Maximum Power Point Tracking method based fuzzy logic control for photovoltaic systems

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Abstract: Maximum Power Point Tracking (MPPT) techniques are most famous application in photovoltaic system to track the maximum power of the PV system. Usually, most of 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 single variable (I or V) have a great attention due to their simplicity and ease in 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 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 experimental results show the high performance of the proposed method compared to P&O method.

Key–Words: Maximum power point; Single sensor; new algorithm; MPPT; Perturb and Observe.

1 Introduction

PV cells are components that convert solar energy directly into electricity by a process called "photovoltaic effect" [1]. The output characteristics of PV cell have become a very important issue in the photovoltaic industry. To harness the energy output of the photovoltaic cell and maximize the effectiveness of these, the photovoltaic cells must work at Maximum Power Point (MPP) all the time [2]. In recent years, many techniques have been proposed for tracking the MPP, the Incremental Conductance method (IncCond) [3, 4], fraction of the short-circuit current [5] fraction circuit voltage open [6]. Neural network [7], fuzzy logic control and other MPPT methods [8, 9, 25, 26]. In practice, the P& O method [10, 12] is the technique most commonly used due to its low cost, ease of implementation and relatively good tracking performance, compared to other techniques. Nevertheless, the P&O method cannot follow the MPP when weather conditions change rapidly. Different techniques of MPPT algorithms has been proposed including variable step size perturb and observe [13, 15], incremental conductance (VINC) [16, 18], P&O algorithms using fuzzy logic control [19, 20, 27] and single variable based variable step size [21]. To improve the performance of the P&O method, this paper presents a novel single variable step size MPPT algorithm using single sensor for PV systems. To further improve speed and regular monitoring. In this paper, A Variable step size technique using fuzzy logic control is proposed to solve tradeoff 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 performance of proposed method and P&O algorithm has been tested using a boost converter connected to indoor solar panel . The experimental and simulation results show that the proposed method can effectively improve the system performance compared to P&O method.

2 PV System Modeling

2.1 PV cell characteristics

The PV generator is essentially a PN junction semiconductor that converts solar energy directly into electricity. The equivalent circuit is shown in fig.1 [22]. The equation describes current-voltage relationship of single PV cell is given as [23]:

The relationship between current and voltage relationship of single PV cell is described by the follow-

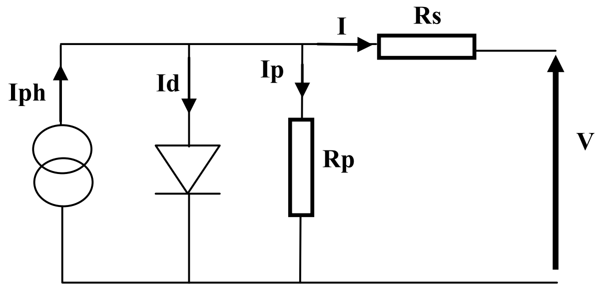

Fig. 1. Equivalent circuit of PV cell.

Table 1
Electrical characteristics of PV panel ($1000W/m^2$, 25°C)

Maximum power (Pmpp)	200W
Voltage at MPP (Vmpp)	50V
Current at MPP (Impp)	4A
Open circuit voltage (Voc)	58.5V
Short circuit current (Isc)	4.42A

ing equation [24]:

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

where V is the PV output voltage, I is the PV output current, Iph is the photocurrent, I_0 is the saturation current, R_s is the series resistance, Rp is the shunt resistance, q is the electronic charge, n is the diode factor, K is the Boltzmanns constant and T is the junction temperature. fig.2.a shows the typical output characteristics of PV cell: maximum power (P_{mpp}), open circuit voltage (V_{oc}), short circuit current (I_{sc}), which are simulated under standard conditions (irradiation (S) = 1000, 700 and $500W/m^2$, temperature (T) = 25°C). fig.2.b shows the output characteristics of PV cell simulated under standard conditions (temperature (T) = 25, 50 and 75°C, irradiation (S) = $1000W/m^2$).

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 [23, 24]. The MPPT using fuzzy logic controller is incrementing or decrementing the duty cycle of the boost converter to achieve the MPP of the PV panel.

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

3 The Perturb and Observe (P&O) Algorithm

The MPPT algorithm most commonly used is the (P & O). However, it has some disadvantages such as oscillations around the MPP and slow speed response. The tracker operates periodically by comparing the actual value of the power with the previous value to determine the change (incrementing or decrementing) on the solar array voltage or current (depending on the control strategy). If the voltage of the PV generator 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 we have an overrun of the MPP, the P & O algorithm reverses the direction of the disturbance. The flowchart of the traditional algorithm P & O is shown in fig.4.

4 Principle of Variable Step Size Using Single Sensor

4.1 Single sensor MPPT

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

$$P = V_{in} \times I_{in} \tag{2}$$

We can introduce the new Variable is given by [23]:

$$G = (1 - D)I_{in} \tag{3}$$

The proposed method is devoted to obtain an effective way to ameliorate the traits of both dynamics and stable state performance. The algorithm of the proposed method is described in the flowchart [5].

Defuzzification adopted in our system is the centre of gravity to calculate the output of this FLC which is the duty ratio (cycle). The centre of gravity method is both very simple and very fast method. Thus, the

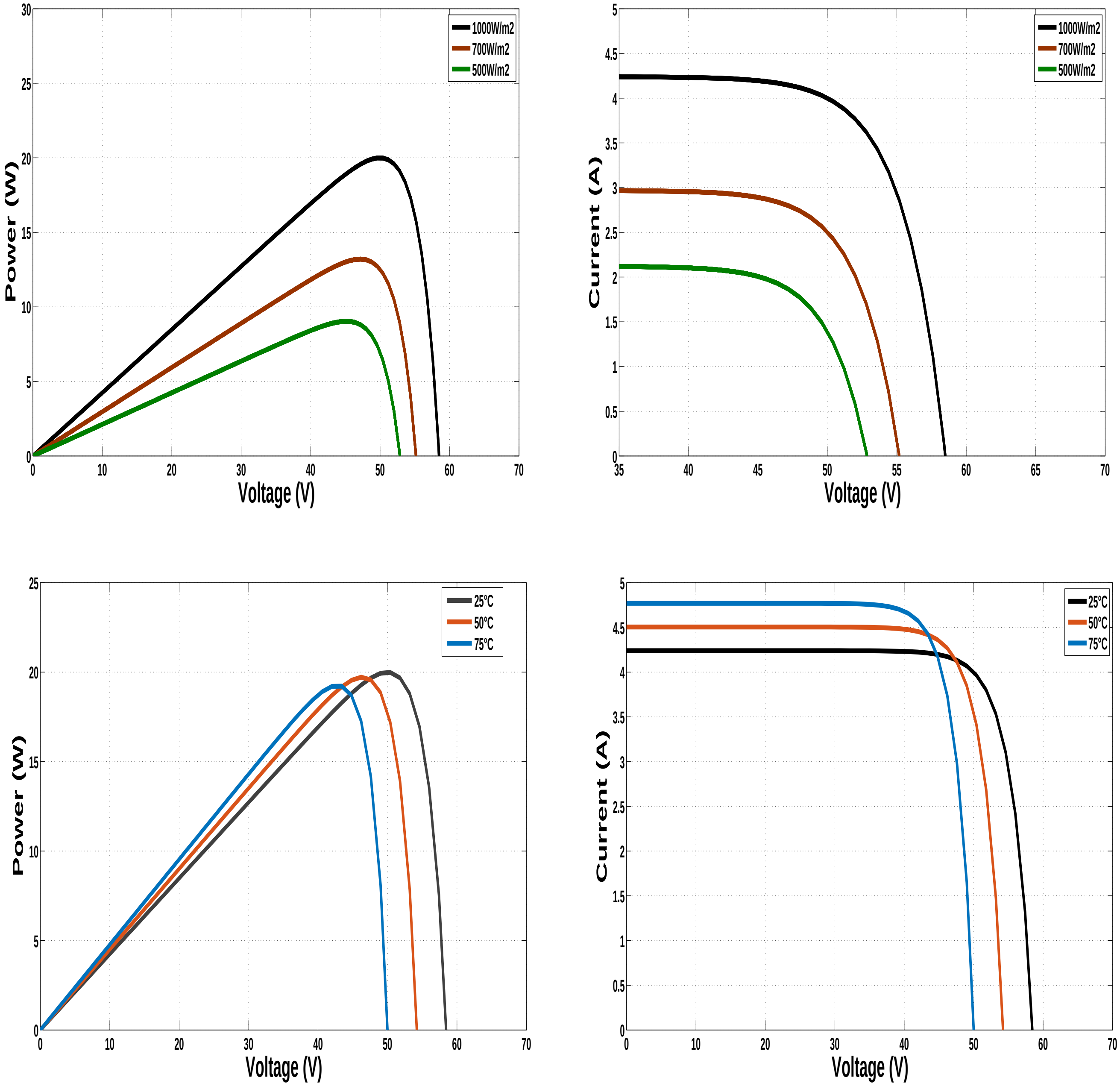

Fig. 2. a) P-V and I-V curve for various irradiation (S=500, 700 and 1000W/m^2, T=25°C), b) P-V and I-V curve for various temperature (T=25, 50 and 70°C, S=1000W/m^2) .

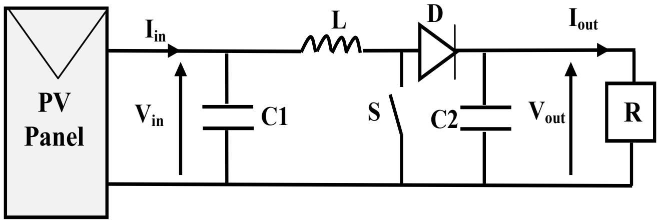

Fig. 3. DC−DC boost converter.

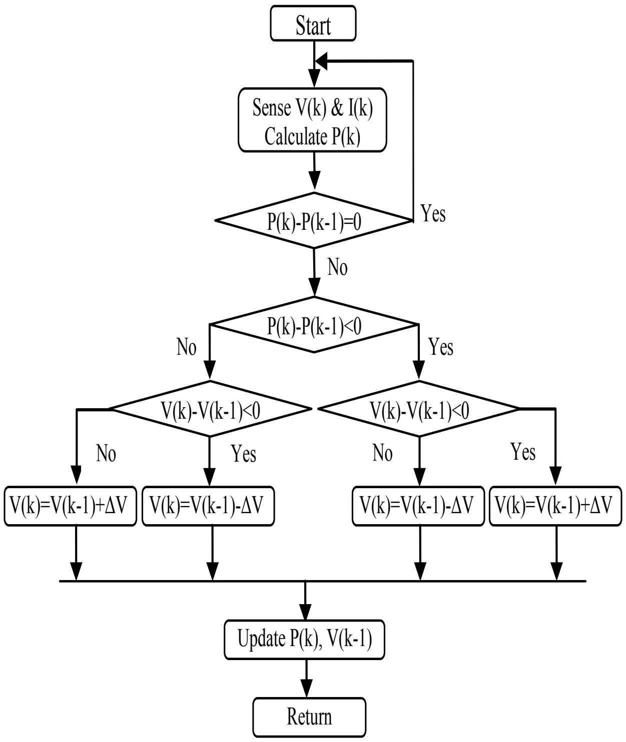

Fig. 4. Classical Perturb and Observe (P&O) Method.

change of duty ratio D is determined by the centre of gravity method as follows:

$$\Delta D(k) = \frac{\sum_{j=1}^{n} \mu\left(\Delta D_j(k)\right) \times \Delta D_j(k)}{\sum_{j=1}^{n} \mu\left(\Delta D_j(k)\right)} \quad (4)$$

Duty ratio, the output of FLC uses to control through PWM which generated pulse to control MOSFET switch in DC−DC converter.

5 Simulation results

In order to verify the feasibility of the proposed method, the simulation models of the PV system are applied in the platform of MATLAB/Simulink. A PV

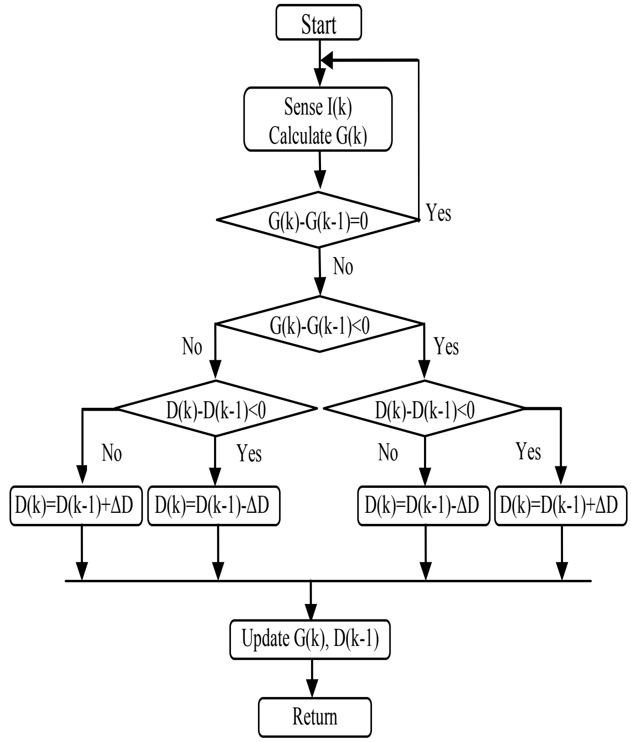

Fig. 5. Classical Perturb and Observe (P&O) Method.

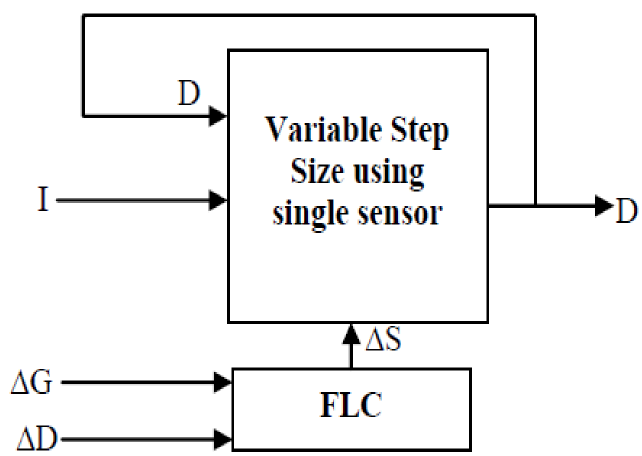

Fig. 6. Variable step-size P&O based Fuzzy Logic control.

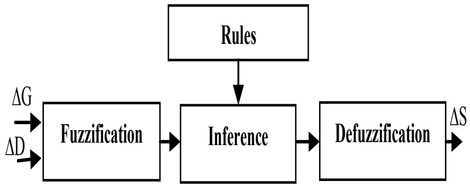

Fig. 7. General diagram of fuzzy logic controller.

system which composed of solar panel, MPPT controller, PWM generator and boost converter. PV specifications are listed in tab.1. The parametric details of the boost converter have been provided in tab.3.

Table 3
Specifications for the boost converter.

Parameters	Label	value
Input capacitor	C_1	0.1 µF
Input capacitor	C_2	470 µF
Boost inductor	L	22 mH
Load	R	220
Tension of battery	V_b	90 V
Switching frequency	f	10 kHz

The P&O and proposed methods are tested under irradiance (900 W/m^2) and temperature (T=25°C) as illustrated in fig.4. The duty cycle and ripple of duty around is shown in fig.5.The proposed method can converged rapidly to MPP. The output power of proposed method could converge finally to MPP at 50ms with good precision. However, the P&O method converge slowly to MPP at 340ms with large oscillation. To analyse and compare the performance of the P&O method and proposed method, the PV system is tested under two types profile of irradiation and temperature. The first profile is triangle function from (500, 1000 and 500) W/m^2 at (0.25-0.75) s and the second profile is ramp function from (500, 1000) W/m^2 at (0.75-1) s. The fig.6.a shows the profile of irradiance, the temperature is constant (25°C). As can see in fig.6.b, the proposed method follows MPP with high dynamic and precision. However, the P&O method converges slowly to MPP with big oscillation and it loses direction to tracking MPP.

The first profile is triangle function from (12.5, 24.5 and 12.5) °C at (0.25-0.75) s and the second profile is ramp function from (12.5, 24.5) °C at (0.75-1) s. The fig.7.a shows the profile of temperature, the irradiance is constant (1000w/m^2). As can see in fig.7.b, the proposed method follows MPP with high dynamic and precision. However, the P&O method converges slowly to MPP with big oscillation and it loses direction to tracking MPP. To conclude tests, the Table 3

Table 4
Electrical characteristics of PV panel (1000W/m^2, 25°C)

Maximum power (Pmpp)	2W
Voltage at MPP (Vmpp)	5V
Current at MPP (Impp)	0.4A
Open circuit voltage (Voc)	5.85V
Short circuit current (Isc)	0.442A

Table 5
Specifications for the boost converter.

Parameters	Label	value
Input capacitor	C_1	0.1 µF
Input capacitor	C_2	470 µF
Boost inductor	L	22 mH
Load	R	220
Tension of battery	V_b	9V
Switching frequency	f	10 kHz

summarize the comparison of the performances between of P&O and proposed method, under variation of atmospheric conditions.

6 Experimental results

To compare the performance of the studied MPPT methods, an experiment platform of PV system is built fig.8 . The experimental setup is shown in fig.9.

The experimental setup is a low power system that permits tests without requiring high−power equipment. The PV emulating system is composed by a DC power supply and PV panel [28]. it includes indoor solar panel, DC-DC converter, MPPT controller and resistive load. The PV panel provides 2W at standard conditions whose parameters are reported in fig.9. The DCDC converter is the boost converter, the components of the boost converter is shown tab.3.

This work uses the fuzzy inference of Mamdani.The centre of gravity defuzzification method is adopted in our FLC proposed method, to calculate the output of this FLC which is the duty ratio. The P&O and propsed method are implemented by microcontroller. To ensure the system attains the steady state before another MPPT cycle is initiated, the sampling time is chosen as 0.05 s. The The output voltage,current and power is shown in fig.10. The proposed method can converged rapidly to MPP. At the same conditions, the output voltage of the P&O and

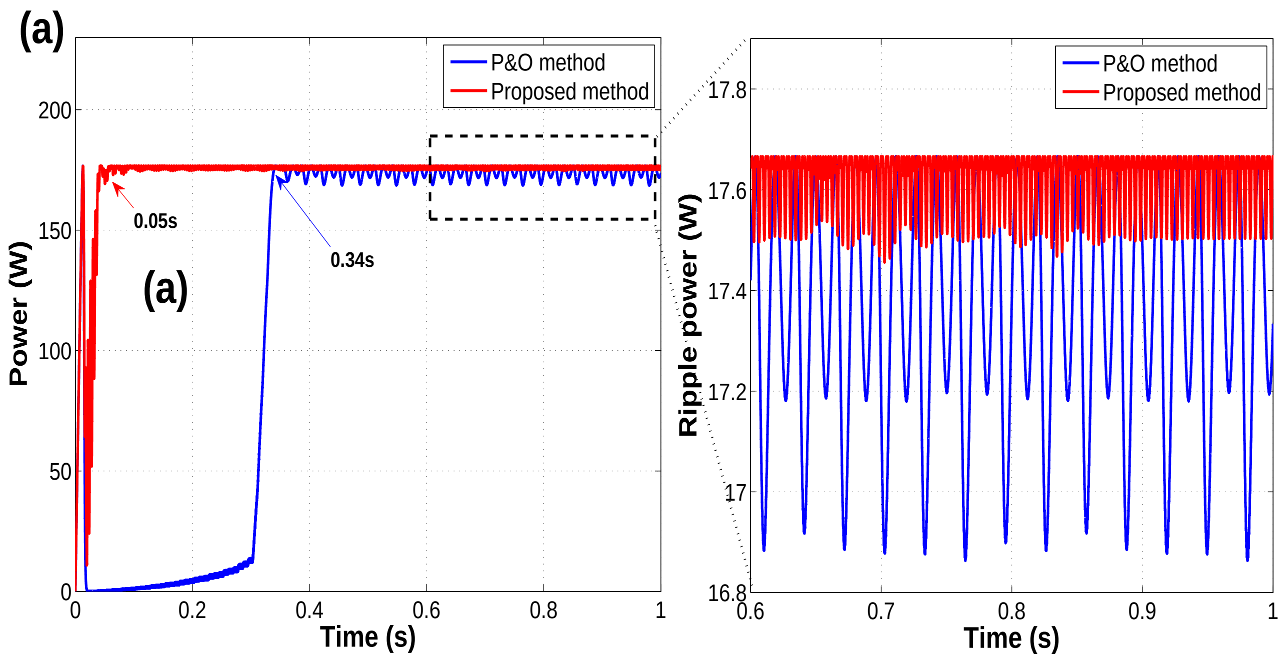

Fig. 8. a) The ouput power , b) The ripple power of the P&O and proposed FLC method

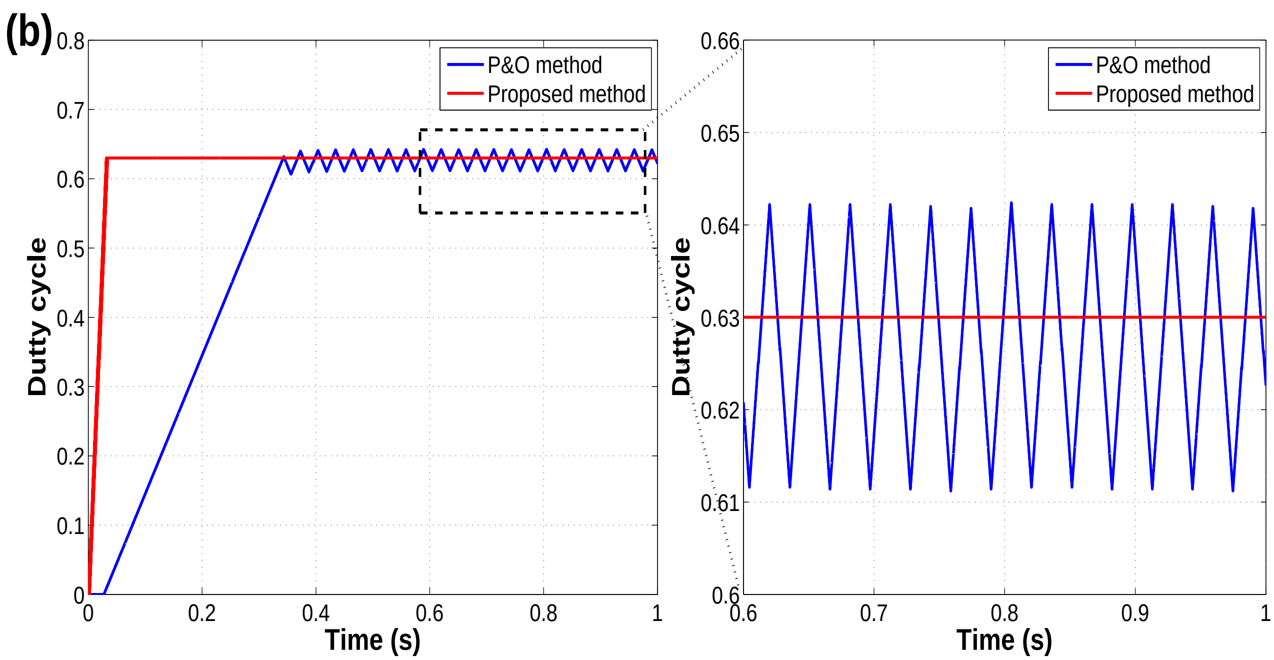

Fig. 9. a) The duty cycle , b) The ripple of duty cycle of the P&O and proposed method

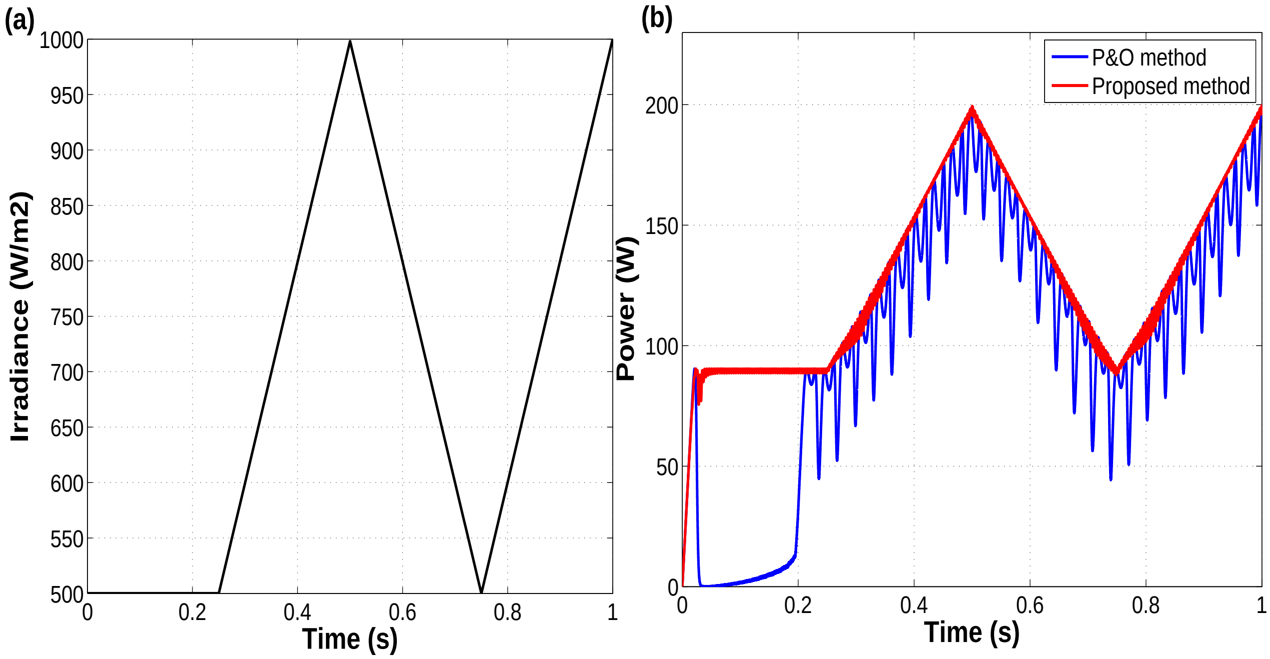

Fig. 10. a) The profile of irradiance , b) The output power of the P&O and proposed method

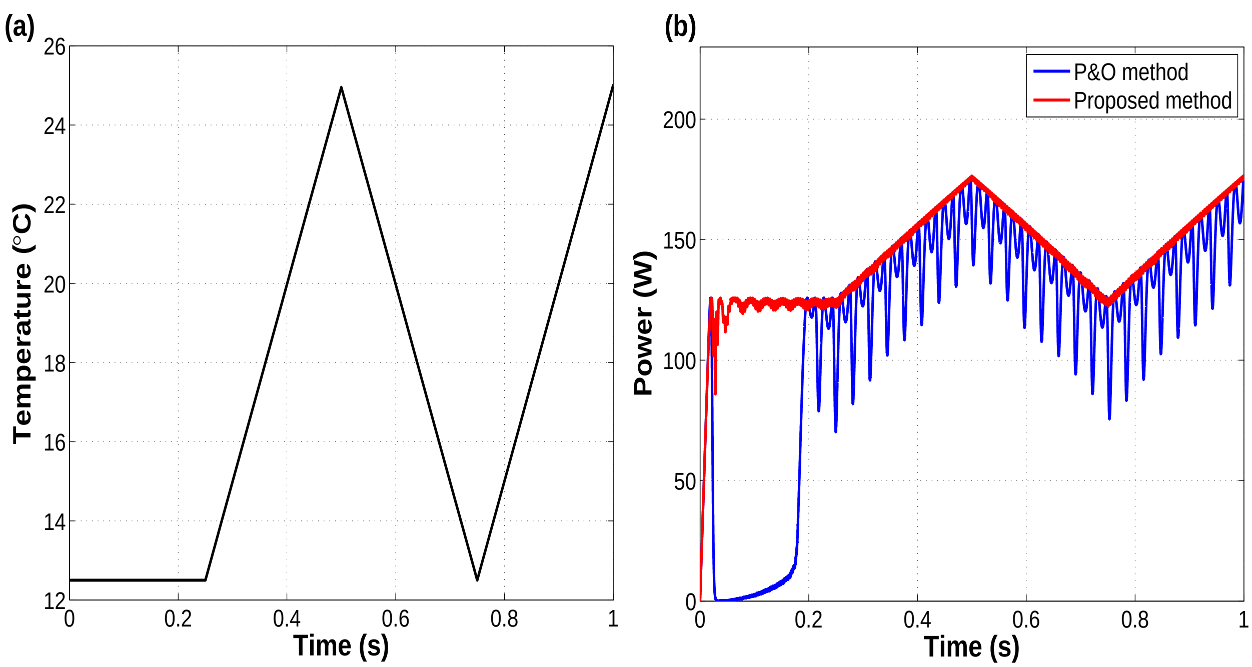

Fig. 11. a) The profile of temperature , b) The output power of the P&O and proposed method

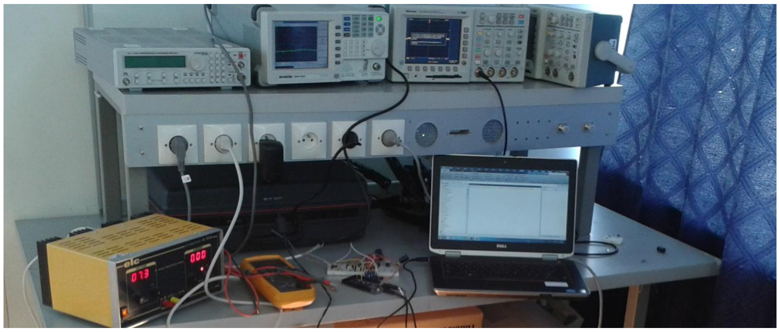

Fig. 12. The experiment platform of PV system.

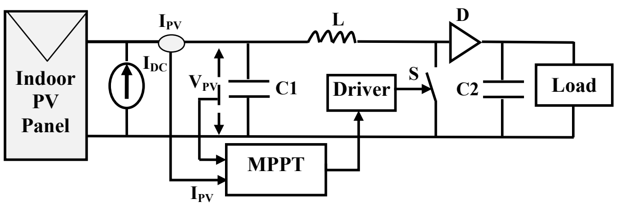

Fig. 13. DC−DC boost converter.

proposed method could convergefinally to MPP at 2s and 17s respectively. Moreover, the ripple power around MPP at steady state for proposed method is very small.

To conclude tests, the tab.5 summarize the comparison of the performances between of P&O and proposed method, under variation of atmospheric conditions.

7 Conclusion

In this paper, we presented new algorithm for extract maximum power point is presented, it is able to improve the dynamic performance of the PV system.The proposed method can converge more rapidly and has good steady state under atmospheric condition changes. The simulation results verify the feasibility and effectiveness of the proposed method.

Table 6
Summary of performance P&O and proposed method for simulation and experimental results.

Test results	MPPT algorithms	Atmospheric conditions	Response times (s)	Ripple power (W) &Efficiency (%)	
Simulation results	P&O method	Stable conditions (900W/m^2, T=25 °C)	0.34s	7W	98%
	Proposed method	Stable conditions (900W/m^2, T=25 °C)	0.05s	2W	99.43%
Experimental results	P&O method	Same condition	17s	—	—
	Proposed method	Same condition	2s	—	—

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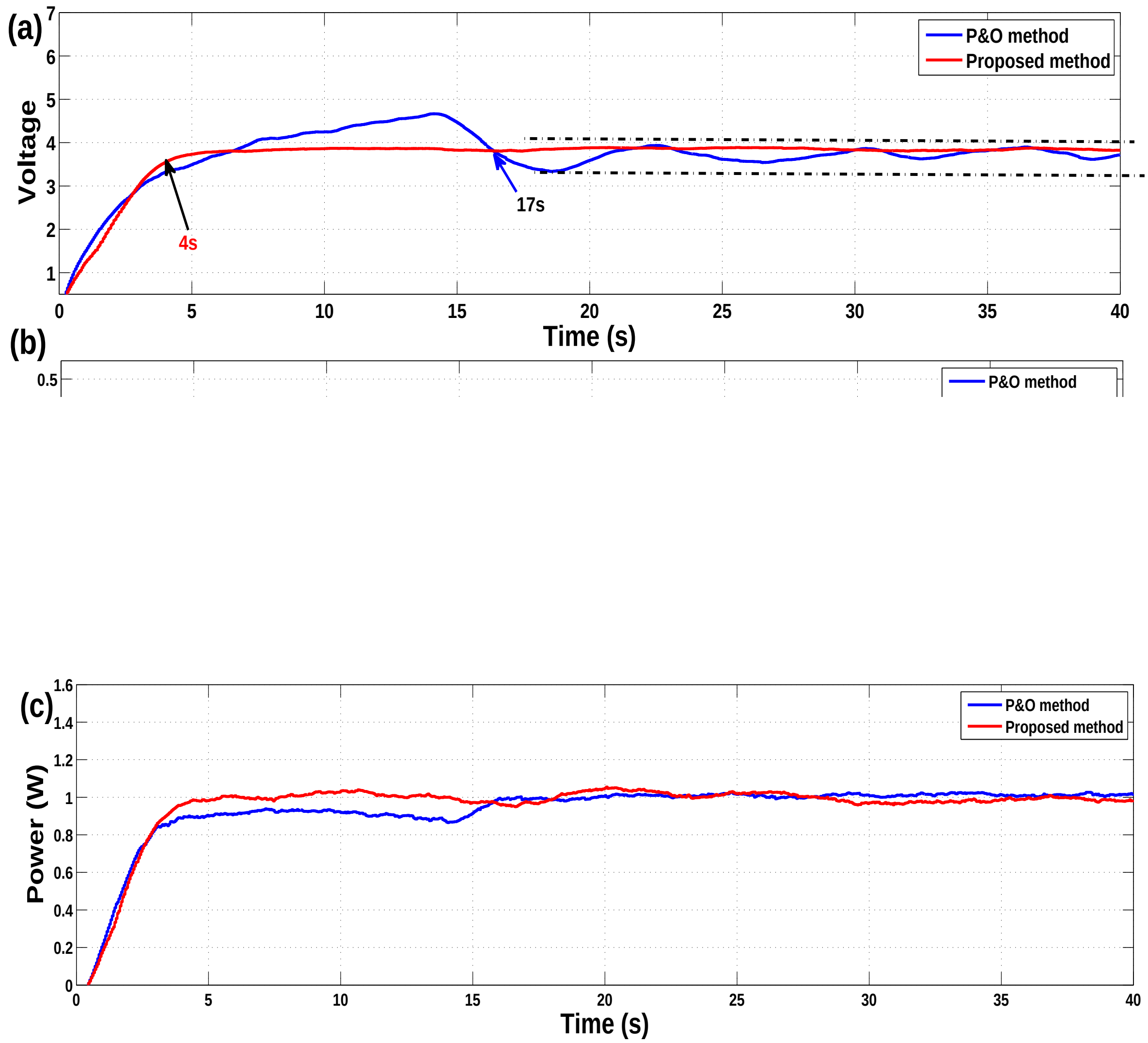

Fig. 14. a) The ouput voltage , b) The output current and c) The output power of the P&O and proposed method.

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