case of the control topology, DC-DC converter is operated with the constant voltage control [8, 9] of the output PV array voltage. And, a isolated load is connected to the output terminal of the converter. Fig. 5 depicts the weather conditions under which the established PV generation system is experimented. Also, it is used as the input data of weather conditions in the simulation analysis for 50 seconds.

The control response of the constant voltage control in the PV generation system needs to be confirmed. The weather condition in which the insolation level is fluctuated is chosen for the comparison purposes.

Table 2 Circuit parameters and control conditions

PWM switching frequency			10kHz
Control of the output voltage of PV array			80 Volt constant
C1	10mF	C2	5μF
L	0.8mH	R	45
Simulation sampling frequency			10μs
Cycle of the real weather condition input data			100Hz

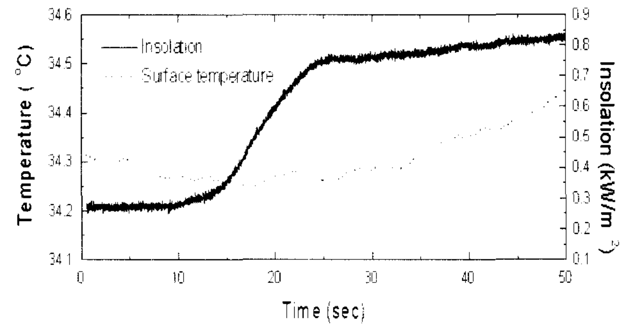

Fig. 5 Real weather conditions with the fluctuation of insolation

3.2 Comparison of the simulation results

Fig. 6 and Fig. 7 show the results of simulation and experiment by Fig. 4 of PV generation system with the constant voltage control at 80volts of input voltage and under Fig. 5 of weather condition. Fig. 6 shows the output voltage curves of PV array obtained both by simulation and experiment. As shown in Fig. 6 the constant voltage control for 80volts is normally operated in both cases. As might be expected, that of experiment is more fluctuated. As shown in Fig. 7, the output current curves of both experiment and simulation go up in

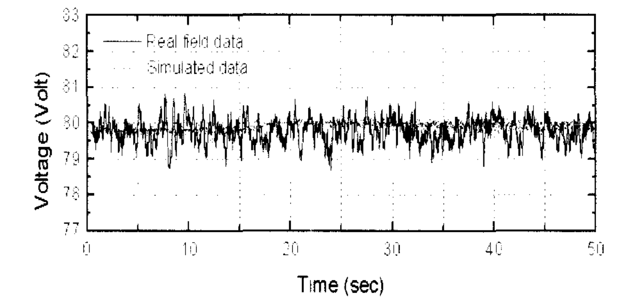

Fig. 6 The real and simulated output voltage curves of PV array

proportion to the insolation increases. Moreover, the output current of experiment and that of simulation are coincided well. It is proved that the SPRW can satisfactorily be utilized as a simulator for the PV generation systems.

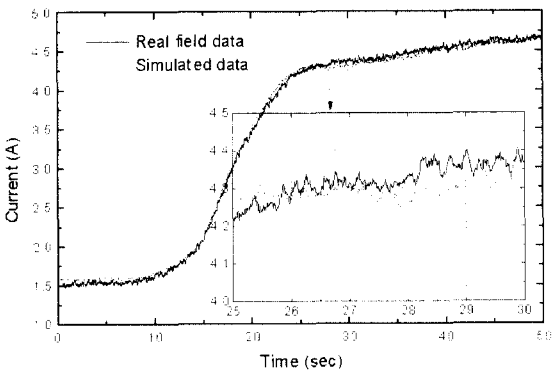

Fig. 7 The output current curves of a PV array

4. Analysis of the Grid Connected PV Generation Systems

4.1 Simulation conditions

A grid connected PV generation system is analyzed using the proposed SPRW method. The operation of a PV generation system connected to utility network is simulated, and various output currents of power DC-AC converter with different MPPT control schemes applied are also analysis objectives of this chapter to confirm the applicability of the SPRW method.

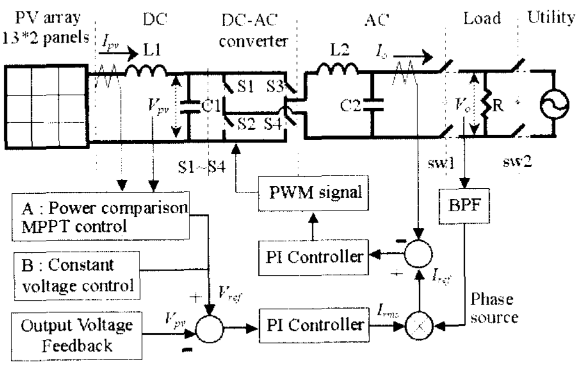

Fig. 8 Schematic diagram of the grid connected PV generation system

Fig. 8 shows the schematic diagram of the grid connected PV generation system.

List of symbols in Fig.8
Ipv = output current of PV array [A]
Vpv = output voltage of PV array [Volt]
Ppv = output power of PV array [W]
Vref = reference voltage by MPPT [Volt]
Io = output current of DC-AC converter [A]
Vo = output voltage of DC-AC converter [Volt]
Irms = command current level [A]
Iref = command output current of DC-AC converter [A]
sw1 = switch gear of power source side
sw2 = switch gear of utility network

Table 3 describes the simulation conditions and circuit parameters. The real field weather conditions used in the simulation are given in Fig. 9. As described in Table 3, the SPRW simulation with Fig. 8 has been operated three times in accordance with MPPT controls for every 5 seconds in PSCAD/EMTDC.

Table 3 Simulation conditions and circuit parameters

PV Array	13 in shunt and 2 panels in series		*Voc-array*	245 Volts
	Rated power (900W)		Isc-array	6 A
Simulation Parameters	Simulation time period	5 sec	Calculation sampling time	1 sec
	Data input cycle	100 Hz		
DC-AC Converter And MPPT	PWM switching frequency			10 kHz
	Power comparison MPPT control (Control cycle 20Hz)		A-1	V = 2 Volts
			A-2	V = 5 Volts
	Constant voltage control		B	200 Volts
DC and AC Filter	C1	8000F	L1	1 mH
	C2	2F	L2	7 mH
Utility network	Voltage of utility power network			AC 100 Volts
	Frequency of utility power network			60 Hz

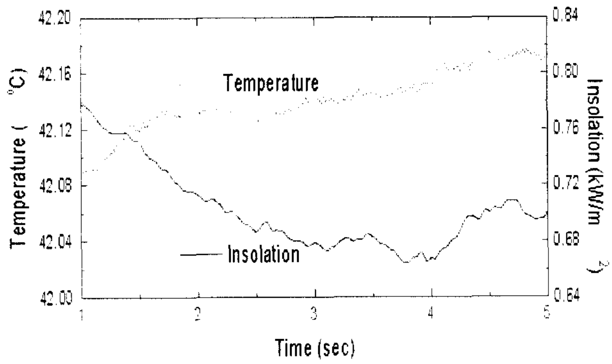

Fig. 9 Real field weather conditions used in the simulation

4.2 Discussions on the simulation results

In this analysis, both the constant voltage control, of which stability of control is very high and controllability is so simple, and the power comparison control [10-16], which is most generalized in real field with high efficiency, are used as MPPT control schemes. In case of the power comparison control, the sampling time is 20Hz, and it is simulated twice for the control voltages, $\triangle$V, of 2volts and 5volts, respectively. In case of the constant

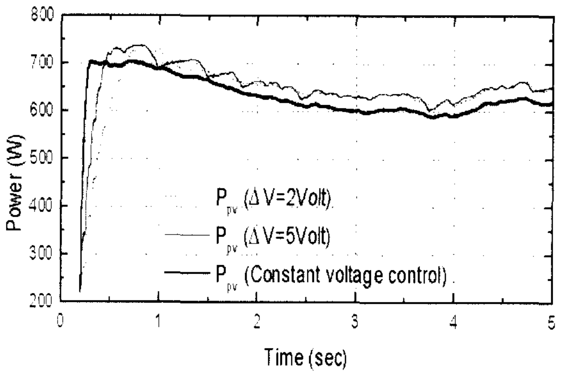

Fig. 10 MPPT based output power curves of a PV array

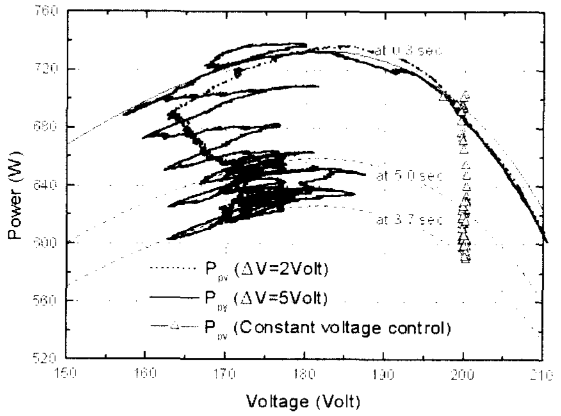

Fig. 11 MPPT based voltage-power characteristics of a PV array

voltage control, the defaulted constant voltage is 200volts. As shown in Fig. 10, the output power of the power comparison control is higher and more fluctuated than that of the constant voltage control. Fig. 11 shows the voltage-power characteristic curves of different MPPT controls, and Fig. 12 depicts the output current characteristic curves of converter for the same MPPT controls. As can be seen in Fig. 11, the output voltage of PV array using the power comparison control is very fluctuated in accordance with the change of the control voltage, ΔV, because the control system never acknowledges what is the reason of variations(increase or decrease) of PV array output power that might be caused by the result of its control or the fluctuation of insolation. And it causes the possibility of tracking failure. Fig. 11 also shows that the fluctuation level of output voltage is proportional to the magnitude of ΔV. In case of the constant voltage control, which has been proposed to overcome the tracking failure and accelerate the controllability, because the decided voltage value, 200volts in this case, is fixed as the reference input voltage of converter, the output voltage must be so stable at 200 volts.

As shown in Fig. 12, the output current characteristics of DC-AC converter is directly influenced by the type of MPPT controls. Fig. 12 is the outcome that are simulated at the same real weather and circuit conditions except using different MPPT controls. In case 5 volts of ΔV, its output current is very oscillated along with the change of insolation level.

Consequently, these results are coincided well with those of the reported before. It means that the grid connected PV generation system could be simulated closer to reality even including control topology like MPPT controls and real field weather conditions.

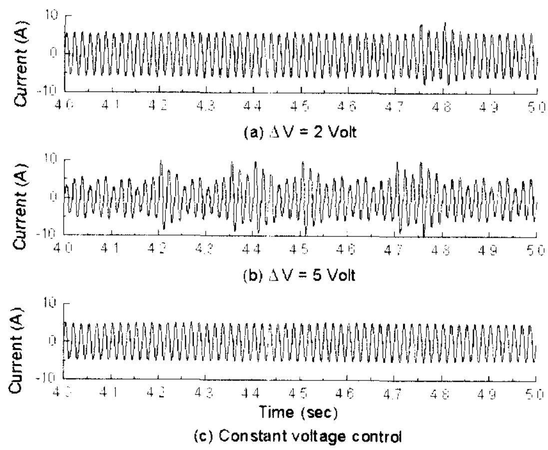

Fig. 12 MPPT based output current characteristics of converter

5. Conclusions

A grid connected PV generation system is simulated using SPRW method. The transient characteristics of the output current of the PV array under the real weather conditions is described and the output current of DC-AC converter flowing through the utility power network is also analyzed with the PWM switching width variations.

Moreover, the MPPT control of PV generation systems is combined with the system in the simulation. For SPRW method, PSCAD/EMTDC is used with the real weather conditions which are interfaced to the EMTDC program using Fortran program interface method.

The outcome of the simulation demonstrates the effectiveness of the proposed simulation scheme. The results shows that the cost effective verifying for the efficiency or availability and stability of utility interactive PV generation systems and the comparison researches of various control schemes like MPPT under the same weather conditions are eventually possible.

Acknowledgment

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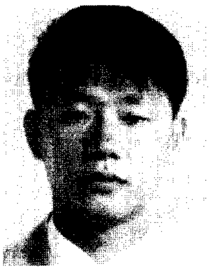

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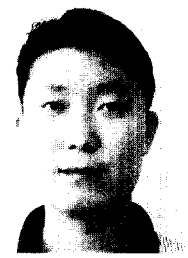

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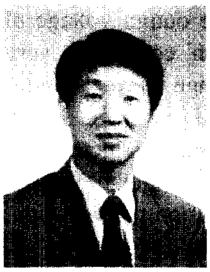

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