A New Efficient Mppt Control Algorithm for Low Insolation Intensity

Gwon-Jong Yu*, Young-Seok Jung* and Ju-Yeop Choi**

Abstract - In this paper, the effectiveness of three different control algorithms are thoroughly investigated via simulation and a proposed efficiency evaluation method of experimentation. Both the steady state and transient characteristics of each control algorithm along with its measured efficiency are analyzed. Finally, a novel two-mode maximum power point tracking (MPPT) control algorithm combining the constant voltage control and the incremental conduction (IncCond) methods is proposed to improve the efficiency of the 3KW PV power generation system at different insolation conditions. Experimental results show that the proposed two-mode MPPT control provides excellent performance at less than 30% insolation intensity, covering the whole insolation area without additional hardware circuitry.

Keywords: PV cell, simulation, MPPT, two-mode, efficiency, low insolation

1. Introduction

As is well-known, the maximum power point (MPP) of a PV power generation system depends on array temperature and solar insolation, so it is necessary to constantly track the MPP of the solar array. For years, research has focused on various MPP control algorithms to draw the maximum power of the solar array. Among them, the constant voltage control method, the perturbation and observation (P&O) method and the incremental conductance method (IncCond) have drawn attention due to the usefulness of each system. In this paper, the effectiveness of these three different control algorithms are thoroughly investigated via simulation and a proposed efficiency evaluation method of experimentation. Both the steady-state and transient characteristics of each control algorithm along with its measured efficiency are analyzed. Finally, a novel two-mode MPPT control algorithm combining the constant voltage control and IncCond methods is proposed to improve the efficiency of the 3KW PV power generation system at different insolation conditions. Especially in cases in which the solar insolation changes rapidly at lower insolation, the P&O and the IncCond MPPT control methods fail to track the MPP. The proposed two-mode MPPT control algorithm, however, works very well due to the adoption of the constant voltage control method.

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2. Simulation Model of the PV Cell

Currently, various numerical models are in use by engineers investigating different aspects of photovoltaic technologies. The fundamental physics associated with solar cells are often studied using programs that model solar cell characteristics. Recent modeling of individual cells has used a highly distributed SPICE model. The proposed simulation program was designed to address the interactive behavior of modules in arrays by accurately simulating the electrical characteristics of individual cells in the modules.

The building block of the PV array is the solar cell, which is basically a p-n semiconductor junction that directly converts light energy into electricity: it has the equivalent circuit shown in Fig. 1 [1]. The current source I_{ph} represents the cell photo current; R_j is used to represent the nonlinear impedance of the p-n junction; and R_{sh} and R_s are intrinsic shunt and series resistance of the cell, respectively. Usually the value of R_{sh} is very large and that of R_s is very small, and hence they may be neglected to simplify the analysis. A total 56 of Samsung SM60PV cells are grouped in larger units called PV modules, which are further interconnected in a parallel-series configuration to form 3KW PV arrays. To simulate a PV cell, a PV simulation model using a software, *PSIM* was used according to the following set of equations.

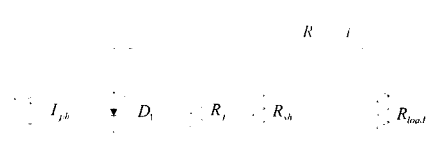

Fig. 1 Equivalent Circuit of a PV Cell

$$I_0 = n_p I_{ph} - n_p I_{rs}[\exp(\frac{q}{kTA}\frac{V_0}{n_s}) - 1] \qquad (1)$$

where I_o is the PV array output current (A); V_o is the PV array output voltage (V); n_s is the number of cells connected in series; n_p is the number of cells connected in parallel; q is the charge of an electron; k is Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); and I_{rs} is the cell reverse saturation current. The factor A in eqn. (1) determines the cell deviation from the ideal p-n junction characteristics. The ideal value ranges between 1 and 5. In our case, A equals 2.15.

The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

$$I_{rs} = I_{rr}[\frac{T}{T_r}]^3 \exp(\frac{qE_G}{kQA}[\frac{1}{T_r} - \frac{1}{T}]) \qquad (2)$$

where T_r is the cell reference temperature, I_{rr} is the reverse saturation current at T_r, and E_G is the band-gap energy of the semiconductor used in the cell. The photocurrent I_{Ph} depends on the solar radiation and the cell temperature as shown in the following equation.

$$I_{ph} = [I_{scr} + k_i(T - T_r)]\frac{S}{100} \qquad (3)$$

where I_{scr} is the cell short-circuit current at reference temperature and radiation, k_i is the short-circuit current temperature coefficient, and S is the solar radiation in mW/cm^2. The PV array power P can be calculated using eqn. (4).

$$P = IV = n_p I_{ph} V - n_p I_{rs} V[\exp(\frac{q}{kTA}\frac{V_0}{n_s}) - 1] \qquad (4)$$

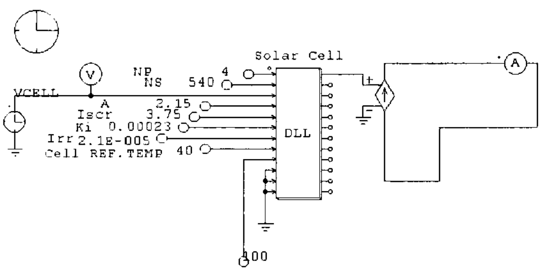

Fig. 2 Simulation of PV Cell Equivalent Circuit

By making step variations in the solar radiation S and the cell temperature T in eqns. (1)-(4), the proposed emulator of Fig. 2 provided the I-V and the P-V characteristics of the PV array as shown in Fig. 3. The following parameters are used for modeling PV cells:

intrinsic shunt resistance of the cell, R_{sh} : $5*10^5$ Ω
intrinsic series resistance of the cell, R_s : 0.00005 Ω
p-n junction manufacturing factor, A : 2.15
number of cells in parallel, N_p: 4
number of cells in series, N_s: 540
cell short-circuit current at reference temperature, I_{scr} : 3.75
cell temperature, T: 300 K
cell reference temperature, T_r : 40° F
short-circuit current temperature coefficient, k_i: 0.00023
reverse saturation current at T_r, I_{rr} : 0.000021

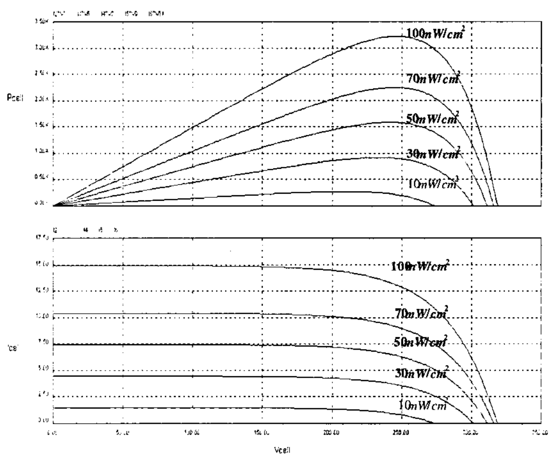

Fig. 3 Simulated Characteristics of the PV Array Power – Voltage (upper), Current – Voltage (lower)

From these curves, it is observed that the output characteristic of the solar array is nonlinear and severely affected by the solar insolation, temperature, and load condition. Table 1 shows the Samsung SM-60PV cell data given in catalogue, experimental data, simulation data, and percentage error, respectively.

Table 1 SM-60PV Data Comparison

SM-60PV	catalogue data	experimental results	simulation results	error (%)
Open-circuit voltage (V_{OC}) [V]	21.10	22.2	21.78	1.9
Short-circuit current (I_{SC}) [A]	3.80	3.92	3.77	3.83
Maximum power(P_M) [W]	59.85	59.89	58.04	3.09
Voltage at Load(V_P) [V]	17.10	16.66	17.03	2.17
Current at Load (I_P) [A]	3.50	3.6	3.34	7.23

3. Proposed Two-mode Control Algorithm for Mppt

As is well-known, the MPP of PV power generation system depends on array temperature and solar insolation, so it is necessary to constantly track MPP of the solar array. For years, research has focused on various MPP control algorithms to draw the maximum power of the solar array. Among them, the constant voltage control method, the perturbation and observation (P&O) method, and the incremental conductance method (IncCond) have drawn attention due to the usefulness of each system. In this section, the effectiveness of these three different control algorithms are thoroughly investigated via simulation and verified by proposed experimental efficiency evaluation setup.

The simulation circuit shown in Fig. 4, consists of the solar cell array (3.2KW), capacitor bank, boost converter, and load. There are three dynamic link libraries (DLL) for the implementation of MPPT algorithm. Ms-user0 (DLL) is the simulator of the PV cell of Fig. 2 and ms_user4 (DLL) and ms_user9 (DLL) are used for the simulation of insolation variations and implementing the MPPT, such as constant voltage control, P&O algorithm, IncCond algorithm, and the proposed two-mode algorithm, respectively.

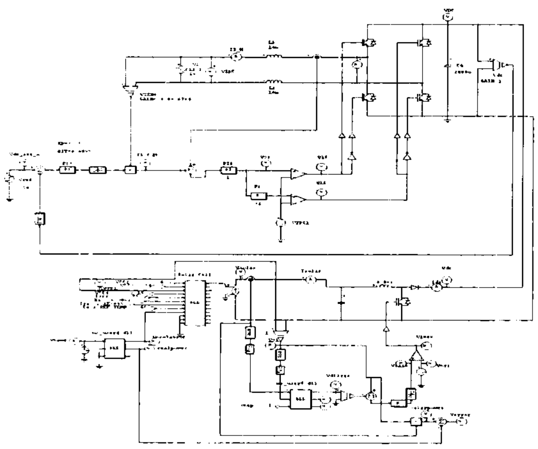

Fig. 4 Simulation Circuit for MPPT Control

Fig. 5 illustrates the experimental setup to evaluate the performance of all four MPPT algorithms. The constant voltage control method is the simplest control method, which keeps the array near the MPP by regulating the array voltage and matching it to a fixed reference voltage. This method starts from the assumption that any variation in the insolation and temperature of the array is insignificant and that the constant reference voltage is an adequate approximation of the true maximum power point. Even though it neglects the effect of the insolation and temperature of the solar array, it is more effective at low insolation than both the P&O method and the IncCond method.

P&O algorithms are widely used in MPPT because of their simple structure and the few measured parameters required. They operate by periodically perturbing (ie., incrementing or decrementing) the array terminal voltage

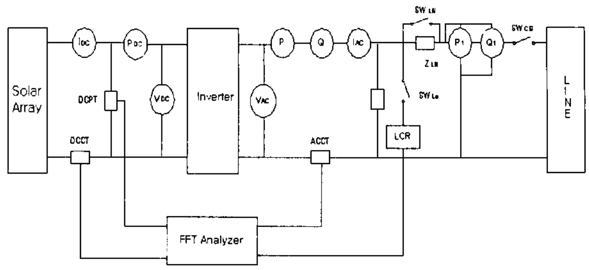

Fig. 5 Schematic of MPPT Efficiency Measuring System

and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing, the perturbation will continue in the same direction in the next cycle; otherwise the perturbation direction will be reversed. This means the array terminal voltage is perturbed every MPPT cycle; therefore when the MPP is reached, the P&O algorithm will oscillate around it, resulting in a loss of PV power, especially in cases of constant or slowly varying atmospheric conditions. This problem can be solved by improving the P&O algorithm's logic for comparing the parameters of two preceding cycles. If the MPP is reached, the perturbation stage is bypassed [2]. Another way to reduce the power loss around the MPP is to decrease the perturbation step, but the algorithm will be slow in following the MPP when the atmospheric conditions start to vary and more power will be lost. In cases of rapidly changing atmospheric conditions as a result of moving clouds, the P&O MPPT algorithm deviates from the MPP due to its inability to relate the change in the PV array power to the change in the atmospheric conditions. The perturbation step size is determined to be 0.1 in this simulation of the MPPT algorithm for all cases.

On the contrary, the array terminal voltage is always adjusted according to its value relative to the MPOP voltage in the IncCond algorithm. The basic idea is that at the MPP, the derivation of the power with respect to the voltage vanishes because the MPP is the maximum of the power curve.

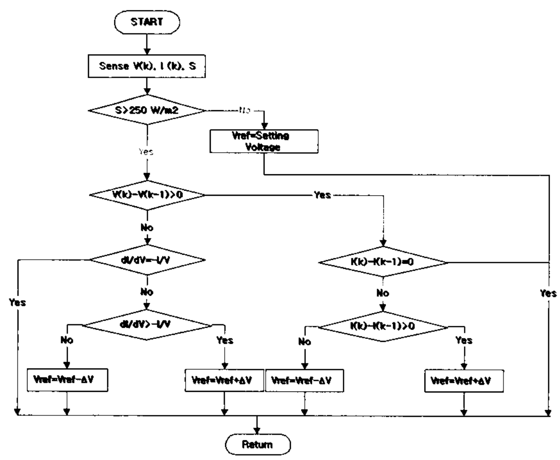

Fig. 6 Flowchart of the Proposed Two-Mode MPPT Control

Since the IncCond method offers good performance under rapidly changing atmospheric conditions, contrary to the P&O method, it is widely used in various applications [3].

Finally, a novel two-mode MPPT control algorithm that combines the constant voltage control at less than 30% normalized insolation intensity and the IncCond method at more than 30% normalized insolation intensity is proposed to improve efficiency of the 3KW PV power generation system at different insolation conditions. Fig. 6 shows the flowchart of the proposed two-mode MPPT algorithm.

4. Simulation Results and Experimental Evaluation

Both the steady-state and transient characteristics of each control algorithm along with its measured efficiency are analyzed. Figures 7, 8, and 9 show the simulation results of each MPPT algorithm due to the step variations of insolation. From the above figures, tracking errors of 0 - 30W occur in the constant voltage control compared with that of 0 - 2W in the P&O method and that of 0 - 1.5W in the IncCond method. The IncCond method is superior to the other method in following the MPP of the system.

The results are listed in Table 2, which shows that the IncCond method provides better efficiency at more than 30% insolation intensity but less than 35% efficiency at 20% insolation intensity. However, the constant voltage

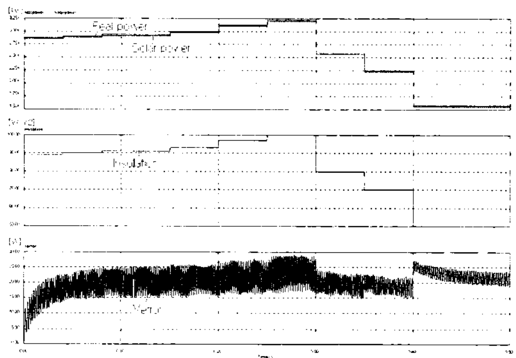

Fig. 7 Simulation Result of Constant Voltage Control Method

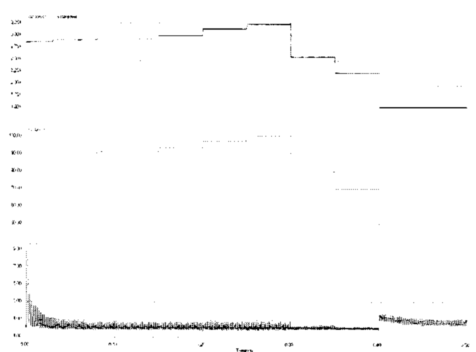

Fig. 8 Simulation Result of P&O MPPT Control Method

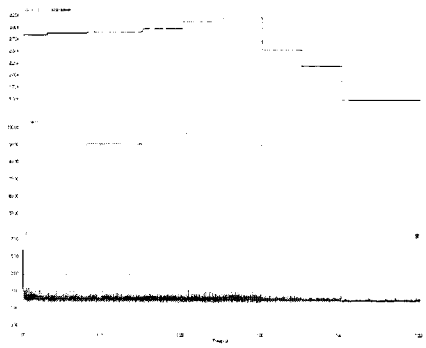

Fig. 9 Simulation Result of IncCond MPPT Control Method

Table 2 MPPT Efficiency Characteristics at Different Insolation Intensity

Insolation (W/m^2)	Experimental Data (%)		
	Constant Voltage MPPT	IncCond MPPT	Two-mode MPPT
100	96.6	97.4	97.4
80	96.5	97.2	97.2
60	96.3	97.5	97.5
40	96.5	97.6	97.6
30	**96.5**	**82.1**	**96.5**
20	96.4	-	96.4
10	38.9	-	38.9

control method at less than 30% normalized insolation intensity is much more efficient than other cases.

Figs. 10 and 11 show the inverter output voltage waveforms of the proposed two-mode MPPT control at insolation step changes, decreasing from 50% to 25% and increasing from 50% to 75%, respectively. Experimental results show that the proposed two-mode MPPT control shows excellent performance at less than 30% insolation intensity.

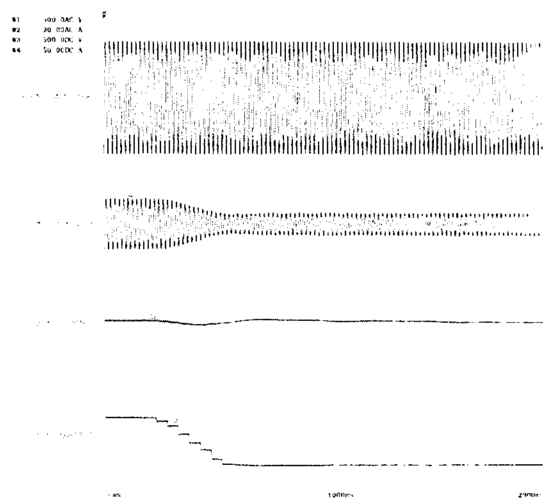

Fig. 10 Inverter Output Waveforms at Insolation Decrease from 50% to 25%

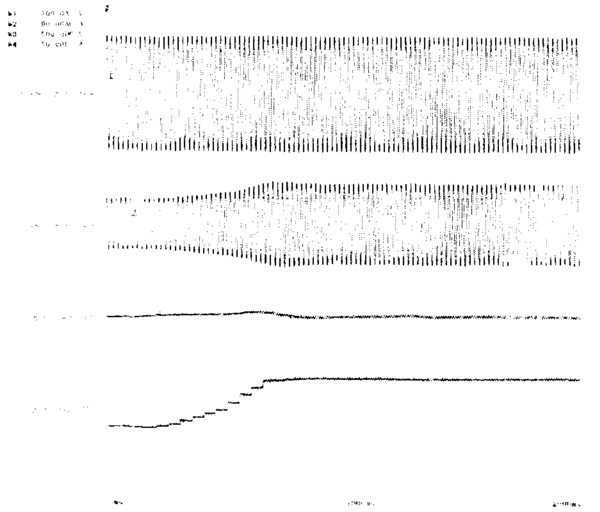

Fig. 11 Inverter Output Waveforms at Insolation Increase from 50% to 75%

5. Conclusions

In this paper, the effectiveness of the three different control algorithms are thoroughly investigated via simulations and proposed efficiency evaluation method of experimentation. Both the steady-state and transient characteristics of each control algorithm along with its measured efficiency are analyzed. Finally, a novel two-mode MPPT control algorithm combining the constant voltage control and the IncCond method is proposed to improve the efficiency of the 3KW PV power generation system at different insolation conditions. Experimental results show that the proposed two-mode MPPT control shows excellent performance at less than 30% insolation intensity, covering the whole insolation area without additional hardware circuitry.

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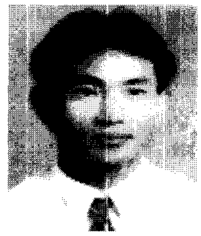

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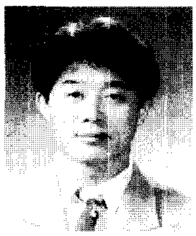

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