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OPTIMIZED PERTURB AND OBSERVE TECHNIQUE WITH FAST CONVERGENCE UNDER RAPIDLY CHANGING OF IRRADIATION

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Abstract

The (P-V) curve of solar cell has one point, at which, the extracted power is maximum and referred to as the Maximum power point. Moreover, the characteristics of the photovoltaic cell are not linear, and it changes with the weather conditions (temperature and illumination). A Maximum Power Point Tracker (MPPT) is a combination of hardware and software used to track and determine this point from the solar cell. Many algorithms have been used to run the MPPT, among them is the Perturb and Observe (P&O) technique. The advantages of P&O technique are efficiency and simplicity. However, the drawback of the P&O is the MPP tracking loss under fast-changing of the irradiation. In this paper, the P&O algorithm is modified to use the photovoltaic output current in modifying the step size. The modified algorithm is appropriate for practical weather conditions. In addition, this algorithm increases the P&O speed and decreases the steady-state oscillation. A boost converter is used to test the modified algorithm. Finally, simulation emphasizes that the modify algorithm increases the efficiency and progresses the dynamic response in comparison with the conventional variable step size P&O algorithms.

Keywords: MPPT, Perturb and observe, Photovoltaic, Renewable energy.

1. Introduction

The power system development is expected to continue because of the demand increment on the power technology where the electricity grid needs to be more flexible leading to the expansion of the microgrids. The microgrid is the solution of integration of many source energy generations, where it leads to more beneficial from the energy especially when the energy is generated from renewable source [1, 2].

The most wonderful renewable energy source is the photovoltaic because of its advantages such as less maintenance need, clean, and its increment by 30% per year [3]. The power curve versus the photovoltaic voltage (P-V) changes with the ambient temperature and irradiance [2, 4]. The extracted power from PV relies on the work point of the P-V curve so that the amount of energy generated by solar cells depends on the weather condition to have a maximum energy of solar cells at any weather condition. Recently, a lot of the maximum power point tracking (MPPT) algorithms have been proposed [5]. These algorithms are different in convergence speed, sensor requirements, costs, operation range and complexity [6].

The most common technique is the perturb and observe the algorithm. The advantages of the technique are simple software, easy to implement and has good performance [6]. Perturb and observe algorithm has several weaknesses [7]. P&O algorithm is developed by monitoring the slope of the photovoltaic power-voltage curve. The slope less than zero on the right of MPPT and the slope greater than zero on the left of the MPPT. To track the peak power, the operating voltage has to be changed according to the slope sign. The performance of the perturb and observe algorithm depends on the time of tracking and oscillation, which is determined by the size of the perturb algorithm. Using the fixed perturb, the large perturb results in a fast response and high oscillation. On the other side using small perturb leads to a decrease in the oscillation and slow in the response [8-10]. To increase efficiency, a variable perturbation is used [11-13].

This paper presents an improvement of the Variable Step Size (VSS) perturb and observe (P&O) algorithm based on the boost converter where the step size is adjusted according to dP/dV and illumination level.

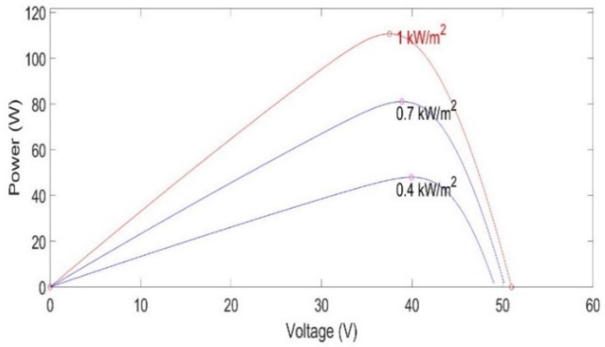
2. Photovoltaic Modeling

The photovoltaic model is built from PV cells. The solar cell transfers the energy from the sunlight to electricity. A small amount of energy is generated from one solar cell. Solar cells are connected in parallel or series to raise the output power PV model. The output current and voltage of the solar cells have a nonlinear relation. The value of the output current and voltage solar cells depends on the temperature and irradiance. The output current of the solar cell is given by Eq. (1) [14].

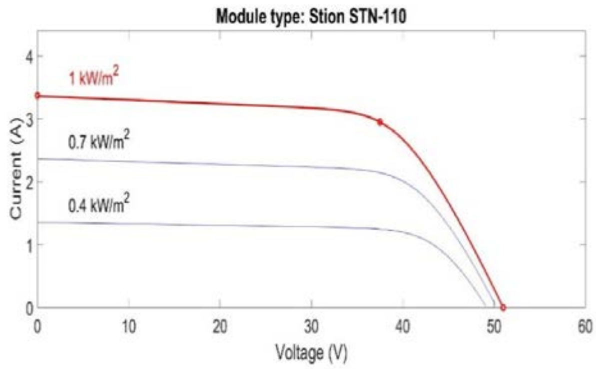
$$I = I_{ph} - I_{sat}\left\{exp\left(\frac{q(V+I*R_S)}{AKT}\right) - 1\right\} - \frac{V+I*R_S}{R_{sh}} \tag{1}$$

where I_{ph} is the current of generated light, I is the output current, V is the output voltage, I_{sat} is the reverse saturation current of the cell, and the A is the diode ideality factor (= 1).

The parameters K, T, q, R_{sh}, R_s, represent the Boltzmann's constant, cell temperature, electronic charge, shunt resistance, and series resistance respectively. The PV module (Stion STN-110) taken from Simulink-MATLAB have been used in this paper. The V-P characteristics and V-I output are shown in Fig. 1 and the specifications are shown in Table 1.



(a) V-P curves with variation irradiation level.



(b) V-I curves with variation irradiation level.

Fig. 1. PV module characteristics at temperature, *T* = 25℃.

Table 1. PV module specifications.

Electrical characteristics	Value
Peak Power (PP)	110.6 W
Voltage at Peak Power (Vp)	37.5 V
Current at Peak Power (Ip)	2.95 A
Open Circuit Voltage (Voc)	51 V
Short Circuit Current (Isc)	3.37 A
Temperature	25℃
Irradiation Level	1000 W/m^2

3. Modified VSS P&O MPPT Algorithm

The P&O algorithm measures the current and voltage then calculate the Δp and Δv. The operating point movement determined by the sign of $\Delta p/\Delta v$, where it increases the reference voltage (V_{ref}) if the sign of Δp/Δv is positive and decreases the V_{ref} if the sign $\Delta p/\Delta v$ is negative. Where the V_{ref} moves by an amount called step and the step size determines the performance and tracking time. A big step leads to fast-tracking, and high oscillation around MPPT. However, the small step leads to low oscillation and requires a long time to track the MPPT.

The fixed step size (FSS) makes a trade-off between the tracking time and oscillation. The long time to track, the more oscillation causing power loss and efficiency degradation. Also, VSS is proposed to improve efficiency [11-13]. Moreover, the DC to DC converter is connected between the solar cells and the load [15]. Furthermore, the duty cycle (*D*) of the DC to DC converter is controlled by the output power of solar cells. To locate MPPT, the V_{ref} is changed, where the V_{ref} value depends on the *D* value. The *D* is calculated using Eq. (2) [11].

$$D(k) = D(k-1) \pm M * \left|\frac{dP}{dV}\right| \quad (2)$$

where P and V represent the solar cells output power and voltage respectively. The step size is scaled by the *M* parameter, in which, the design steps M is tuned. The *M* parameter is determining the performance of the VSS MPPT algorithm. The following rule must be met to get the variable step convergence to the MPPT.

$$M\left|\frac{dP}{dV}\right| < \Delta D_{max} \quad (3)$$

In the fixed step of MPPT algorithm, the Dmax is the largest step size, and for VSS P&O MPPT algorithm, the Dmax is selected as the maximum limit for step size. The scaling factor *M* can be derived from Eq. (3):

$$M < \Delta D_{max} / \left|\frac{dP}{dV}\right| \quad (4)$$

The VSS P&O MPPT algorithm has the scaling factor, which is limited by Eq. (4) and if the scaling factor *M* exceeds the limitation of Eq. (4), the P&O MPPT will not work with the VSS, but it will work with the FSS. The VSS P&O reduces the oscillation and increases the speed of convergence.

The dp/dv changes when the temperature or irradiation is changed as shown in Fig. 2 [16], where power 2 is much smaller than power1 (P2<<P1). The VSS P&O MPPT algorithm for P1 cannot be recognized by using the scaling factor, which is obtained from Eq. (4) because ΔDmax/N > |dP/dV | is not satisfied; therefore, the VSS P&O MPPT will work with an FSS ΔDmax. With the same scaling factor for p2, the system always works with VSS because the ΔDmax/N > |dP/dV | is always satisfied. Therefore, the speed of the system will be reduced. Hence, for the VSS, it is impossible to find the optimum value of the scaling factor to suit P1 and P2 power curves. Figure 2 shows power versus current slopes under different irradiation conditions.

To make the VSS P&O MPPT algorithm suitable for P1 and P2 power curve, this paper will do the task by adjusting the VSS P&O MPPT algorithm. Therefore, the line Dmax/N is adjusted depending on irradiation. The implementation of the VSS P&O MPPT algorithm can be done without the need of the irradiation sensor where the output current has a direct relation with irradiation. The step size value changes based on the output PV current. The duty cycle will be calculated using Eq. (5):

$$D(k) = D(k-1) \pm \frac{M}{I} * \left|\frac{dP}{dV}\right| \quad (5)$$

The VSS P&O MPPT algorithm condition is (I**ΔD*max)/N > |dP/dV | where it changes with the irradiation. Therefore, this condition will be satisfied with different irradiation levels. The flowchart of the adjusted VSS P&O MPPT algorithm is shown in Fig. 3.

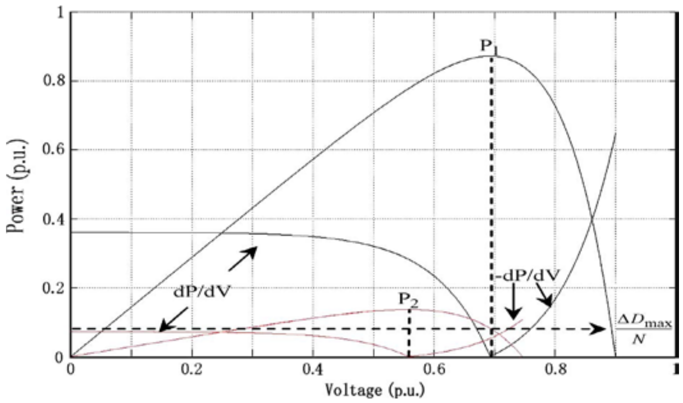


Fig. 2. Power and current slopes under different irradiation conditions [16].

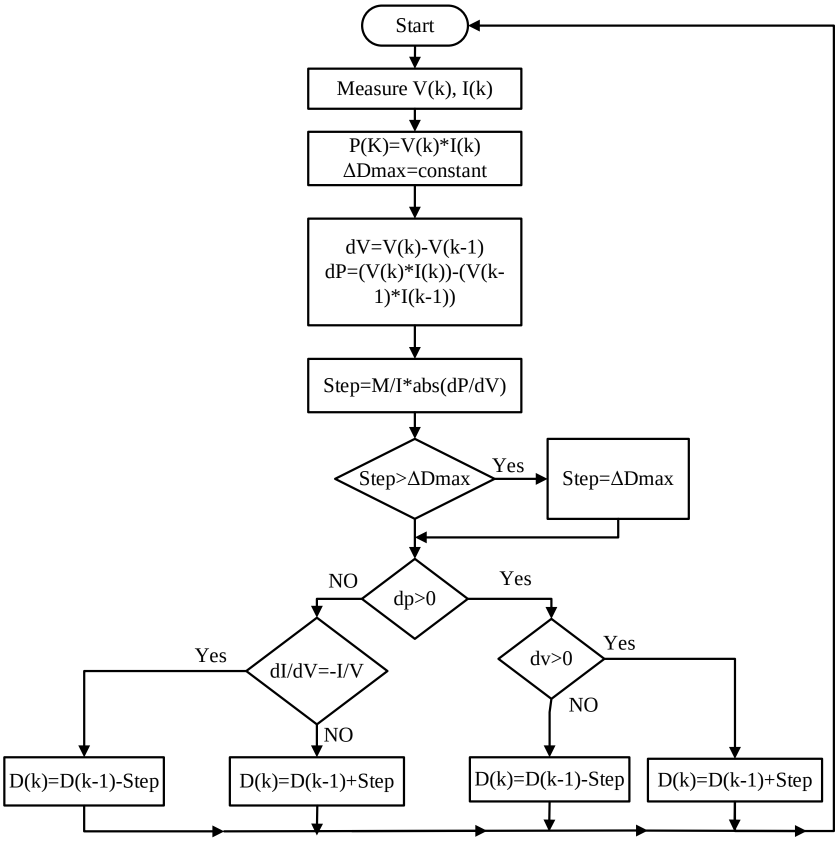


Fig. 3. Flowchart of suggested VSS P&O MPPT algorithm.

4. Simulation and Experimental Results

A boost converter has been used between the PV and the load as a power electronic interface to get the peak power as shown in Fig. 4.

The boost converter has been designed in MATLAB Simulink, which has the following parameters as shown in Table 2.

A PV with MPPT system is used to simulate the feasibility of the suggested algorithm. This system is designed in MATLAB Simulink as shown in Fig. 5.

Table 2. Boost converter circuit parameters.

Circuit parameters	Value
Input capacitance	500 µF
Inductance	400 µH
Output capacitance	100 µF
Switching frequency	50 kHz
Load	20 Ω

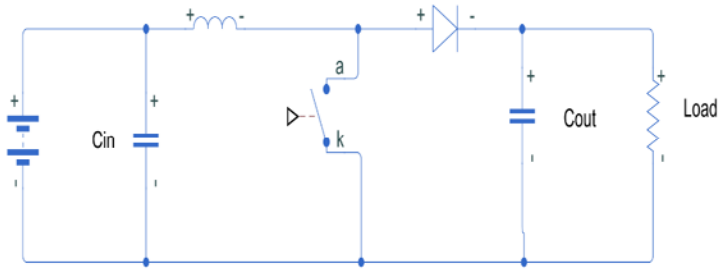


Fig. 4. Boost converter configuration.

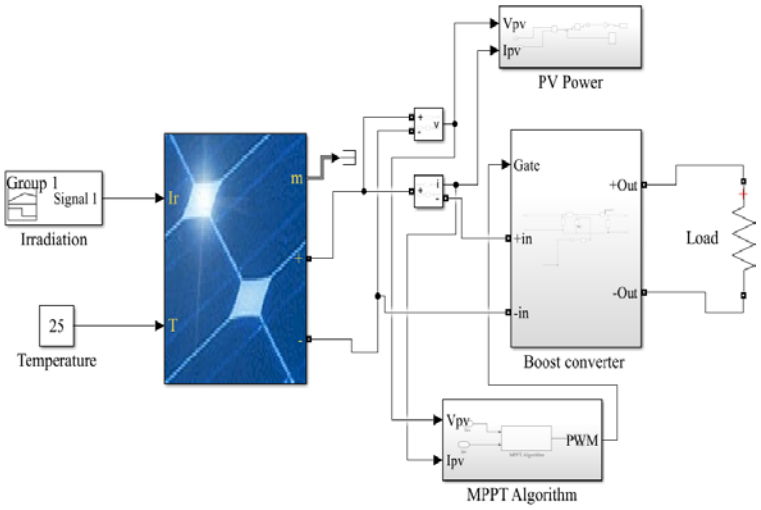
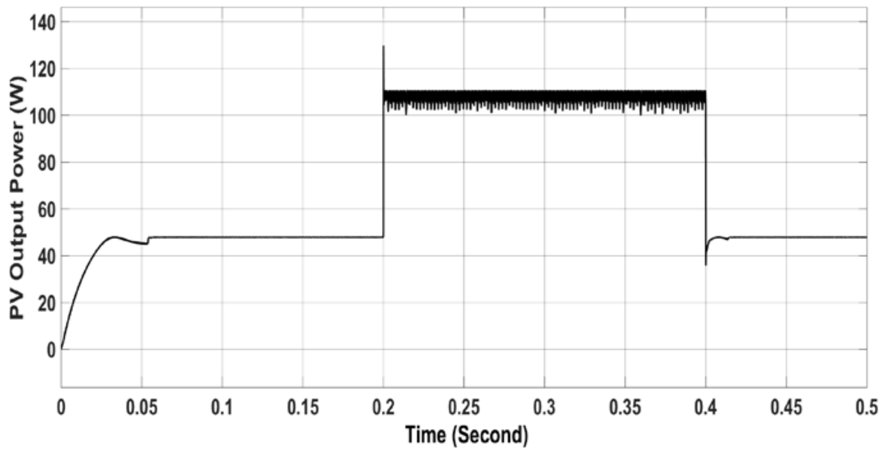


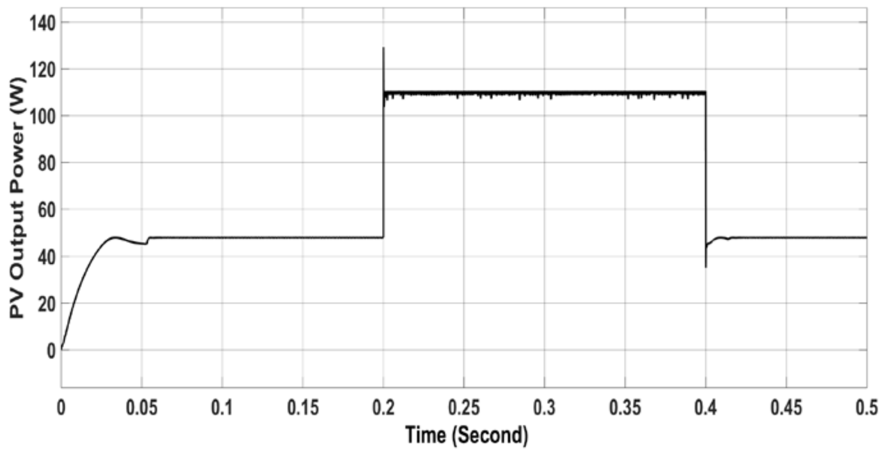
Fig. 5. PV with MPPT system.

To test the suggested VSS P&O algorithm performance and comparing it with the conventional VSS P&O, the temperature has been set at 25 ℃ and the level of the sun irradiation suddenly changed from 400 W/m^2 to 1000 W/m^2 at 0.2 s and then changed from 1000 W/m^2 to 400 W/m^2 at 0.4 s.

The result of the VSS P&O is shown in Fig. 6. From this figure, the output does not converge at 1000 W/m^2 when using M = 0.002 and ΔDmax = 0.02 because the ΔD has big value as shown in Fig. 6(a). Figure 6(b) shows the result when the M = 0.001 and ΔDmax = 0.02 where the efficiency increases and the steady-state oscillation decreases but the speed of the convergence reduces at t = 0.4 s.



(a) PV array output power with conventional variable VSS P&O MPPT (*M* = 0.002).

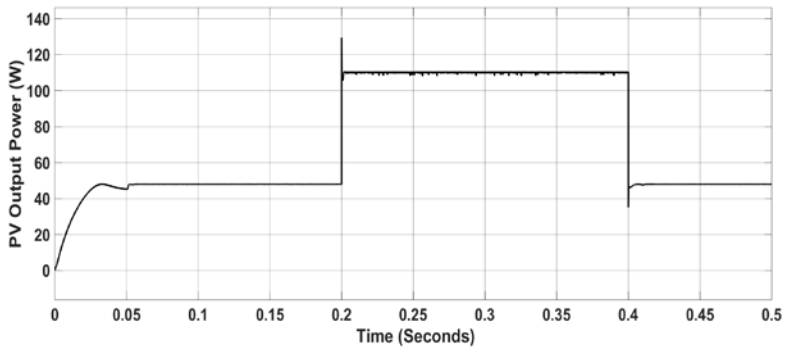


(b) PV array output power with conventional VSS P&O MPPT (*M* = 0.001).

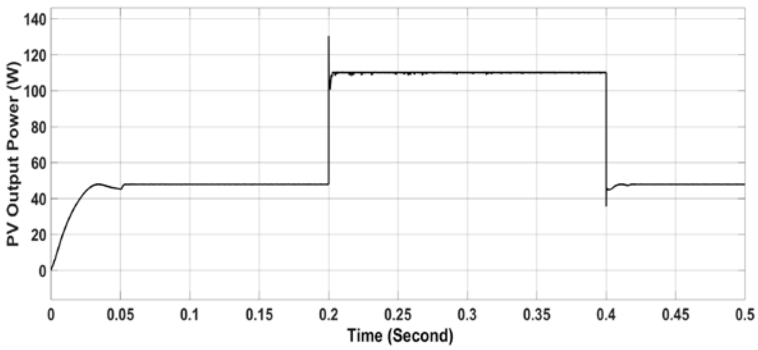
Fig. 6. PV array output power with conventional variable step size P&O MPPT (Irradiation step change from 400 to 1000 W/m^2 at 0.2 s and changed back to 400 W/m^2 at 0.4 s).

Figure 7 shows the result of the suggested algorithm where *M* = 0.002 and 0.001 respectively. To compare the suggested algorithm with the VSS, the ΔDmax is set to 0.02. From Fig. 7, it is obvious that the suggested algorithm increases the speed convergence and decreases the oscillation of the steady-state. The main source of power losses in the PV system is oscillation. Figure 7 shows the high operation performance of the suggested VSS P&O algorithm where the oscillation around the MPP is very small. Therefore, both convergence speed and efficiency are enhanced as shown in Table 3. In the comparison of adaptive techniques [11, 17-19], Kabir et al. [18] mentioned that the obtained efficiency is 94.5%, while Pandey et al. [11] stated that the obtained efficiency is 98.6% and Radjai et al. [19] proposed that the obtained efficiency is 98%. The adjusted algorithm needs less time to track the peak power with compare to the other works [19, 20].

In this work, the needed time to track the peak power when the irradiation changes from 400 to 1000 W/m^2 is 0.007 s. In addition, based on studies by Radjai et al. [19], the needed time to track the peak power change when the irradiation changes from 500 to 1000 W/m^2 is 2.09 s. Also, according to Soon and Mekhilef [20], the needed time to track the peak power when the irradiation change from 400 to 1000 W/m^2 is 0.275 s.



(a) PV array output power with suggested VSS P&O MPPT, with *M* = 0.002.



(b) PV array output power with suggested VSS P&O MPPT, with *M* = 0.001.

Fig. 7. PV array output power with suggested variable step size P&O MPPT (Irradiation step change from 400 to 1000 W/m^2 at 0.2 s and changed back to 400 W/m^2 at 0.4 s).

Table 3. Performance comparison between VSS P&O MPPT and adjusted VSS P&O MPPT methods.

Method	ΔDmax	*M*	Efficiency%
Variable step size P&O MPPT	0.02	0.001	99
	0.02	0.002	97.2
Adjusted variable step size P&O MPPT	0.02	0.001	99.5
	0.02	0.002	99.4

5. Conclusions

In this work, a new improved VSS P&O MPPT algorithm has been suggested. Where this algorithm increases the speed convergence and decreases the oscillation of the steady-state for a wide range of working. The suggested VSS P&O algorithm is more compatible with the practical operating conditions. In addition, the suggested algorithm has been tested in MATLAB. The suggested VSS P&O algorithm has been compared with conventional VSS P&O algorithms. Feasibility and effectiveness of the suggested algorithm have been confirmed in the simulation, where the results verify the increment of the VSS P&O efficiency by using this method.

Nomenclatures

D	Duty cycle
Dmax	Largest step size
dp/dv	Change power/change voltage, W/V
K	Boltzmann's constant, J/K
P	Power, W
q	Electronic charge, C
R_s	Series resistance, Ω
R_{sh}	Shunt resistance, Ω
T	Temperature, ℃
V_{ref}	Reference voltage, V

Abbreviations

FSS	Fixe Step Size
MPPT	Maximum Power Point Tracker
P&O	Perturb and Observe
PV	Photovoltaic curve
VSS	Variable Step Size

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