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A Maximum Power Point Tracking Control for Photovoltaic Array without Voltage Sensor

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ABSTRACT

This paper presents a maximum power point tracking algorithm for Photovoltaic array using only instantaneous output current information. The conventional Hill climbing method of peak power tracking has a disadvantage of oscillations about the maximum power point. To overcome this problem, we have developed an algorithm that will estimate the duty ratio corresponding to maximum power operation of solar cell. The estimation of the optimal duty ratio involves, finding the duty ratio at which integral value of output current is maximum. For the estimation, we have used the well know Lagrange's interpolation method. This method can track maximum power point quickly even for changing solar isolation and avoids oscillations after reaching the maximum power point.

Keywords: Maximum power point tracking, Output current, Analog integral circuit, PV system.

1. Introduction

Recently, since the global environmental problem is worsening, the research and development for the natural energy is actively progress around the world. Photovoltaic array system has been a focus of attention for residential photovoltaic energy system because solar cell can directly convert solar energy to electric energy[1]. Solar cell has the optimum operating point, and if the PV array operates at this point gives its maximum power output. But this optimum operating point of solar cell varies with load, solar insolation, and temperature. Thus, maximum power point tracking (MPPT) control is required to extract maximum power from the solar cell for all conditions.

Several methods are proposed for MPPT[2-6]. In general, the MPPT control is implemented using the output power information. This output power information is obtained using voltage, current sensors and low-pass filter.

Therefore, it leads to complex construction and increases the cost of PV system. Further, the conventional MPPT methods use Hill climbing algorithm for maximum power tracking. This Hill climbing method tracks the maximum power point by incrementing the duty factor by constant values. The disadvantage of this method is that it takes more time to track the maximum power point and the operating point oscillates even after the maximum power point is reached. To overcome these problems we proposes a new MPPT algorithm of photovoltaic array using instantaneous output current information. Because in regulated bus PV systems[6], the power output is proportional to the output current. Therefore the MPPT can be in implemented by finding the integral value of output current (average value) rather than output power

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information. The integral value of output current is obtained by a simple integral circuit. In this new MPPT algorithm, the optimum operating point is estimated using the Lagrange's interpolation method. The proposed method also works well even if solar insolation changes rapidly. Performance of the proposed method is compared with that of Hill climbing method through experimental results.

2. Configuration of PV system

The proposed MPPT is implemented using only instantaneous output current information. Configuration of the PV system is shown in Fig. 1. Photovoltaic array and battery specifications are shown in Tables 1 and 2, respectively. The proposed PV system consists of a two-phase DC-DC boost converter. The converter switches operate with phase difference ϕ of 180° and a switching frequency of 20kHz. Integral value of output current V_{int} is the output through an integral circuit shown in Fig. 1, and is detected through an A/D converter. The integral circuit diagram used in experiment is shown in Fig. 2.

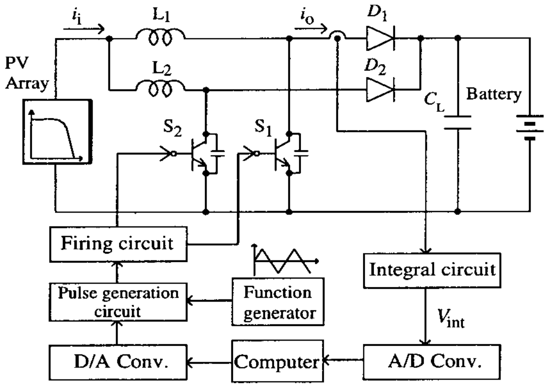


Fig. 1. Configuration of PV system.

Table 1. Photovoltaic array specification.

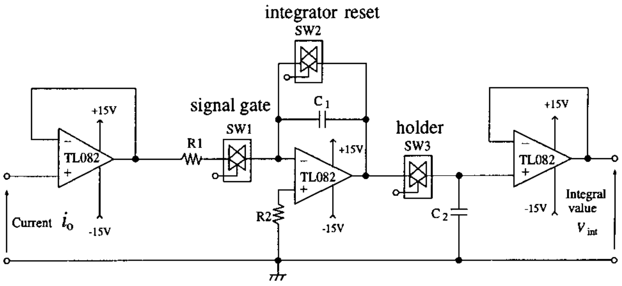
Maximum power (PMAX)	48.0 W
Open circuit voltage (VOC)	20.7 W
Short circuit current (ISC)	3.10 A
Operating voltage at maximum power	16.7 V
Operating current at maximum power	2.88 A
Module efficiency	1.0 %

(AM1.5, 1000W/m^2, 25°C)

Table 2. Battery specification.

Rating voltage	12.0V
Rating capacity	28.Ah

The detailed integral circuit consists of three analog switches, main integral circuit, sample-hold circuit, and a voltage-buffer circuit. The integral circuit operates at interval of flowing output current i_o. Time-chart diagram for the integral circuit is shown in Fig. 3. The output current i_o when S_1 of the converter in Fig. 1 is off. While S_1 is off, SW1 is turned on. Then both SW2, SW3 are off. It means that the output current i_o is integrated by the integral circuit with SW1 on. Next, when S_1 of the converter is turned on, the SW1 is turned off and the SW3 is turned on. Then the output voltage of the integral circuit in Fig. 2 is transferred to the c_2 capacitor in Fig. 2 by SW3. The on period of SW3 is 6μsec. It is created by TTL IC 74LS123 with using the on/off signal of S_1 of the converter. After that, SW2 is turned on. The on period of SW2 is 6μsec. SW2 is the reset switch for the c_1 capacitor. It means that the integrated the output current i_o again.



R1, R2: 1kΩ, C_1, C_2: 8200pF, SW1, SW2, SW3: M4066BP

Fig. 2. Integral circuit.

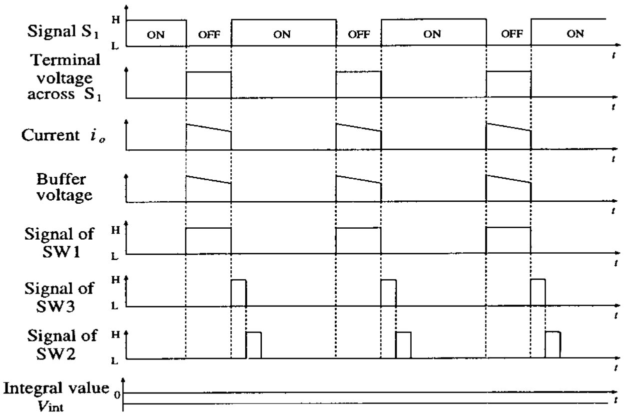


Fig. 3. Time-chart diagram.

When duty factor changes from 0 to 1, the output power characteristics of PV array for two different solar insolations are shown in Fig. 4 and the integral value of output current characteristics are also shown in Fig. 5. It is evident that the solar cell has the optimum operating point at which it gives maximum power. Then the integral value of output current also changes in the same fashion as that of output power. Since the integral value of output current is proportional to the output power of PV array, it is possible to track the maximum power point of PV array using only the output current information instead of output power information.

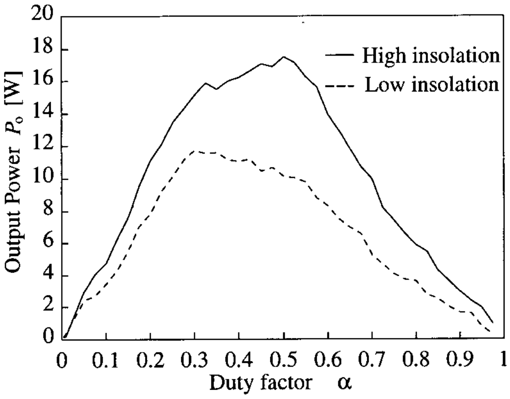


Fig. 4. P_0 versus α.

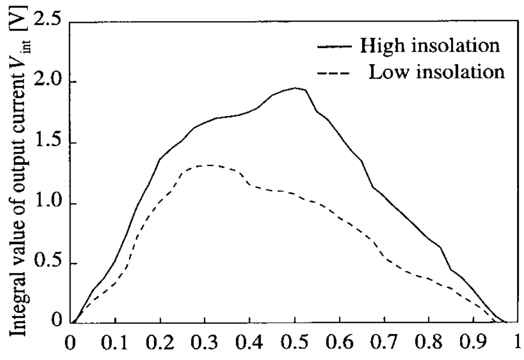


Fig. 5. V_{int} versus α.

3. Maximum power point tracking control

In MPPT control, to obtain a good tracking performance, the duty factor $\hat{\alpha}_{opt}$ corresponding to maximum power point of the PV array is estimated based on V_{int} characteristic curve approximation using Lagrange's interpolating method. The estimated value of duty ratio $\hat{\alpha}_{opt}$ converter tracks the maximum power point. Further, the operating point of PV array reaches the maximum power point quickly and will not make any oscillations about this maximum power point. The tracking method is described in the following steps.

Step 1: When duty factor is α = 0.1, 0.2, 0.3,..., 0.7, determine corresponding integral values of output current V_{int}. These values let say $V_{int} = V_{int1}, V_{int2}, V_{int3}, \ldots, V_{int7}$.

Step 2: The integral value of output current between the values determined as in STEP1 is estimated by using Lagrange's interpolation method. The estimated V_{int} is defined as $\hat{V}_{int}$.

The first Lagrange interpolation

To estimate V_{int} from α = 0.1 to α = 0.4, $\hat{V}_{int}$ is estimated in the intervals of incremental duty ratio $\Delta\alpha$ = 0.02 by using the already known V_{int}. $\hat{V}_{int}$ is calculated by using the following equation,

$$\begin{aligned}\hat{V}_{int} &= \frac{(x-x_1)(x-x_2)(x-x_3)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)}y_0 \\ &+\frac{(x-x_0)(x-x_2)(x-x_3)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)}y_1 \\ &+\frac{(x-x_1)(x-x_2)(x-x_3)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)}y_2 \\ &+\frac{(x-x_1)(x-x_2)(x-x_3)}{(x_3-x_0)(x_3-x_1)(x_3-x_2)}y_3\end{aligned} \tag{1}$$

where, x is α estimated, and $(x_0, y_0) = (\alpha_{0.1}, V_{int1})$, $(x_1, y_1) = (\alpha_{0.2}, V_{int2}), \ldots, (x_3, y_3) = (\alpha_{0.4}, V_{int4})$.

The second Lagrange interpolation

To estimate V_{int} from α = 0.4 to α = 0.7, $\hat{V}_{int}$ is estimated at intervals of incremental duty ratio $\Delta\alpha$ = 0.02 by the detected V_{int}. $\hat{V}_{int}$ is calculated by the above equation (1). Fig. 6 shows the result of Lagrange's interpolation method for high solar insolations. As shown in Fig. 6, the $\hat{V}_{int}$ estimated is exactly matching with that obtained in Lagrange's interpolation.

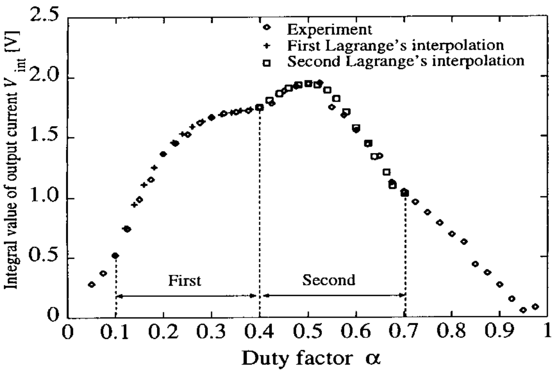


Fig. 6. The results of the Lagrange's interpolation for high insolation.

Step 3: Select maximum V_{int} which has a maximum value in the above estimated $\hat{V}_{int}$ and the detected V_{int}. The selected V_{int} is defined as $\hat{V}_{imax}$. Then, $\hat{\alpha}_{opt}$ which has $\hat{V}_{imax}$ is defined as duty ratio corresponding to maximum power point. The experimental setup adjusts the duty ratio to $\hat{\alpha}_{opt}$ and tracks the maximum power point.

Step 4: The estimation error is determined by the following equation,

$$| \hat{V}_{imax} - V_{int} | = 0.10 \text{ (V)} \qquad (2)$$

where, $\hat{V}_{imax}$ is the selected V_{int} by *Step*3. V_{int} is actual integral value of output current corresponding to $\hat{\alpha}_{opt}$.

If the estimated error satisfies equation (2), it appears that the maximum power point of PV array is reached by using $\hat{\alpha}_{opt}$. Then, *Step*4 is repeated, using its $\hat{\alpha}_{opt}$. It means that this method can avoid oscillations after reaching the maximum power point. When the estimated error is not satisfied equation (2), the error is considered big. Then it necessary to go back to *Step1*, because it means that $\hat{\alpha}_{opt}$ is not corresponding to the maximum power point. Equation (2) represents the evaluation of the estimated error. In case of variable solar insolation if equation (2) is not satisfied, go to *Step*1, because it appears that solar insolation changes suddenly. Based on the above algorithm, the maximum power point tracking is implemented experimentally.

4. Experimental Results

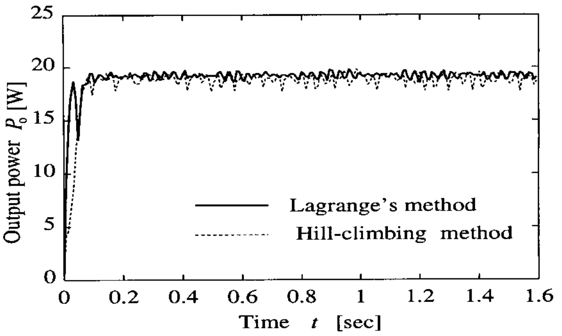
To examine the effectiveness of the proposed MPPT methods, experimental results are presented for constant and stepwise insolations. In the experiment, the performance of the proposed algorithm using the Lagrange's method and the proposed MPPT using instantaneous output current are compared with the Hill climbing method, where the sampling periods are 8 msec, respectively. The initial duty factor α_0 = 0.1, the incremental (or decremental) duty factor $\Delta\alpha$ in the Hill climbing method is 0.05.

4.1 Experimental Results for High Solar Insolation

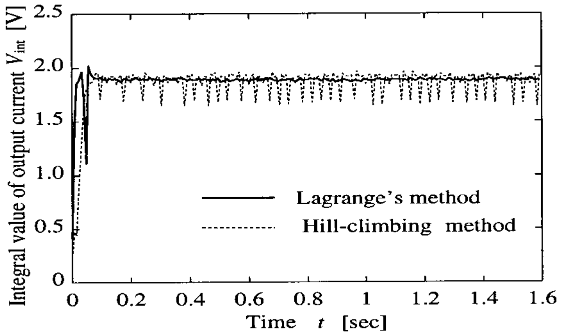
The performance of MPPT at high solar insolation is shown in Fig. 7. Figs. 7(a), 7(b), and 7(c) show the output power, integral value of output current V_{int}, and duty factor α, respectively. From the output power shown in Fig. 7(a), the proposed method tracks the maximum power point quickly, which is the same as the result obtained from the Hill climbing method. It shows that optimum operating point $\hat{\alpha}_{opt}$ is exactly estimated in Fig. 7(c), where $\hat{\alpha}_{opt}$ is close to 0.52. Since it can estimate $\hat{\alpha}_{opt}$ in the seven data point, it will take about 56 msec for tracking the maximum power point. From Fig. 7, it can be noticed that the proposed algorithm reaches the maximum power point and tracks continuously without any oscillations about this maximum power point.

4.2 Experimental Results for Low Solar Insolation

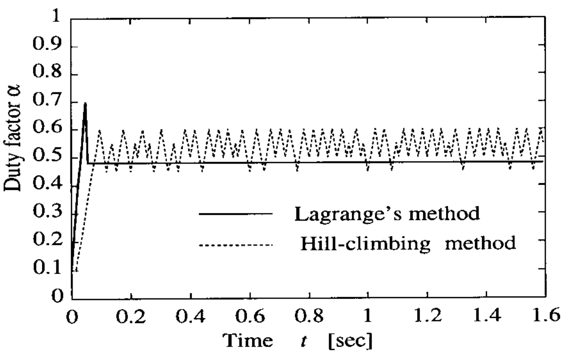
The performance of the MPPT for low solar insolation is shown in Fig. 8. Figs. 8(a), 8(b), and 8(c) show output powers, integral value of output current V_{int}, and duty factor α, respectively. From the output power shown in Fig. 8(a), the proposed method tracks the maximum power point as quickly as that of the Hill climbing method does. It is seen that the optimum operating point $\hat{\alpha}_{opt}$ is exactly estimated as shown in Fig. 8(c), where $\hat{\alpha}_{opt}$ is close to 0.30. In this case, the proposed method can shorten the tracking time of MPPT without making any oscillations.



(a) Output power P_{o}.

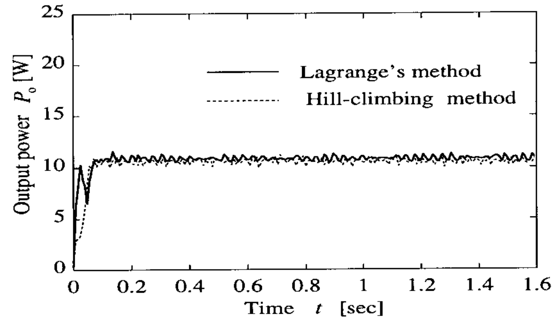


(b) Integral value of output current V_{int}.

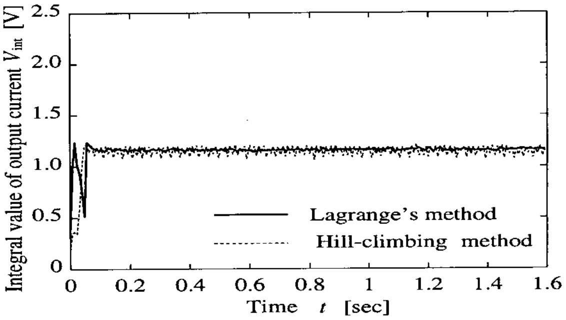


(c) Duty factor α.

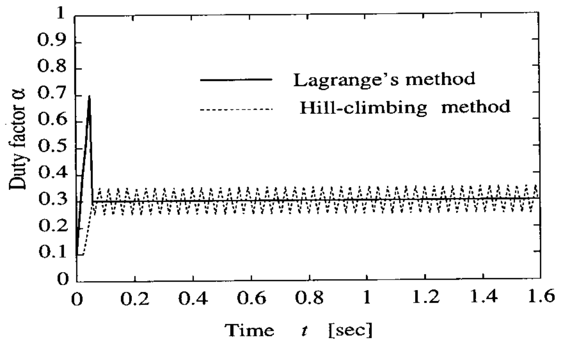
Fig. 7. Maximum power point tracking performance for high solar insolation.



(a) Output power P_{o}.



(b) Integral value of output current V_{int}.



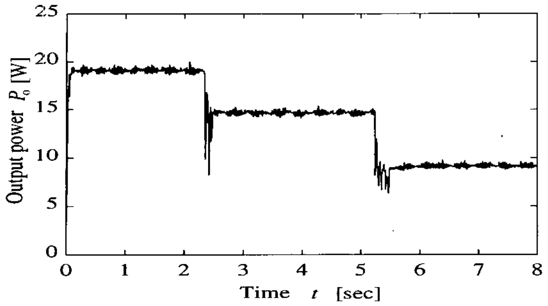
(c) Duty factor α.

Fig. 8. Maximum power point tracking performance for low solar insolation.

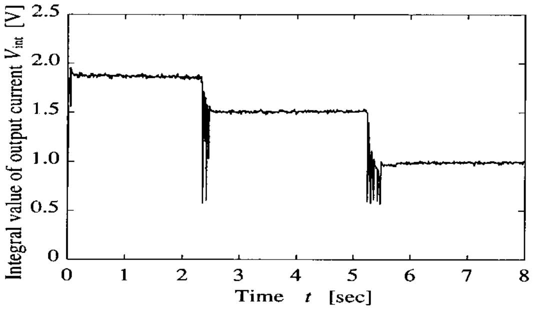
4.3 Experimental Results for Stepwise Solar Insolation

Fig. 9 shows the experimental results, for the case in which the solar insolation is changing in stepwise manner. Figs. 9(a), 9(b), and 9(c) show the output power, integral value of output current, and duty factor, respectively. From the output power shown in Fig. 9(a), the proposed method tracks the maximum power point even if the solar insolation is changing.

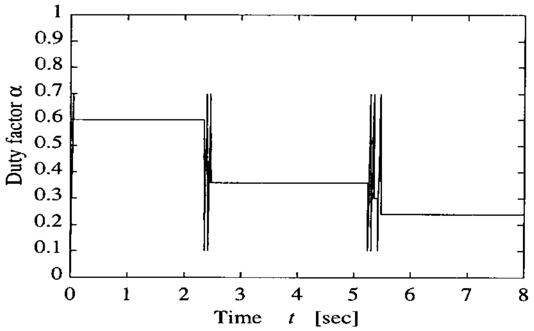
Therefore, when V_{int} reach at its maximum value, the output power moves close to the maximum power point as shown in Fig. 9(a). From the above experimental results, it is demonstrated that the MPPT control using output current and the proposed algorithm can track the maximum power point quickly without making any oscillations about the operating point.



(a) Output power P_{0}.



(b) Integral value of output current V_{int}.



(c) Duty factor α.

Fig. 9. Maximum power point tracking performance for changing solar insolations.

5. Conclusion

A voltage sensorless maximum power point tracking algorithm is developed. In the proposed algorithm, the optimum operating point of PV array is estimated using output current information. The tracking effectiveness is demonstrated through experimental results. The experimental results show that the proposed algorithm tracks the maximum power point at a faster rate without showing any oscillations.

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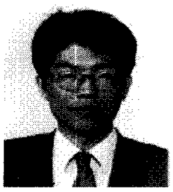

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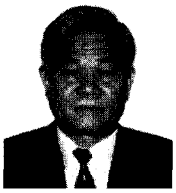

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