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Experimental Verification of the Main MPPT Techniques for Photovoltaic System

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ABSTRACT

Photovoltaic (PV) technology is one of the important renewable energy resources as it is pollution free and clean. PV systems have a high cost of energy and low efficiency, consequently, they not made it fully attractive as an alternative option for electricity users. It is essential that PV systems are operated to extract the maximum possible power at all times. Maximum Power Point (MPP) changes with atmospheric conditions (radiation and temperature), it is difficult to sustain MPP at all atmospheric levels. Many Maximum Power Point Tracking (MPPT) have been developed and implemented. These methods varied according to several aspects such as a number of sensors used, complexity, accuracy, speed, ease of hardware implementation, cost and tracking efficiency. The MPPT techniques presented in the literature indicate that Variable step size of Perturb & Observe(VP&O), Variable step size of Incremental Conductance (VINC) and Perturb & Observe (P&O) using Fuzzy Logic Controller (FLC) can achieve reliable global MPPT with low cost and complexity and be easily adapted to different PV systems. In this paper, we established theoretical and experimental verification of the main MPPT controllers (VP&O, VINC, and P&O using FLC MPPT algorithms) that most cited in the literature. The three MPPT controller has been tested by MATLAB/Simulink to analyze each technique under different atmospheric conditions. The experimental results show that the performance of VINC and P&O using FLC is better than VP&O in term of response time.

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1. INTRODUCTION

The uses of PV systems are becoming more and more important due to their environment-friendly and economically sustainable energy source[1]. The efficiency of the PV system depends on atmospheric conditions like the solar radiation and ambient temperature [2]. Therefore, to make the PV generation systems more efficient, MPPT controller is required to track the MPP at all atmospheric conditions.

In literature, several notions have been proposed such us: fixed step size and variable step size. The techniques based fixed steps such as P&O algorithm [3], hill climbing (HC) [4] and incremental conductance method (INC) [5]. The disadvantage of techniques based fixed step size is a dilemma of response time and accuracy.

The techniques based variable step size such us VP&O [6-8], VINC [9-12] and P&O algorithms using FLC [13-15]. The techniques based variable step size overcomes the drawbacks of fixed step size. other techniques, such us P&O based hybrid MPPT, Variable step size modified P&O MPPT algorithm using GA−based hybrid A two−steps P&O algorithm and other techniques[15-20].

These methods are distinguished according to several aspects such as a number of sensors used, oscillations around the MPP, algorithm complexity, speed, ease of hardware implementation, cost and tracking efficiency [42].

In this paper, we compare and analysis the main MPPT controllers (VP&O , VINC ,and P&O algorithms using FLC) that most cited in the literature, and they present some advantages compared to others techniques in terms convergence speed, oscillations around the MPP, algorithm complexity, cost and electronic equipment requirements.

2. PHOTOVOLTAIC SYSTEM MODELING

2.1. PV cell characteristics

The PV cell is consists of a PN 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 Fig.1.

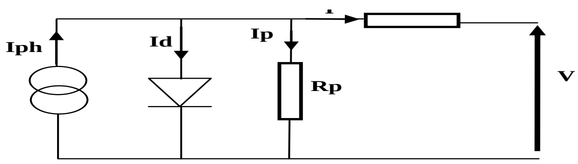

Fig. 1. Equivalent circuit of PV cell.

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

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

where V is the PV output voltage, I is the PV output current, I_{ph} is the photo-current, I_0 is the saturation current, R_s is the series resistance, R_p is the shunt resistance, q is the electronic charge, n is the diode factor, K is the Boltzmann constant and T is the junction temperature. Fig.2.a shows the output power characteristics of PV cell, which are simulated under different irradiation levels and the temperature is constant (irradiation (S) = 1000, 700 and 500W/m^2, temperature (T) = 25°C). Fig.2.b shows the output characteristics of PV cell simulated under different temperature levels and the irradiation is constant (temperature (T) = 25, 50 and 75°C, irradiation (S) = 1000W/m^2).

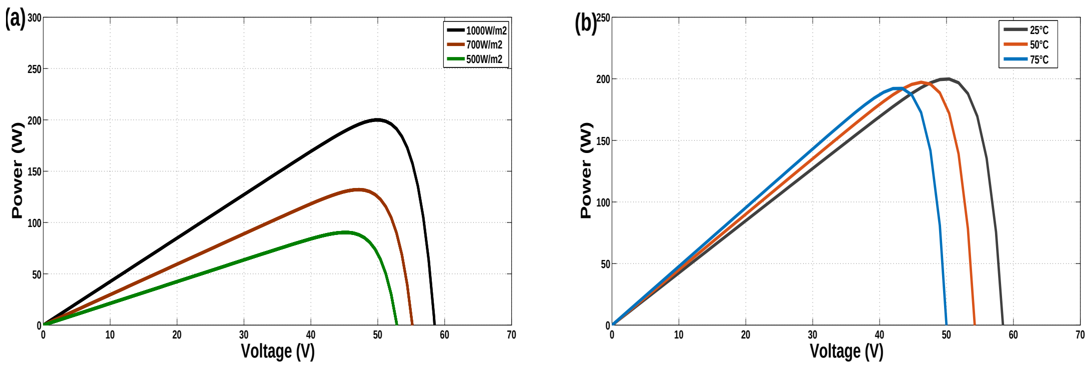

Fig. 2. a) P−V curve for various irradiation (S=500, 700 and 1000W/m^2, T=25°C), b) P−V curve for various temperature (T=25, 50 and 75°C, S=1000W/m^2) .

2.2. DC−DC Boost Converter

A DC−DC boost converter connected to a PV module with a resistance load. The power switch is responsible for regulating the energy transfer from the PV panel to the resistance load by varying the duty cycle

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

D [15].

3. MPPT CONTROL ALGORITHMS

MPPT algorithms work in such a way as to modify the duty ratio of the DCDC converter at the output of the solar array such that the load impedance visualized by the solar PV array will make it operate at the MPP for a given temperature and insolation.The following sections describe some of the MPPT algorithms.

3.1. Variable step size P&O MPPT

The flowchart of the variable step size P&O MPPT algorithm is shown in Fig.3, where the step size is automatically tuned according to the PV array operating point. When a step change in the solar irradiance occurs, the step size is automatically tuned according to the operating point. If the operating point is far from the MPP, it increases the step size which enables a fast tracking ability. The variable step size adopted to reduce the problem mentioned above is shown as follows:

$$D(k) = D(k-1) \pm N \times |\Delta P| \tag{2}$$

Where: P(k), V(k): output power and voltage of the PV array at the (k) the sample of time.

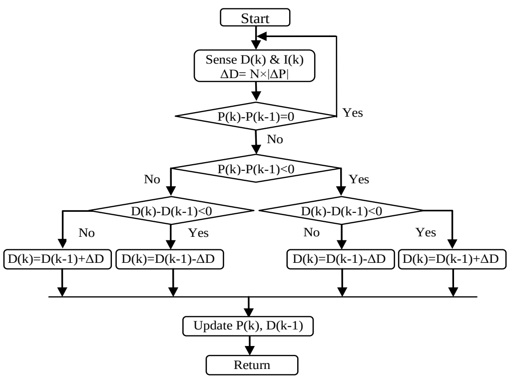

Fig. 3. Variable step size Perturb and Observe (P&O) Method.

3.2. Variable step size INC MPPT

The variable step size algorithm for the incremental conductance MPPT method is adopted to find a simple way to improve tracking accuracy and response speed. The step size is automatically adjusted according to the operating point. If the operating point is far from MPP, the algorithm increases the step size. If the operation point is near to the MPP, the step size becomes automatically small that the oscillations are well reduced. The flowchart of the VINC MPPT algorithm is shown in Fig.4. The variable step size adopted for this algorithm is given by the following equation:

$$D(k) = D(k-1) \pm N \times \left| \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \right| \tag{3}$$

Where: P(k), V(k): output power and voltage of the PV at the (k) the sample of time.

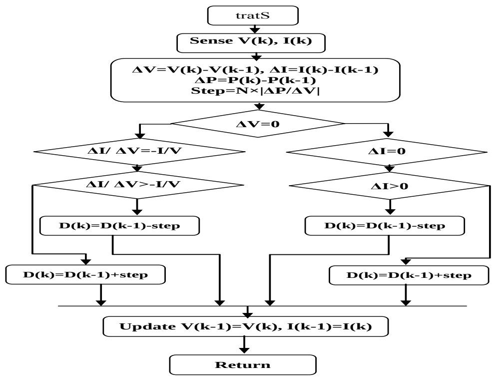

Fig. 4. Variable step size Incremental conductance (INC) Method.

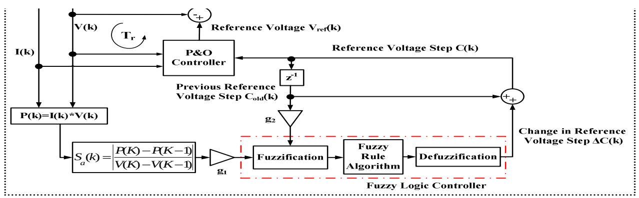

Fig. 5. Variable step-size based Fuzzy Logic control.

3.3. P&O based Fuzzy logic control

The variable step size P&O MPPT using FLC is shown in Fig.5. The input variables of the FLC are (ΔP) and (ΔV), whereas the output of the FLC is the variable step-size (ΔD) of the P&O algorithm. The member function is coding by Positive Big (PB), Positive Small (PS), Zero (Z), Negative Small (NS), and Negative Big (NB). The output of the FLC defuzzified using the center of gravity method to calculate the output ΔD.

The fuzzy based rules of the FLC consist of 25 rules as illustrated , which determine ΔD the output of the controller. These rules are framed based on the logic that if the operating point is far away from MPP, then step−size of perturbation should be very large and it should be gradually decreased to zero as the operating point approaches to zero. At MPP, the slope of P−V curve will be zero; hence the perturbation should also become zero so that stability in the power can be achieved. From which the output of the FLC defuzzified using a centre of gravity (COG) method to calculate D.

4. SIMULATION RESULTS

In order to compare the performance of studied MPPT methods, the simulation models of the PV system are applied in the platform of MATLAB/Simulink. A PV system which composed of PV panel, MPPT controller, PWM generator and boost converter. PV specifications are listed in Table 1. The parametric details of the boost converter have been provided in Table 2.

4.1. Stable conditions

The VP&O, VINC and P&O using FLC are tested under irradiance (1000 W/m^2) and temperature (T=25°C). The output power is shown in Fig.6.

Table 2. 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
Switching frequency	f	10 kHz

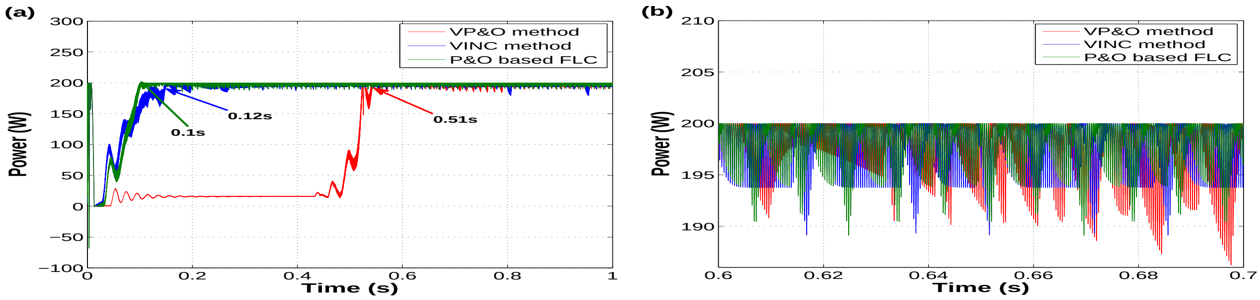

Fig. 6. a) The ouput power , b) The ripple power of the VP&O, VINC and P&O using FLC methods.

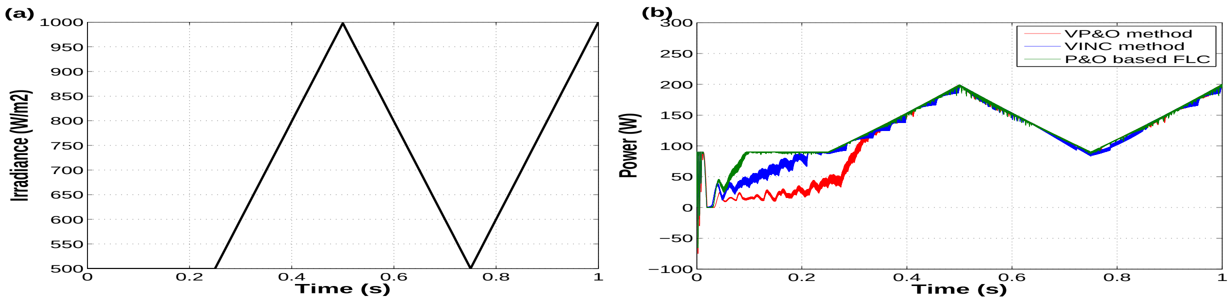

Fig. 7. a) The profile of irridiance and the temperature is constant (25°C) , b) The output power of the VP&O , VINC and P&O using FLC methods.

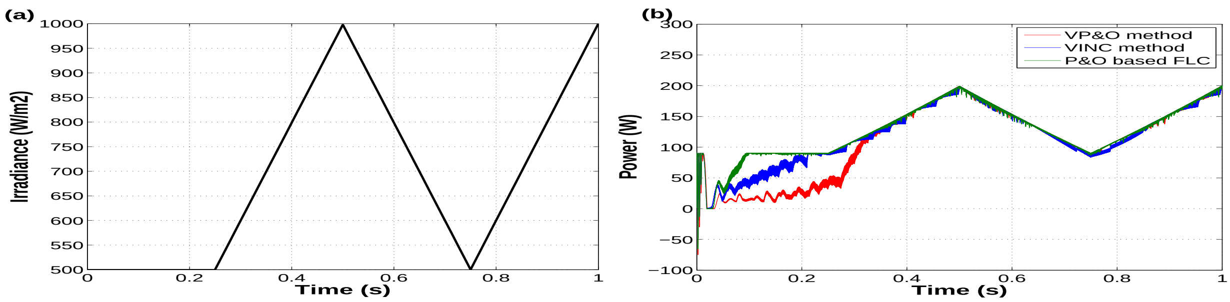

Fig. 8. a) The profile of temperature and the irradiance is constant (25°C) , b) The output power of the VP&O, VINC, and P&O using FLC methods.

Table 3. 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

The output power of VP&O, VINC , and P&O using FLC could converge finally to MPP at 0.51s, 0.12s, and 0.1s respectively. Moreover, the VP&O presents large oscillation around MPP compared to VINC and P&O using FLC. In the standard conditions test, we can be deduced that the VP&O method track the MPP slowly with large oscillation around MPP compared to VINC and P&O using FLC. However the VINC and P&O using FLC present almost similar performance in terms of response time and precision.

4.2. Varying conditions

To analyze and compare the performance of MPPT studied methods, the PV system is tested under different conditions of irradiation and temperature.

The main objective of the first test is to varying the irradiation and the temperature is constant. In this case, we adopted two types of profile, the first profile is triangle function from (500, 1000 and 500) W/m^2 at (0.25−0.75) s and the other profile profile is ramp function from (500, 1000) W/m^2 at (0.75−1) s.

The Fig.7.a shows the profile of irradiance, the temperature is constant (25°C). The Fig.7.b, presents the output power of the PV panel.

As can seen in Fig.7, VINC and P&O using FLC follow MPP at 0.2s and 0.09s respectively and with good precision. However, the VP&O method converges slowly to MPP and it loses direction to tracking MPP from (0.2−0.4)s.

The second test consists to varying the temperature and irradiation is constant. 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.8.a shows the profile of temperature, the irradiance is constant (1000w/m^2). The Fig.8.b presents the output power of the PV panel.

As can seen in Fig.8, VINC and P&O using FLC follow MPP with at 0.1s. However, the VP&O method converges slowly to MPP and sometimes it loses direction to tracking MPP.

In the varying conditions test, we can be deduced that the VP&O method track the MPP slowly with large oscillation around MPP and sometimes it loses the direction of the MPP. However the VINC and P&O using FLC present almost similar performance in terms of response time and precision.

5. EXPERIMENTAL RESULTS

To compare the performance of the studied MPPT methods in real environment, an experimental platform of PV system is built. The experimental device is shown in Fig.9.

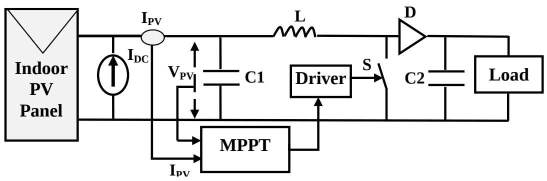

Fig. 9. DC−DC boost converter.

The PV emulating system is composed of a DC power supply and PV panel. 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 Table 3. The DCDC converter is the boost converter, the components of the boost converter is shown Table 2.

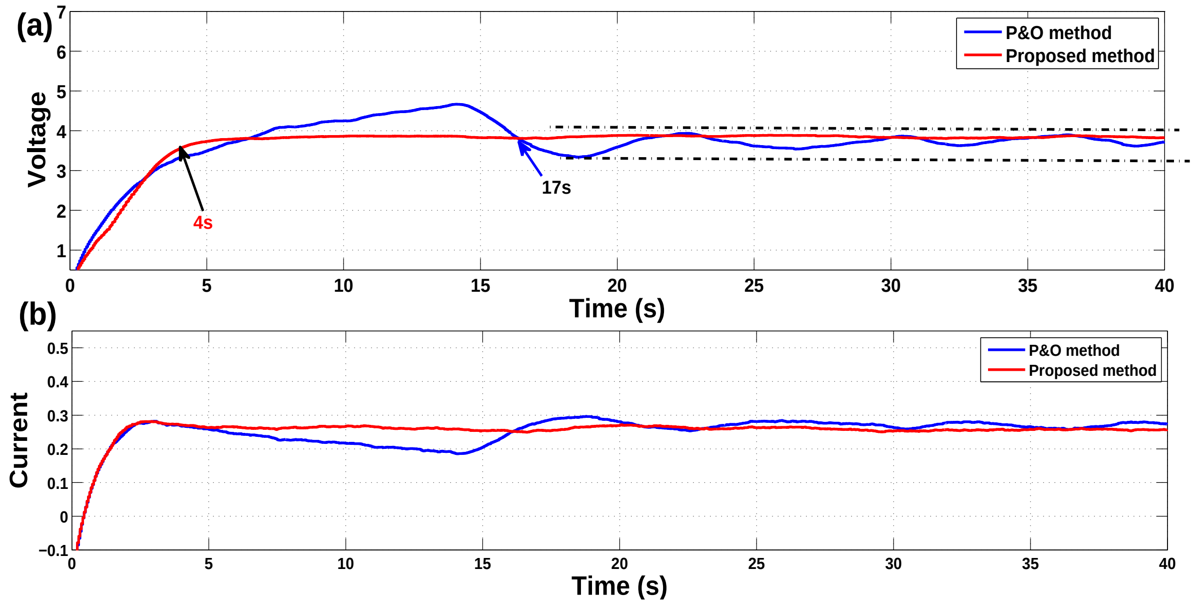

Fig. 10. a) The ouput voltage and b) The output current of the studied method.

This work uses the fuzzy inference of Mamdani. The center of gravity defuzzification method is adopted in our FLC proposed method, to calculate the output of this FLC which is the duty ratio. The studied methods are implemented by micro-controller. The output voltage and current is shown in Fig.10. The P&O using FLC and VINC can converge rapidly to MPP. At the same conditions, the output voltage of VP&O, VINC, and P&O using FLC could converge finally to MPP at 8s, 10s and 25s respectively. Moreover, the ripple power around MPP at steady state for VP&O, VINC, and P&O using FLC is small.

6. CONCLUSION

This paper is presented a theoretical and experimental verification of the main MPPT methods that most cited in literature. This comparison is based on studying the performance of these MPPT such us: response time, efficiency and ripple around the MPP. In this context, the VP&O, VINC and P&O using FLC methods present the most importance techniques to extract the maximum power point available in PV panel. Among the methods evaluated, the VINC and P&O using FLC were an excellent solution regarding the best response time, smaller ripple power in the steady state, and the good transient performance under changing irradiation and temperature condition. However, the VINC and P&O using FLC are complicated to implemented in microcontroller. The VP&O method tracks the MPP slowly with large oscillation around MPP and in varying atmospheric conditions it loses the direction of the MPP. However the VP&O method is relatively easy to implemented compared to VINC and P&O using FLC methods.

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