Single-Sensor Based MPPT for Photovoltaic Systems

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Abstract- Maximum Power Point Tracking (MPPT) techniques are the most famous application in the photovoltaic system to track the maximum power of the PV system. Usually, most of the maximum power point tracking algorithms used fixed step and two variables: the photovoltaic (PV) array voltage (V) and current (I). Therefore, both PV array current and voltage have to be measured. The maximum power point trackers that based on a single variable (I or V) have a great attention due to their simplicity and ease of implementation, compared to other tracking techniques. With traditional perturb and observe algorithm based on two variable (I and V) using fixed iteration step-size, it is impossible to satisfy both performance requirements of fast response speed and high accuracy during the steady state at the same time. To overcome these limitations a new algorithm based on a single variable method with variable step size has been investigated which has been implemented using fuzzy logic control. The proposed method has been evaluated by simulation using MATLAB under different atmospheric conditions. The obtained results show the effectiveness of the proposed technique and its ability for practical and efficient tracking of maximum power.

Keywords Maximum power point, Variable step size, Perturb and Observe, Fuzzy logic control, photovoltaic system, MPPT.

1. Introduction

The growing demand for energy, together with the increased price of the oil products and the attention paid to environmental pollution, have progressively increased the interest in renewable energy sources. Many renewable energy sources are now available. Solar energy is a very attractive renewable source amongst all the aforementioned renewable sources due to relative small system size, free and sustainable generation source or fuel, noise free operation due to the absence of moving parts, the possibility to put it close to the user, ease of installation and systems require relatively little regular maintenance.

The characteristic of the output current-voltage is nonlinear, which depend on solar irradiation level, operating temperature [1]-[2]. To solve these problems with the utilization of solar arrays for electrical power, the photovoltaic (PV) cells must work at maximum power point (MPP) all the time using some tracking algorithms, where the system operating point is forced towards the optimal operating conditions [3]- [4].

Several MPPT has been proposed Hill climbing, Perturb and Observe (P&O) [5]–[6]–[7]-[8]-[9], INcremental Conductance (INC) [10]–[11]-[12], fuzzy logic control using single sensor [13], artificial-intelligence-based algorithms [14]–[15] and single variable based variable step size [16].

Most of the algorithms mentioned above use both current and voltage sensors at the array side for sampling and calculation. Sensor-reduction has been a topic of research of late wherein attempts are made to use one sensor instead of two for cost-reduction and reliability. Constant-voltage method, using only voltage sensor is simple to implement but is less efficient [17]. Single (current) sensor technique for applications with battery at the output operates by maximizing a new variable given by G [18].

In this paper, A Variable step size technique using fuzzy logic control is proposed to solve trade-off between fast dynamic response and high-efficiency steady-state operation with lower oscillations around the MPP, which may be implemented using a fuzzy logic controller.

The simulation study was performed, and the corresponding result confirms that the proposed method can effectively improve the system performance.

The following sections of this paper are organized as follows. Section II described the model of the PV system. In Section III, the P&O algorithm. After that, the variable step size using single sensor is described in Section IV. Simulation results and conclusion are given in Section V and VI, respectively.

2. PV System Modeling

2.1. PV cell characteristics

The PV cell is consists of a P–N junction fabricated by semiconductor that converts solar energy directly into electricity. A PV cell equivalent electrical circuit can be represented by a single diode model as shown in in Fig. 1.

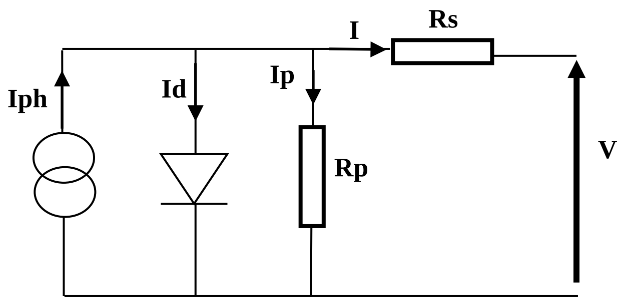


Fig. 1. Equivalent circuit of PV cell

The relationship between current and voltage relationship of single PV cell is described by the following equation [19]:

$$I = I_{ph} - I_0 \left(\exp \frac{q(V + R_s I)}{nKT} - 1 \right) - \frac{V + R_s I}{R_p} \quad (1)$$

where V and I are are the output current and output voltage of the photovoltaic cell, respectively, Iph is the photocurrent, I0 is the saturation current, Rs is the series resistance, Rp is the shunt resistance, and q is the electronic charge (1602×10-19C), n is the diode factor, K is the Boltzmann's constant (1380×10-23J/K), T is the junction temperature. Table 1 shows the electrical parameters of the PV panel.

The Fig. 2.a presents P-V characteristics and Fig.2.b presents I-V characteristics of the PV cell for different irradiation levels irradiation levels (1000, 800, 600 and 400W/m²) and the temperature is set at 25°C. The PV module used in this paper is Shell SP 75W, the maximum power delivered by the PV panel (Pmpp) is 75W under standard conditions (S=1000W/m² and T=25°C).

Table 1. Electrical Parameters of PV Array

Maximum power(Pmpp)	75 W
Voltage at MPP(Vmpp)	17 V
Current at MPP(Impp)	4.4 A
Open circuit voltage(Voc)	21.7 V
Short circuit current(Isc)	4.8 A

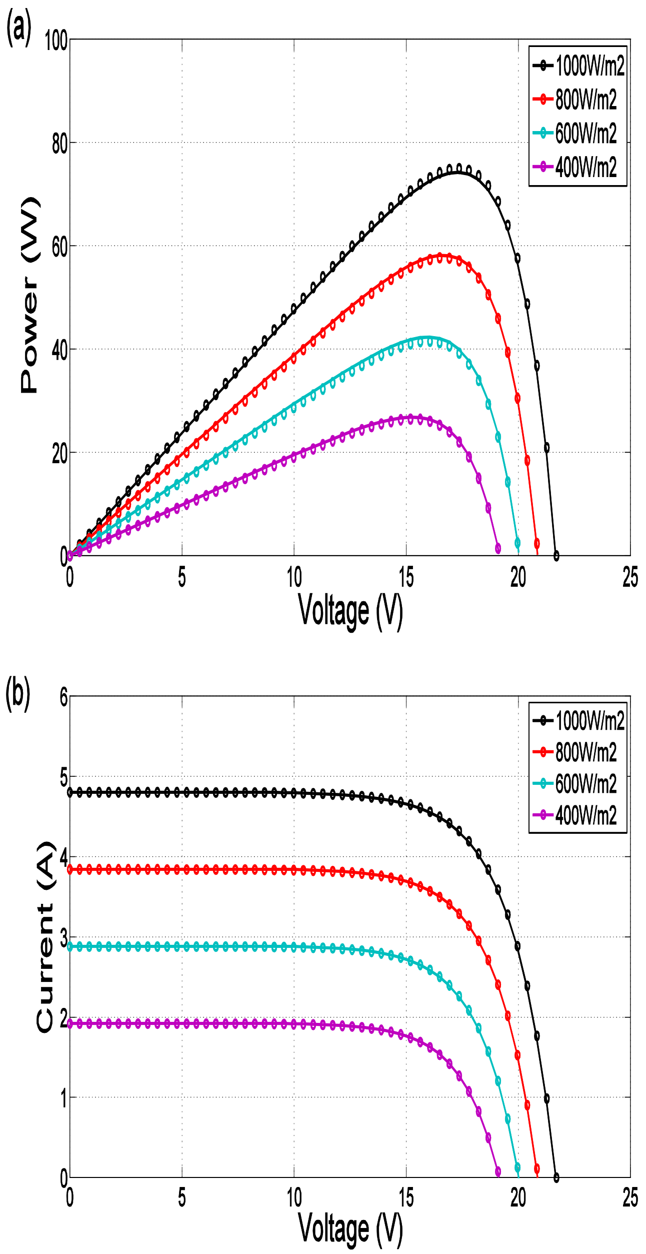


Fig. 2. Output characteristics curves with different irradiation (a) U-P curves (b) U-I

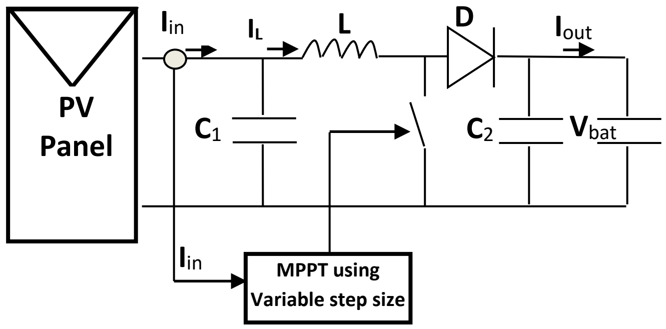


Fig. 3. Block diagram of a PV solar power system MPPT with fuzzy logic MPPT control.

2.2. DC-DC Boost Converter

A DC-DC boost converter connected to a PV module with a battery as illustrated in Fig. 3. The power switch is responsible for regulating the energy transfer from the PV panel to the battery by varying the duty cycle D [2-4]. The MPPT using a fuzzy logic controller is incrementing or decrementing the duty cycle of the boost converter to achieve the MPP of the PV panel.

The relationship between voltage and current input and output of the boost converter is described by the following equations [20].

$$\frac{V_{in}}{V_{out}} = 1- D \tag{2}$$

$$D = 1- \frac{V_{in}}{V_{out}} \tag{3}$$

where Vin is the input voltage and Vout is the output voltage of the boost converter.

3. The Perturb and Observe (P&O) Algorithm

The MPPT algorithm most commonly used is the P & O due to its low cost, ease of implementation and good tracking performance, compared to other techniques. However, it presents some disadvantages such as drawback between accuracy and response time. When P&O operating with big step size, it results great oscillation around MPP and fast response time, when P&O operating with small step size, it results small oscillations around the MPP and slow speed response.

The P&O algorithm operates periodically by comparing the actual value of the power with the previous value to determine the variation (incrementing or decrementing) on the output voltage. If the voltage of the PV panel is perturbed in one direction and dP / dV> 0, the algorithm P&O could then continue to disrupt the PV voltage in the same direction. If dP / dV <0, then the P & O algorithm reverses the direction of the disturbance. The flowchart of the classical algorithm P & O is shown in Fig. 4.

4. Variable Step Size Using Single Sensor

The output power of the PV panel provided to the battery is described by the following equation [21]:

$$P= V_{in} \times I_{in} \tag{4}$$

According to equations (2) and (4), we can deduce the new Variable is given by [22]:

$$G = (1- D)\, I_{in} \tag{5}$$

The new variable is depending essentially on the input current of the PV system and to duty cycle. It is characterized by MPP at respect value of duty cycle.
Generally, the algorithm based single variable is run with a

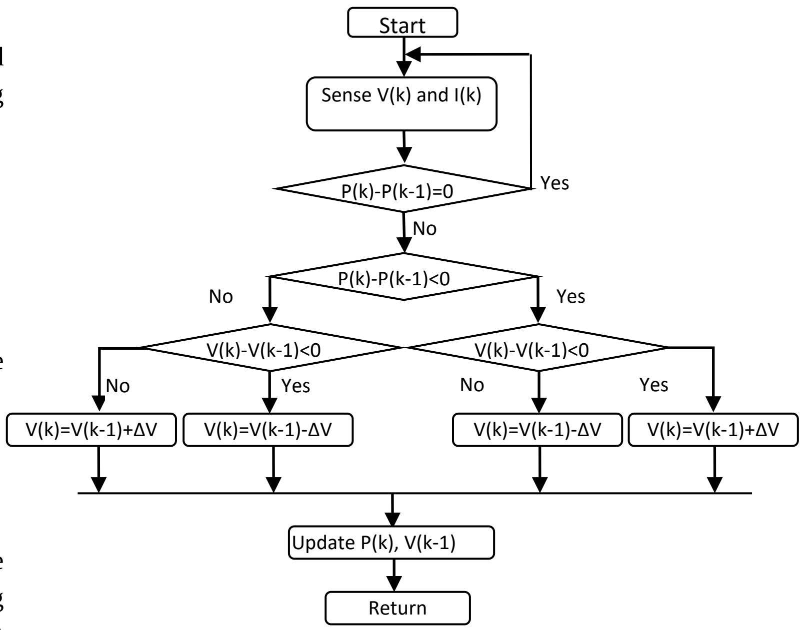


Fig. 4. Perturb & Observe (P&O) Method

fixed step size. If this step-size is set to be large, the algorithm will have a faster response to dynamics to track the MPP. However, the algorithm with a large step-size results in excessive steady state oscillation, which reduces power efficiency. This performance situation is reversed when is running with a small step-size. Therefore, the algorithm based single variable MPPT with fixed step-size does not allow a good trade-off between steady-state oscillation and dynamic response to changing operating conditions. Therefore, in this work a single variable based variable step size MPPT algorithm is proposed, which may be implemented using fuzzy logic control as shown in Fig. 5.

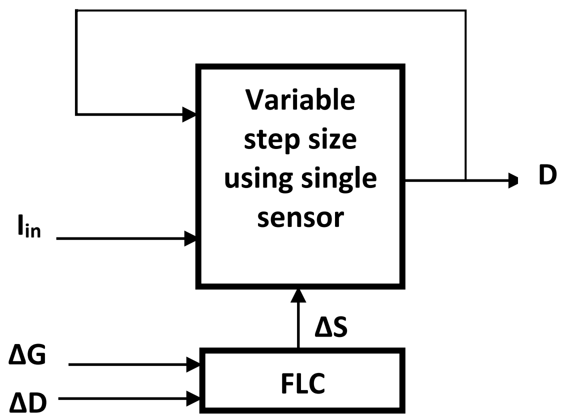


Fig. 5. Variable step-size P&O based Fuzzy Logic control

The input variables of the FLC are (ΔG) and (ΔD) the variation of new variable and the variation of a duty cycle, respectively; moreover the output of the FLC is the duty cycle (ΔS). The main elements of the FLC systems are shown in Fig. 6. The fuzzy based rules of the FLC ar presented in Table 2. The member function is coding b Positive Big (PB), Positive Small (PS), Zero (Z), Negativ Small (NS), and Negative Big (NB). The output of the FL defuzzified using a center of gravity method to calculate th output ΔS.

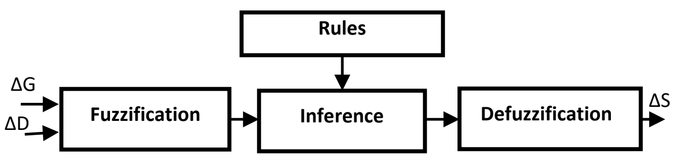


Fig. 6. General diagram of the fuzzy logic controller.

Table 2. Fuzzy Rules Base

ΔD	ΔG				
	NB	NS	ZZ	PS	PB
NB	NB	NS	NS	ZZ	ZZ
NS	NS	ZZ	ZZ	ZZ	PS
ZZ	ZZ	ZZ	ZZ	PS	PS
PS	ZZ	PS	PS	PS	PB
PB	PS	PS	PB	PB	PB

5. Simulation Results

To verify the feasibility of the proposed algorithm, the simulation of the PV system is applied in the environment of MATLAB/Simulink. The PV system is composed of PV panel, MPPT using the fuzzy logic controller, and boost converter. The electrical specifications of PV panel are presented in Table 1. The parameters of the boost converter are listed in Table 3.

The MPPT using fuzzy logic controller method is tested under irradiance (500 W/m2) and temperature (T=25°C) as presented in Fig 7. The proposed algorithm can converge rapidly to MPP. The output power of proposed method could converge finally to MPP at 0.02s. Though, the P&O method converges to MPP at 0.04s.

Table 3. Parameters Boost Converter

Parameters	Values
C1	4mF
C2	800uF
L	10mH
R	20Ω
Vbat	70V

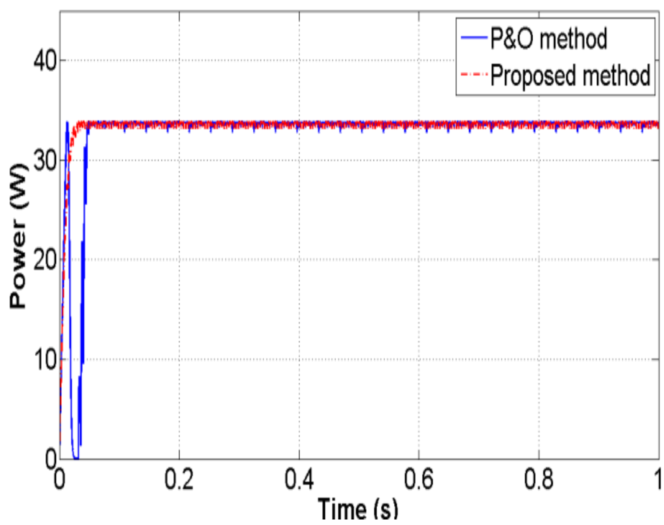
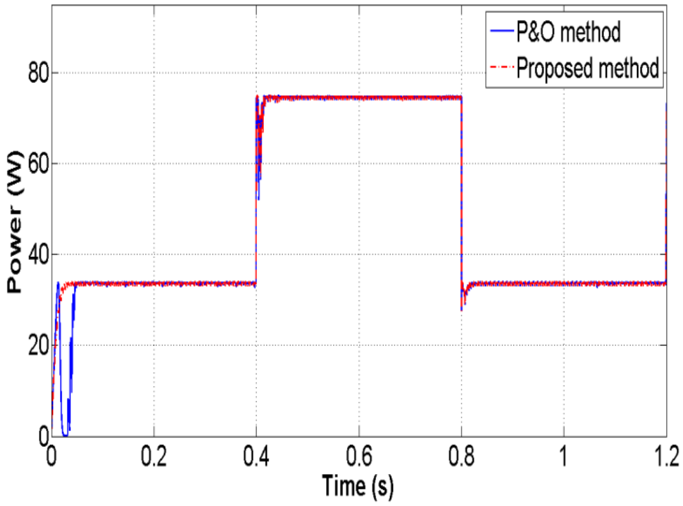
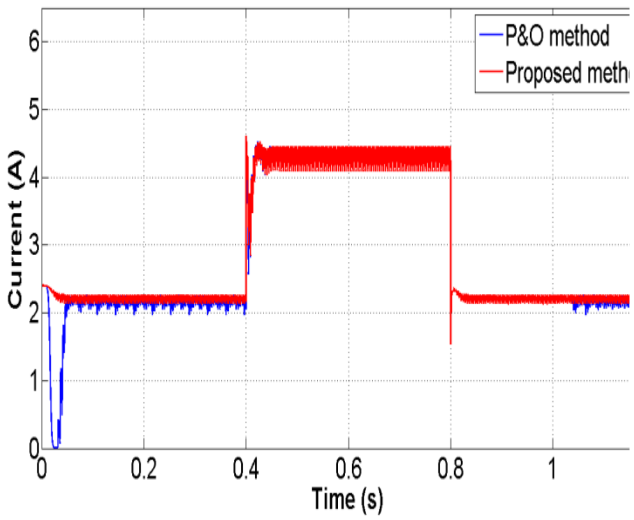


Fig. 7. The output power of the PV The proposed method.



(a)



(b)

Fig. 8. The outputs PV array under irradiation step change. (a) Power, (b) Current.

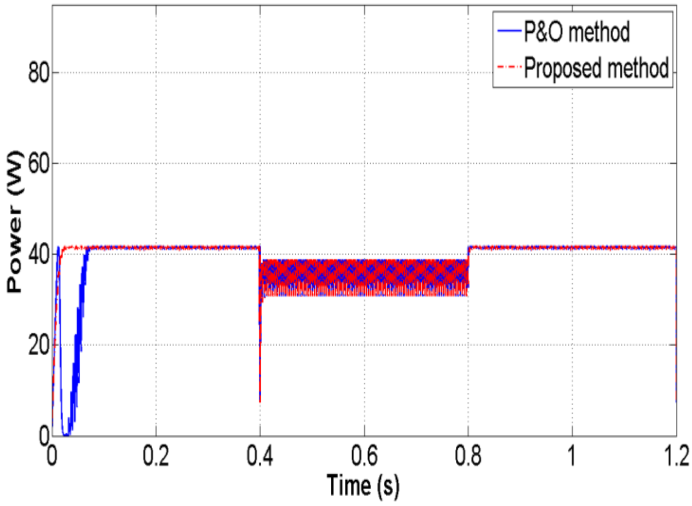
The output power and current performance of the proposed method when the irradiation changes are illustrated in Fig. 8. In each case, the temperature is set at 25°C, the irradiation is suddenly changed from 500 to 1000W/m2 at 0.4 s, from 1000 to 500W/m2 at 0.8 s.

Fig. 8 demonstrates that the P&O method converged slowly to MPP when the irradiation. However, Fig. 8 shows the proposed method has better performance than P&O method and it could converge to MPP efficiently when the irradiation changes.

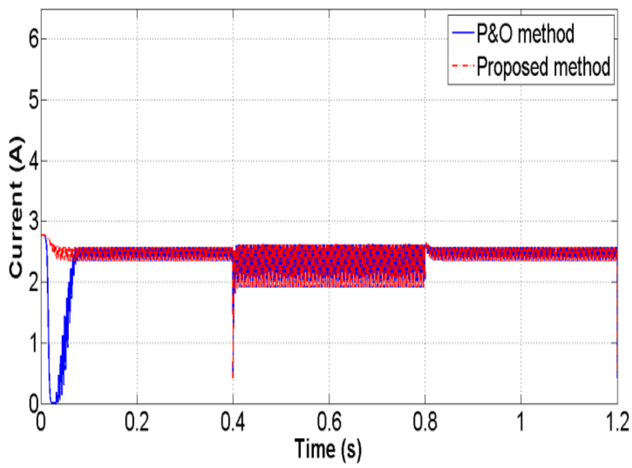
The output power and current performance of the proposed method and P&O method when the temperature changes are shown in Fig. 9. In each case, the solar irradiation is set at 600W/m2, and the temperature is suddenly varied from 10 to70°C at 0.4 s and from 70 to 10°C at 0.8 s.

Fig. 9 shows that the P&O method has a slow response speed and great oscillations under the temperature changes. Nevertheless, shows the fuzzy logic control is rapid and it has good steady state performance under the temperature changes.

As demonstrate in Fig. 8 and Fig. 9, the proposed method has a better dynamic performance of the PV system. To conclude test, the Tables 4 and 5 summarize the comparison of the performances between of P&O and proposed method, under variation of irradiation and temperature, respectively.



(a)



(b)

Fig. 9. Output PV array under temperature step change. (a) Power, (b) Current.

Table 4. Comparison results under 500w/m², T=25°C

MPPT	Response time	Ripple Current	Mean value (33.79W)
P&O	**0.04s**	**0.1625A**	**31.29W**
Proposed method	**0.02s**	**0.06A**	**33.49W**

Table 5. Comparison results under 500w/m², T=10°C

MPPT	Response time	Ripple Current	Mean value (33.92W)
P&O	0.04s	0.6A	30.92W
Proposed method	0.03s	0.07A	33.42W

6. Conclusion

The output current-voltage and power-voltage characteristics of the photovoltaic system are nonlinear, and the operating conditions of the optimum PV power gained from the PV array are affected by solar irradiation, cell temperature and loading conditions.

In this paper, the simulated results match the characteristics given by the datasheet under different atmospheric conditions (irradiation and temperature). The effect of temperature and irradiation on the PV panel output characteristics have been investigated with varying load conditions. A single variable based variable step size has been proposed and evaluated using a fuzzy logic control to give variable step-size convergence to improve the efficiency of the PV system. To set up the complete PV system simulation model a boost dc-dc converter was included with a PWM controller. The performance of the proposed method is evaluated and compared with a traditional P&O algorithm using MATLAB simulation. In the standard conditions, the simulation results show that the proposed method achieves the MPP at 0.02s, compared to P&O method achieves the MPP at 0.04s; Moreover, the proposed method has small oscillation around MPP, compared to P&O method. Hence, the proposed method has the ability to improve both the steady-state and dynamic performance of the photovoltaic power generator system.

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