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An Improved Perturbation and Observation Based Maximum Power Point Tracking Method for Photovoltaic Systems

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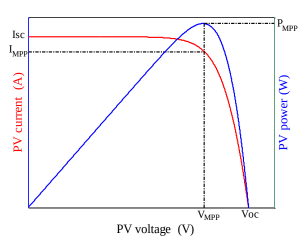
Graphical abstract



Abstract

In photovoltaic (PV) system, maximum power tracking (MPPT) is crucial to improve the system performance. Irradiance and temperature are the two important parameters that affect MPPT. The conventional perturbation and observation (P&O) based MPPT algorithm does not accurately track the PV maximum power point. Therefore, this paper presents an improved P&O algorithm (Im-P&O) based on variable perturbation. The idea behind the Im-P&O algorithm is to produce variable step changes in the reference current/voltage for fast tracking of the PV maximum power point. The Im-P&O based MPPT is designed for the 25 SolarTIFSTF-120P6 PV panels, with a capacity of 3 kW peak. A complete PV system is modeled using the MATLAB/Simulink. Simulation results showed that the Im-P&O based MPPT achieved faster and accurate performance compared with the conventional P&O algorithm.

Keywords: Perturb and observe algorithm; maximum power tracking; photovoltaic

1.0 INTRODUCTION

Renewable energy (RE) is presently getting more attention all around the world, particularly due to depletion of fossil fuels [1]. It is considered as the future energy source because it is clean, secure, and environmentally friendly. Among all the RE sources, photovoltaic (PV) energy systems seems to be widely applied because of the availability of enormous energy received from the sun [2]. However, PV systems have the problem of discontinuous power generation under different weather conditions [3]. In addition, the extracted power from PV system depends highly on the power-voltage (P-V) and current-voltage characteristic which vary with irradiance (G) and temperature (T) [4]. Therefore, to increase the PV system efficiency, it is crucial to operate the system at the maximum power point (MPP) which is a unique point on the P-V curve. In addition, the maximum power point tracking (MPPT) algorithm needs to be developed to increase the efficiency of PV systems [5].

Many MPPT algorithms have been mentioned in the literature which varies from simple algorithms, such as perturb and observe (P&O) [6], hill climbing (HC) [7] and incremental conductance (IC) [8], to complicated algorithms, such as fuzzy logic controller based MPPT [9], artificial neural network based MPPT [10], and other soft computing (SC) based MPPT [11]. The P&O algorithm is one of the first algorithms that deal with MPPT issue. It is used to observe the change in power in the system. However, the P&O algorithm does not have the ability to track accurate MPP because it suffers from oscillation around the MPP. Moreover, the P&O method depends on the fixed step size of the current/voltage which limits its performance [12]. Another MPPT algorithm is HC which is similar to P&O but the difference between them is that the HC method perturbs the duty cycle instead of the current/voltage. In addition, the HC approach is prone to failure in cases of large changes in weather conditions. IC is another simple MPPT algorithm which tracks the PV module power against the voltage curve to determine the MPP. However, the IC algorithm suffers from its inability to extract maximum power from the PV panel due to oscillation around the MPP.

Recently, another MPPT algorithms based on artificial intelligence have been presented. Fuzzy logic controller (FLC) has been utilized for tracking MPP because it is robust and less depends on the mathematical model [13]. However, FLC depends highly on the membership functions and control rules which usually are obtained by time consuming trial and error procedure [14]. Meanwhile, ANN has been used to track the MPP. However, ANN requires large number of data for training [15]. SC optimization based MPPT algorithms have also been mentioned in the literature [16]. The disadvantage of the SC methods is that it suffers from trapping in the local minimum solutions. Therefore, there is still a need to develop a simple, fast, and accurate MPPT algorithm. This paper presents a robust, simple, fast, and accurate MPPT algorithm by improving the P&O algorithm.

2.0 PV MODELLING

The solar irradiation (G) and the temperature (T) are the main two parameters responsible for determining the operating point of PV panel and hence the MPP. The equivalent electrical circuit for the PV shown in Figure 1 is used to obtain the characteristics of a PV cell. It consists of a current source connected in parallel with resistor and diode, and a series resistor. The mathematical model of the circuit which represents the cell output current, I, is expressed as [9]:

$$I = I_{ph} - I_o\left(e^{\left(\frac{q(V+I.R_s)}{n.K_B.T}\right)} - 1\right) - \frac{V + I + R_s}{R_{sh}} \qquad (1)$$

where I is cell output current (A), I_{ph} is light-generated current (A), Io is cell reverse saturation current or dark current (A), q is electronic charge (1.6 *10-19 C), V is cell output voltage (V), n is ideality factor, K_B is Boltzmann's constant (1.38*10-23 J/K) and T is cell temperature (K).

In this study, 25 SolarTIFSTF-120P6 PV modules are used to supply a 3 kW peak. The modules are arranged in series-connection configuration which produces DC output voltage of 435 V. The characteristic of a typical PV module is depicted in Table 1.

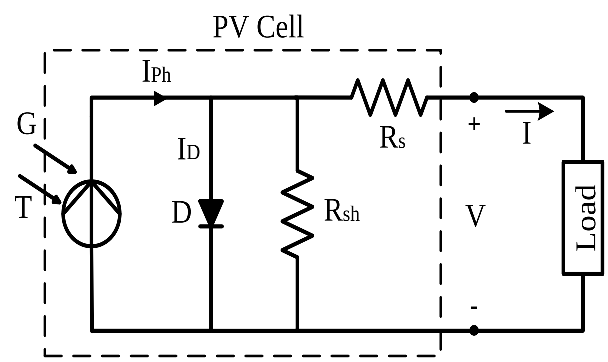


Figure 1 Electrical equivalent circuit of PV cell

Table 1 PV module characteristics

PV module	SolarTIFSTF-120P6
Maximum Power (P_{MPP})	120W
Open circuit voltage (V_{oc})	21.5 V
Short circuit current (I_{sc})	7.63 A
Voltage at maximum power (V_{MPP})	17.4 V
Current At maximum power (I_{MPP})	6.89 A
Current temperature coefficient (α)	6.928 mA/ ° C
Voltage temperature coefficient (β)	-0.068 V/ ° C

3.0 CONVENTIONAL P&O BASED MPPT

The conventional P&O algorithm always measures the power (P) in order to find the direction of the progress which has the relationship with the reference current/voltage. The goal is to track the MPP as depicted in Figure 2. The conventional P&O algorithm measures the current and voltage at a sampling time, t, then calculates P(t) and compares it with the previous sample P(t-1). The algorithm then continues increasing the reference current/voltage by a fixed value defined by the ratio of small change of voltage to current (Δv/Δi). If the result of the comparison [P(t)-P(t-1)] is greater than zero, it indicates that the algorithm move towards the MPP. On the hand, it will continue decreasing the reference current/voltage by a fixed value (Δv/Δi), if the result of the comparison [P(t)- P(t-1)] is less than zero, thus, indicating that the algorithm is moving away from the MPP. The conventional P&O algorithm does not adjust current/voltage, if the result of [P(t)- P(t-1)] is equal to zero. The performance of the conventional P&O algorithm depends highly on the fixed step of Δv/Δi. Increasing the value of the fixed step makes the algorithm response fast but at the same time lead to large oscillation around the MPP. On the other hand, decreasing the value of the fixed step makes the response slow but leads to small oscillation around the MPP. Therefore, the conventional P&O algorithm still needs to be improved.

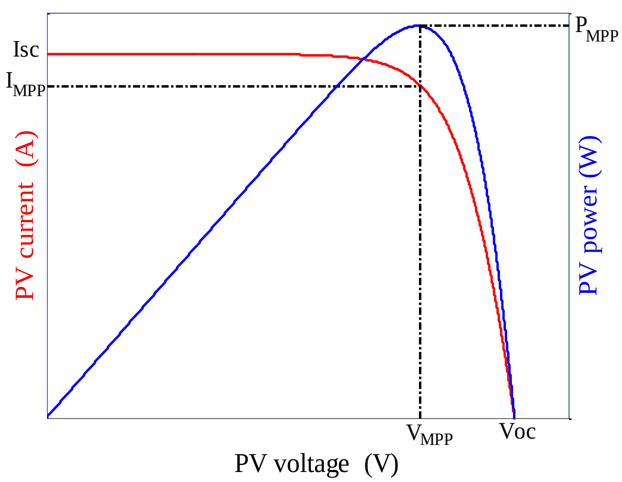


Figure 2 P-V curve of a PV module

4.0 IMPROVED P&O BASED MPPT

As noted in the conventional P&O based MPPT procedure, the main drawback of the conventional P&O algorithm is the selection of the fixed step value of Δv/Δi. An improper selection of this fixed step value leads to poor performance of the overall system. Therefore, this paper presents an improved P&O (Im-P&O) method which uses a variable step size.

The variable step size means that the value of the step size Δv/Δi should be directly proportional with the value of the difference in power [P(t)-P(t-1)]. The mechanism of the Im-P&O depends on the following logic:

- If the [P(t)-P(t-1)] >>0 then the Δv/Δi = very large
- If the [P(t)-P(t-1)] >0 then the Δv/Δi= large
- If the [P(t)-P(t-1)] =0 then the Δv/Δi= 0

According to this logic, the Im-P&O method can move quickly towards the MPP if it is far, and steps slowly if it is near the MPP, and finally stops at the MPP. In this way, the proposed Im-P&O algorithm is expected to achieve faster response and stability at the MPP, because the oscillation in the conventional P&O around MPP occurs due to the fixed Δv/Δi value. The reference current/voltage in the proposedIm-P&O algorithm can be expressed as:

$$I^*,V^* = I^*,V^* + \Phi * f(x) \tag{2}$$

where I^*,V^* is the reference current/voltage. $f(x)$ is one of the mathematical functions shown in Figure 3. Three functions have been investigated as shown in Figure 3. The linear equation is found to be the best function to be used in Im-P&O algorithm. The overall procedure of the Im-P&O algorithm is described in Figure 4.

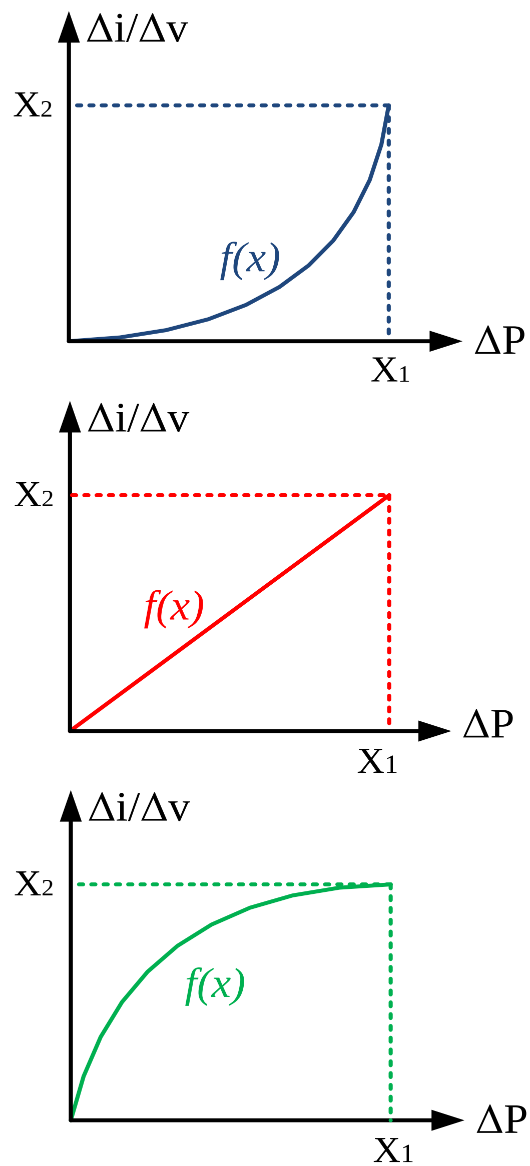


Figure 3 Investigated equations for *f(x)*

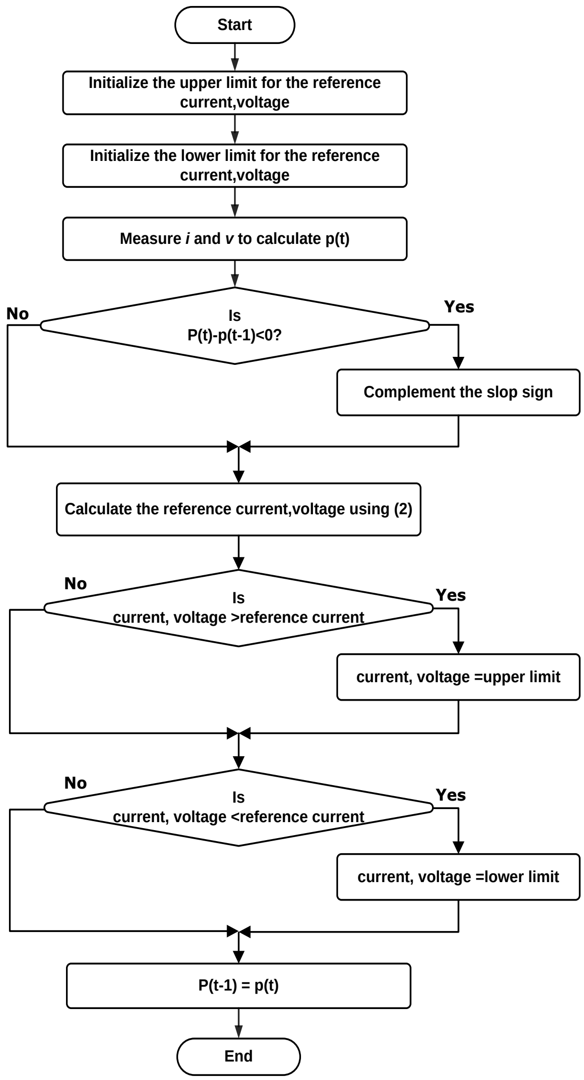


Figure 4 Flowchart of the proposed Im-P&O algorithm

5.0 RESULTS AND DISCUSSION

The response and performance of the MPPT to track MPP for 3 kW PV system with SolarTIFSTF-120P6 PV modules has been validated using MATLAB/Simulink. The performance of the Im-P&O algorithm is compared with the conventional P&O algorithm to exhibit its capability to track the MPP under nominal condition for SolarTIFSTF-120P6 PV modules as shown in Figure 5. The figure clearly shows that the Im-P&O algorithm can track the 3kW power and achieve very fast response compared with the conventional P&O algorithm. The rise time achieved by the Im-P&O is approximately 0.02 s meanwhile the rise time achieved by the conventional P&O is approximately 0.57 s. Therefore, the speed response of MPPT has been significantly improved by the proposed Im-P&O algorithm compared to the conventional P&O algorithm. The behavior of the MPPT based on the Im-P&O algorithm is also characterized by a stable and oscillation free power around the MPP, meanwhile the behavior of the MPPT by the conventional P&O algorithm has a large oscillation around the MPP as shown in Figure 6. Hence, the results indicated that the proposed Im-P&O algorithm is robust compared with the conventional P&O algorithm.

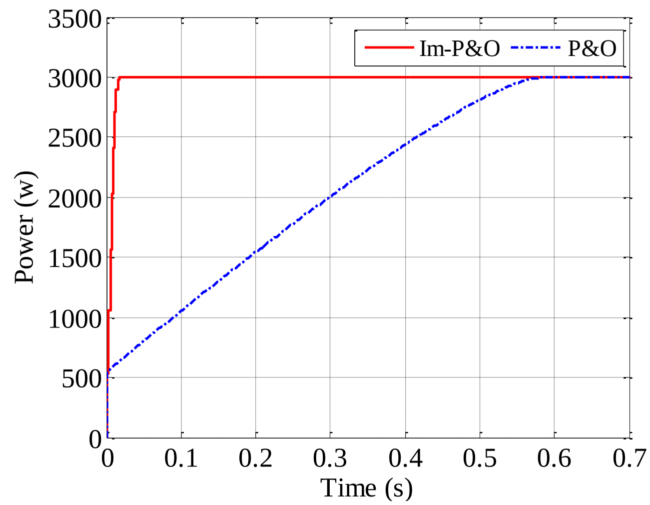


Figure 5 Speed response of the Im-P&O and conventional P&O

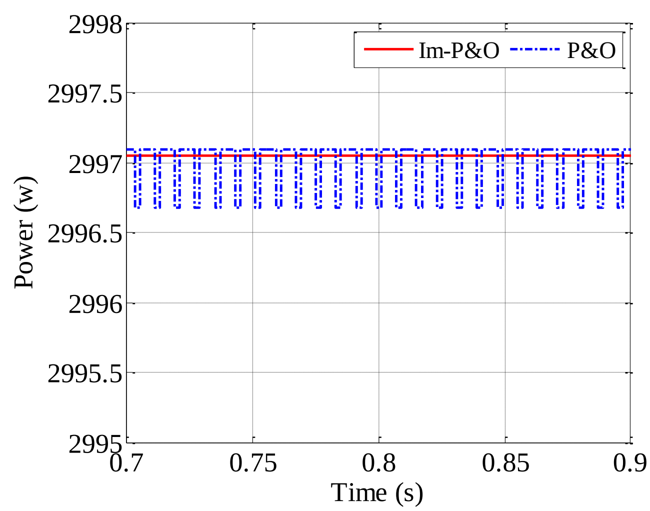


Figure 6 Steady state responses of the Im-P&O and conventional P&O

For further evaluation, simulations were carried out under various solar irradiances (G) with constant temperature (T) where the irradiance is changed with a ramp from 1000 W/m² to 950 W/m² as shown in Figure 7. For this case, the response for the ramp irradiance changes as shown in Figure 8. It clearly shows that the proposed Im-P&O algorithm can extract more power compared with the conventional P&O algorithm. Moreover, the Im-P&O achieved faster response with small oscillation meanwhile the conventional P&O algorithm shows a large oscillation during the ramp irradiance change.

The step irradiance change is also implemented for further evaluation. A step change of G from 1000

W/m^2 to 950 W/m^2 as shown in Figure 9 was simulated. The response for the step G change is shown in Figure 10. It can be seen from Figure 10 that the proposed Im-P&O algorithm can achieve very fast response and track the MPP with very short time compared with the conventional P&O algorithm. Moreover, the proposed Im-P&O achieved the MPP with very small oscillation unlike the conventional P&O algorithm as shown in Figure 10.

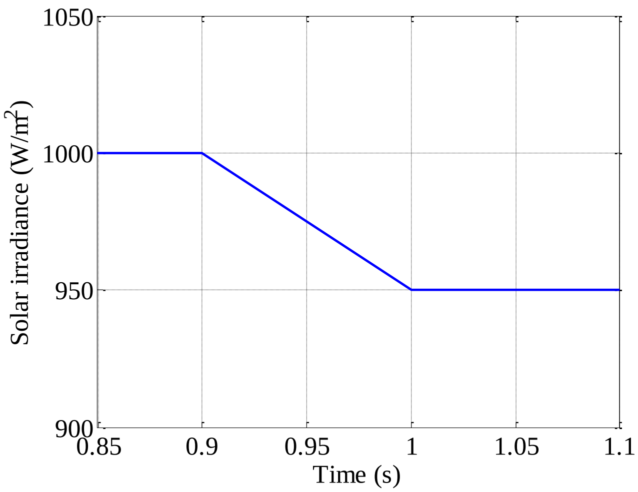


Figure 7 Ramp irradiance change

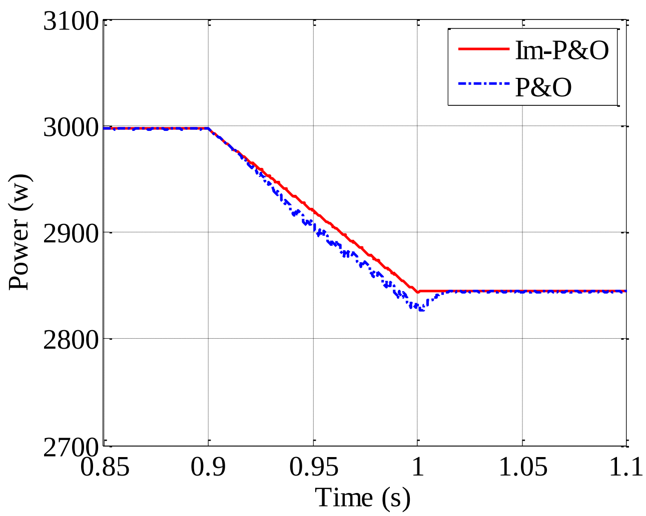


Figure 8 Response of Im-P&O and P&O for the ramp irradiance change

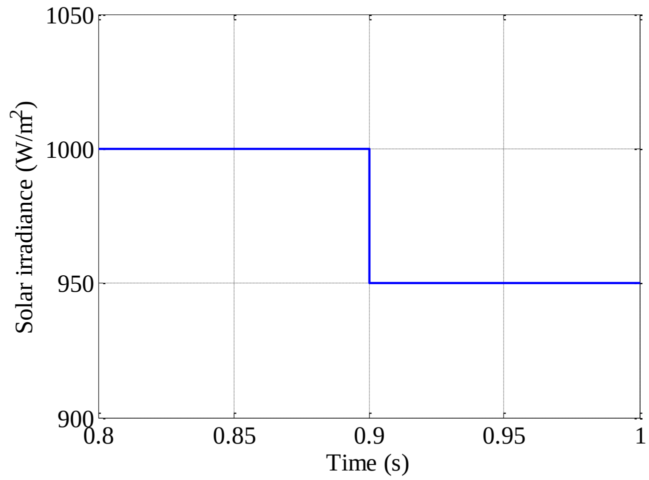


Figure 9 Step irradiance change

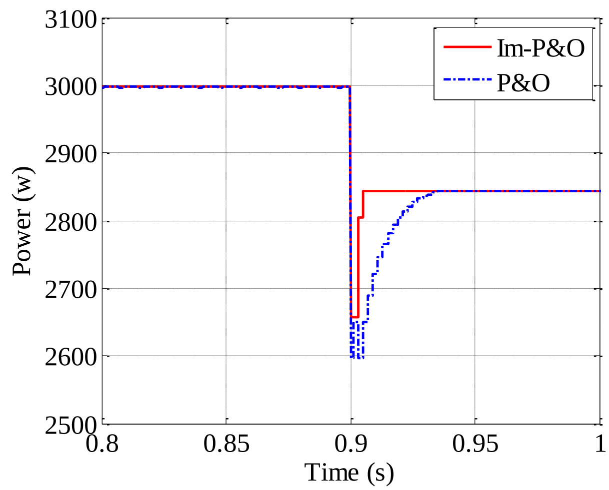


Figure 10 Response of Im-P&O and P&O for the step irradiance change

Another evaluation is made by carrying out simulations under various temperatures (T) with constant irradiance (G) where the T ramps from 43.6°C to 53.6°C as shown in Figure 11. The responses of the ramping T obtained by the Im-P&O and P&O algorithms are shown in Figure 12. The extracted power from the Im-P&O algorithm is again greater compared with the extracted power from the conventional P&O algorithm with much faster response time as can be seen in Figure 12.

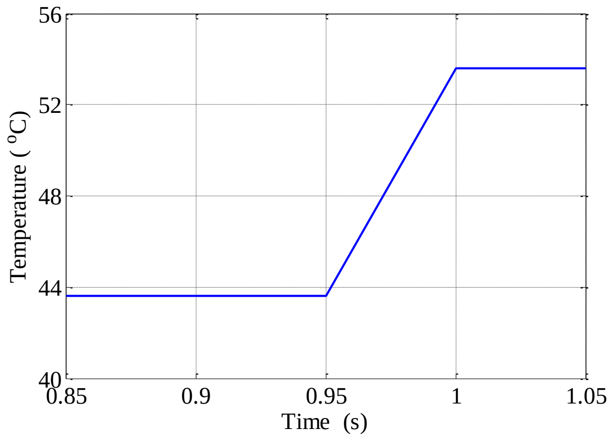


Figure 11 Ramp temperature change

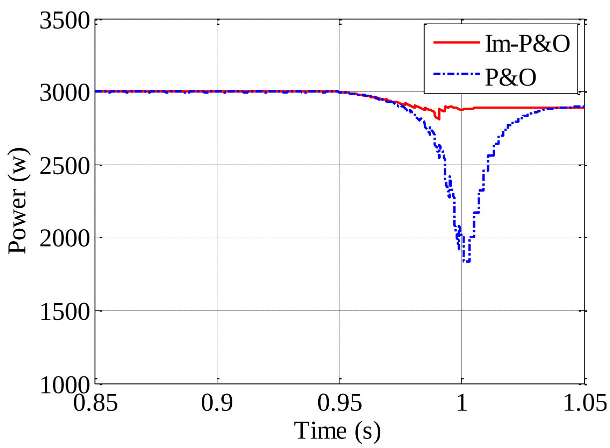


Figure 12 Response of Im-P&O and P&O for the ramp temperature change

The last test case is simulated with a step T change as shown in Figure 13 from 43.6°C to 53.6°C and the corresponding response is shown in Figure 14. The response shows that the Im-P&O algorithm achieves better performance compared with the conventional P&O algorithm. The Im-P&O algorithm tracks the MPP with a shorter time with acceptable oscillation as can be seen in Figure 14.

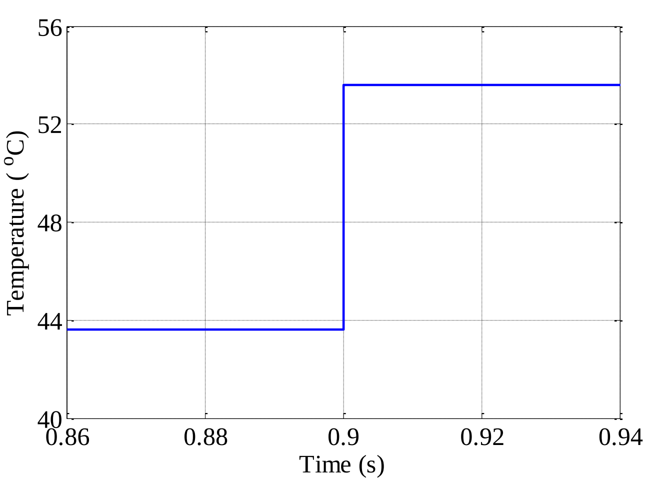


Figure 13 Step temperature change

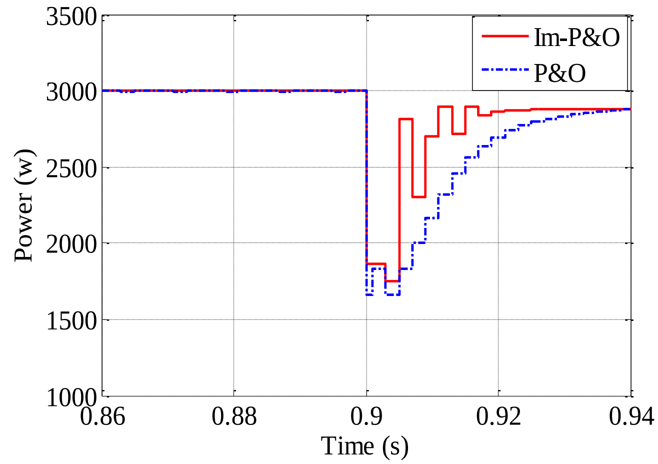


Figure 14 Response of Im-P&O and P&O for the step temperature change

6.0 CONCLUSION

An improved P&O algorithm based MPPT for PV systems has been proposed by considering variable step change. To validate the performance of the proposed MPPT algorithm, PV modelling with the MPPT was developed in the Matlab/Simulink environment to simulate various conditions and changes in solar irradiance and temperature. Simulation result showed that the proposed Im-P&O algorithm can achieve better performance compared with conventional P&O algorithm in all conditions. The Im-P&O algorithm succeeds to track the MPP in all the test cases. Furthermore, the results showed that the proposed Im-P&O algorithm is robust, simpleand accurate compared with the conventional P&O algorithm.

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