Comparison of Three-Point P&O and Hill Climbing Methods for Maximum Power Point Tracking in PV Systems

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***Abstract*—Solar energy and photovoltaic (PV) systems will play an important role in the future production market. One of the challenges in optimal operation of solar PV systems is the low efficiency of these systems compared to fossil fuel production units. The reason is the sudden changes in climate factors, including the temperature and intensity of radiation in the environment. One of the solutions used to solve the low power efficiency problem in PV systems is the MPPT techniques which have been widely investigated by many researchers. In this paper, a new form of conventional Perturb and Observe (P&O) method named three-point P&O is introduced and compared with Hill Climbing (HC) method under constant and variable atmospheric conditions. The DC-DC converter is Boost which has an acceptable performance in solar applications. The simulation results in MATLAB and experimental results indicate a better performance of three-point P&O method in terms of output power fluctuations and maximum power point tracking capability.**

Index Terms - Maximum Power Point Tracking, Three-Point Perturb & Observe, Hill Climbing, Boost Converter.

I. INTRODUCTION

The characteristics of photovoltaic systems are inherently stochastic and are function of environmental parameters such as radiation and ambient temperature. Therefore, by choosing the correct operating point of the PV array, the maximum power can be obtained from the PV array under constant radiation and temperature conditions. If environmental conditions change, the PV's operating point will be changed, so maximum power point tracking (MPPT) technique as an alternative will be introduced [1], [2]. The results show that using of MPPT can increase the efficiency of the PV system by 20% to 30% [3]. The maximum output power of PV modules not only depends on the intensity of radiation, but also depends on the energy conversion efficiency. In order to ensure that maximum power is achieved, the maximum power point (MPP) must be specified before the operating point of the system is directed to it [4]. This task is performed by electric power circuits, which are called DC-DC converters which change the impedance seen from the PV modules to its optimum value [5]. Generally, the converters have two major goals: coupling between photovoltaic panels and renewable energy sources or power grids, and directing the operating point of the PV panel to the maximum power point [6]. Fig. 1 shows an example of a photovoltaic system including MPPT and DC-DC converter.

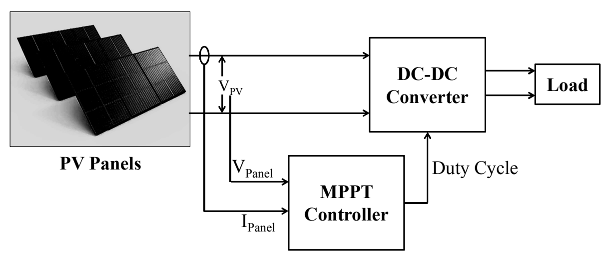


Fig. 1 PV system with MPPT and DC-DC converter

Among MPPT methods, the Hill Climbing (HC) is commonly used because of its simplicity and low cost [7]. The HC algorithm works by disturbing the system by changing the duty cycle of DC-DC converter and observing its impact on the output power produced by the PV modules. One of the problems of HC algorithm is selecting the size of the disturbance and also fluctuations of power, which will increase the energy losses, especially in the sudden change of weather conditions [8]. Also, conventional Perturb and Observe (P&O) method is one of the most widely used MPPT algorithms in PV systems [9-12]. The main advantage of this method is its simplicity, which has led to its becoming more common in new control systems. Additionally, this algorithm does not require prior knowledge of the PV panel's features. Also, this method has an acceptable performance when the radiation and temperature does not change very fast. The disadvantage of this method is rather high power fluctuations around the operating point in steady state specially when there are sudden changes in ambient conditions [11], [13]. To cope with the problems above, a new form of conventional P&O method is presented in this paper and its performance is compared with HC method under constant and varying ambient conditions.

The paper is organized as follows. The Section 2 presents the new 3-point P&O and conventional HC methods. The simulated PV system and its characteristics are described in Section 3. Simulation results and discussion will be presented in Section 4 and finally the last section draws conclusions.

II. MPPT ALGORITHMS

A. Conventional Hill Climbing Method

This method has a simple procedure and only works based on measuring the voltage and current and calculating the output power of PV module in each step and comparing it with the value calculated in prior step [14]. The flowchart of HC method is depicted in Fig. 2 [14].

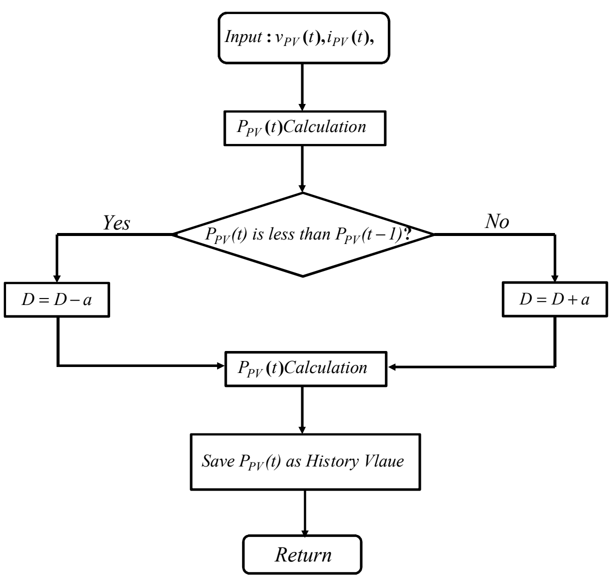


Fig. 2 MPPT algorithm based on HC technique [14]

B. The 3-Point P&O Method

In this algorithm, unlike the conventional two-point P&O, three points on P-V curve are compared. These three point are "a" (the previous operating point), "b" (the point that is obtained by increasing the duty cycle by one unit) and "c" (the point that is achieved by reducing the duty cycle by one unit). According to Fig. 3, there are 9 different states for operating point in P-V curves. Based on the existing status, the variable "M" is initialized. If the power of point "b" is more or equal to point "a", then the "M" will be increase by one unit, otherwise, "M" decreases by one unit. Also, if the power of point "c" is less than the power of point "a", then "M" is increased by one unit, otherwise "M" is reduced by one unit.

If the value of "M" equals 2, then point "b" is chosen as the operation point in the next cycle, but if the value "M" equals -2, then point "c" is chosen as the operation point in the next cycle. In other cases ("M" is equal to 0, 1 or -1), the system has reached the maximum power point or the radiation has suddenly changed, and it is not necessary to change the operating point, so the point "a" is considered as the operating point of PV system. The flowchart of the 3-point P&O is illustrated in Fig. 4.

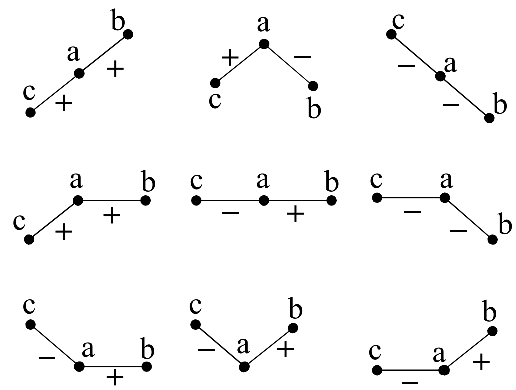


Fig. 3 Possible modes for power point according to 3-point P&O method

In the conventional 2-point P&O method, if the size of the disturbance is large, there are fluctuates around the MPP point, and if the disturbance size is small, the MPP tracking is slowed down. The benefits of this conventional method are low cost, easy implementation and relatively simple control algorithm, and its drawback is failure of this method in tracking the MPP under rapid changes in temperature and solar radiation, causing energy losses.

We use the 3-point P&O algorithm to track the maximum power point despite sudden changes of temperature and radiation. This method compares the real power point with two previous ones before specifying the sign of disturbance. As a consequence, the fluctuations around the operating point under sudden changes of ambient conditions will be eliminated considerably. This is the basic advantage of the 3-point P&O which will be demonstrated based on simulation results in Section 4.

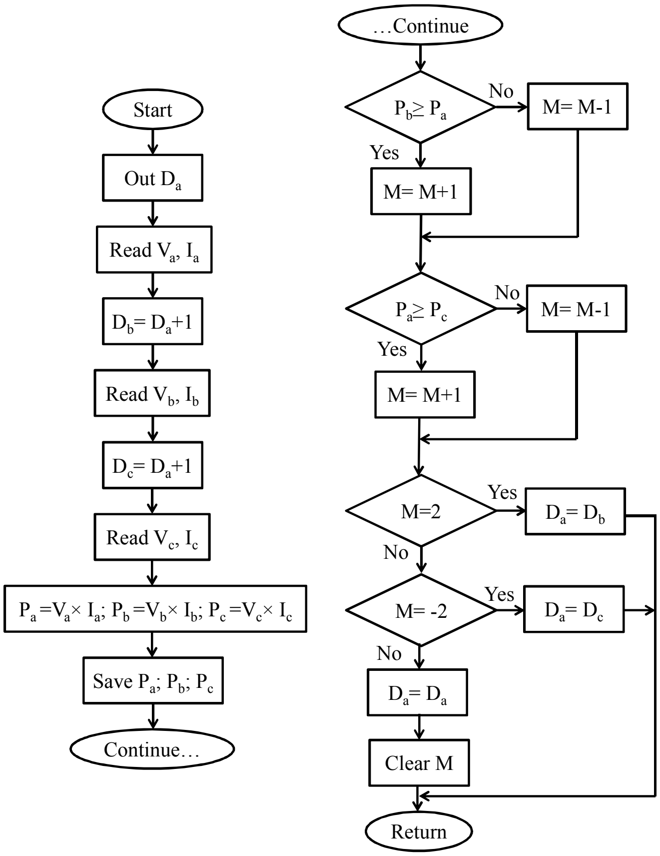


Fig. 4 MPPT algorithm based on 3-point P&O technique

III. PV System and MPPT Implementation

In this section, a solar cell with the characteristics of Table 1 is simulated in MATLAB/Simulink environment, and two mentioned MPPT algorithms are applied. The performance of MPPT algorithms is compared in terms of fluctuations of power and output voltage as well as maximum power point tracking capability. A practical single diode model based on [14] is implemented as PV module and MPPT algorithm is applied based on HC and 3-point P&O methods, separately. The P-V curves of the simulated photovoltaic panel at different solar radiation and temperature conditions are shown in Figs. 5 and 6, respectively.

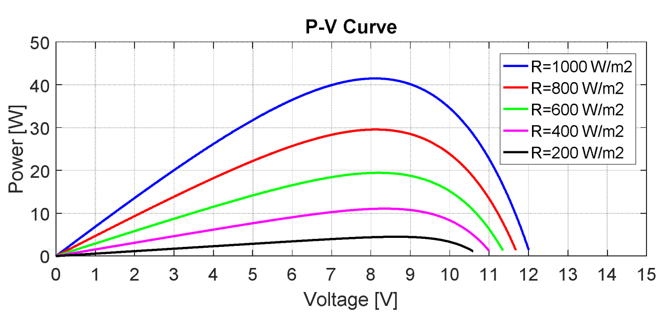


Fig. 5 Power-Voltage curves of the intended PV panel at different radiations (T=25 ºC)

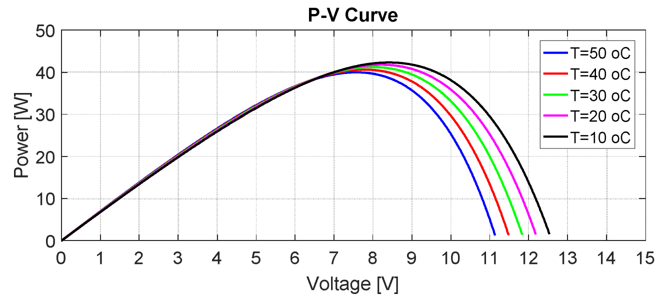


Fig. 6 Power-Voltage curves of the intended PV panel at different temperatures (R=1000 W/m^2)

TABLE I
SIMULATION PARAMETERS

Parameter	Value
K	1.3806488×10^{-2}
q	1.6021766×10^{-19}
K_i	1.33×10^{-3}
E_g	2.60
N_s	12
N_p	8
T_r	264.20
V_{oc}	$23.41/N_s$
I_{sc}	$6.54/N_p$

Also, a Boost converter is simulated based on Table 2. Detail descriptions of DC-DC converter are not given in this context due to space limitation and for more details we refer the reader to [14]. A simple RL load is considered as “ac” load (R=10^{Ω} and L=0.01^{H}) and a single phase PWM inverter is used as the DC-AC conversion device.

TABLE II
SIMULATED BOOST CONVERTER PARAMETERS

Parameter	Definition	Value
C	DC-DC converter Capacitor	2 mF
L	DC-DC converter Inductor	0.1 H
R_{on}	Internal Resistance of IGBT	0.001 Ω
V_f	Forward Voltage of Diode	0.8 V

IV. Simulation and Experimental Results

A. Constant Atmospheric Conditions

As already mentioned, the MPPT-based controller is implemented in MATLAB based on the conventional HC method and the 3-point P&O method, separately. At first, simulations are carried out for the constant ambient conditions (R=1000 W/m^2 and T=25°C). The PV voltage and output power using two mentioned MPPT algorithms are shown in Figs. 7 and 8, respectively.

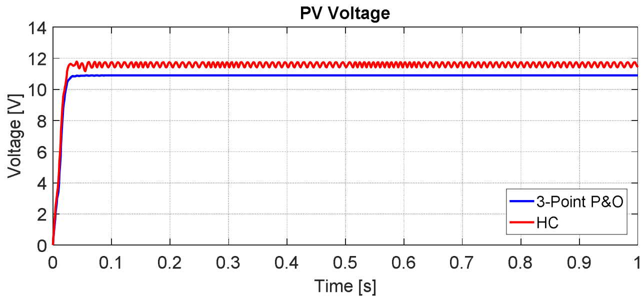


Fig. 7 PV voltage under constant ambient conditions (R=1000 W/m^2 and T=25°C)

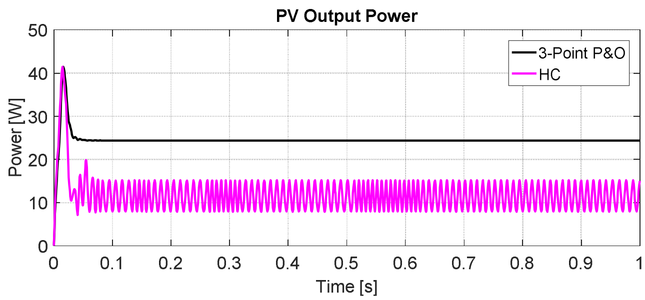


Fig. 8 PV output power under constant ambient conditions (R=1000 W/m^2 and T=25°C)

Based on the simulation results, it is obvious that the performance of the 3-point P&O method is better compared with HC method in terms of the power fluctuations as well as achieving the maximum power point.

B. *Varying Atmospheric Conditions*

In the next step, the same trend is repeated for a situation in which sudden radiation and temperature changes are considered in ambient conditions. The performance of the MPPT-based controller is evaluated and compared with each other. The PV voltage and output power using two mentioned MPPT algorithms under varying conditions are shown in Figs. 9 and 10, respectively.

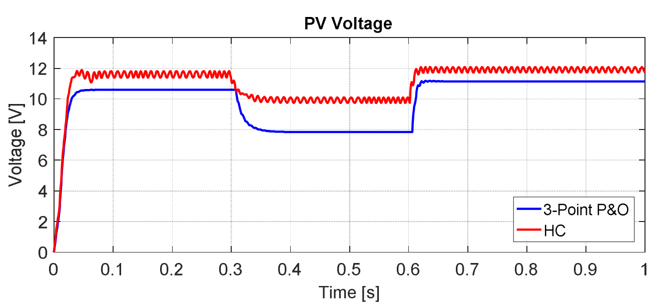
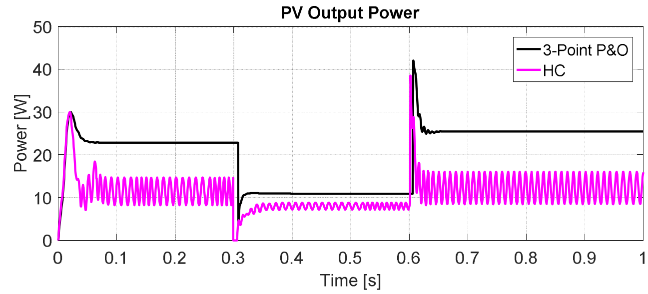


Fig. 9 PV voltage under varying ambient conditions

Under the varying ambient conditions, it is also observed that the performance of the 3-point P&O method is much better than the HC method in terms of fluctuations of the output power and also tracking the maximum power point. Also, 3-point P&O algorithm has preferable performance in the sense of the output power transients and the overshoot of power waveform is less compared with HC method.



Fig, 10 PV output power under varying ambient conditions

The experimental setup is shown in Fig 11.

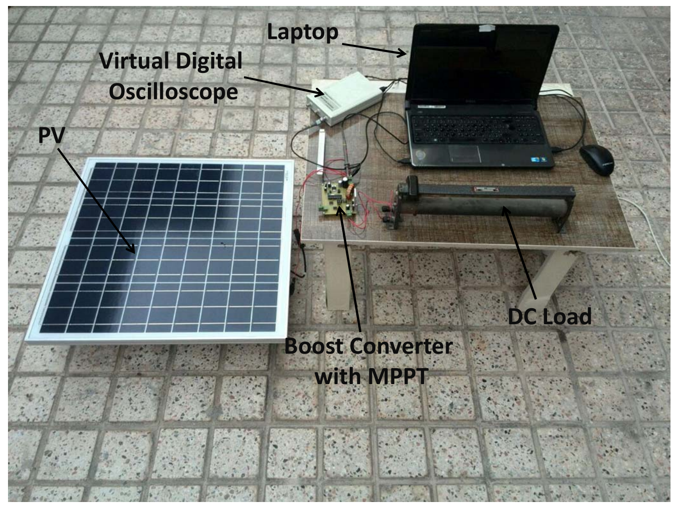
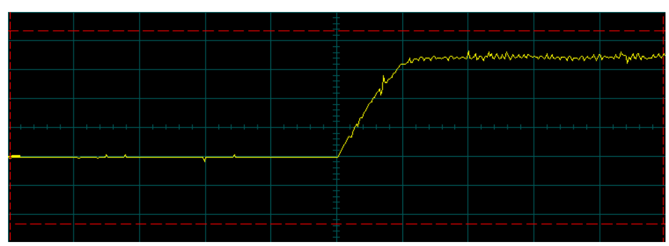
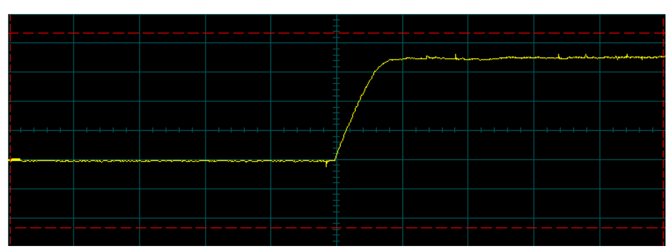


Fig. 11 Experimental setup

The experimental results are shown in Fig. 12. As it can be seen in this figure, the PV voltage fluctuations will be reduced by applying the 3-point P&O method.



(a)



(b)

Fig. 12 PV voltage using (a) HC method (b) 3- point P&O method

V. Conclusions

The results of this paper demonstrate the better performance of the 3-point P&O method compared to the Hill Climbing method in terms of extracting the maximum power from the PV system. The other result to be noted is that when using the MPPT method to generate DC-DC gating signals, the output power from the panel will be greater compared with constant duty cycle (without MPPT). The performance of the 3-point P&O-based controller is better than the HC-based controller in both constant ambient conditions and the variability of the temperature and intensity of the radiation. The more general conclusion is that using of the MPPT method helps to extract more power from a PV panel compared with situations where constant duty cycle is exploited to generate the gating signals of DC-DC converter under the same conditions.

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