Archives of Current Research International

15(1): 1-12, 2018; Article no.ACRI.43457
ISSN: 2454-7077

Modeling and Comparative Analysis of PV Module with Improved Perturbation & Observation Based MPPT Technique for PV Applications

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Authors' contributions

This work was carried out in collaboration between all authors. Author AKG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MG and RS managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ACRI/2018/43457
Editor(s):
(1) Dr. Moses O. Oyesanya, Professor, Department of Mathematics, University of Nigeria, Nsukka, Nigeria.
Reviewers:
(1) Himanshu Dehra, India.
(2) Anonymous, Higher School of Technology, SMBA University, Fez, Morocco.
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(5) P. S. Manoharan, Thiagarajar College of Engineering, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/26474

Original Research Article

Received 11 July 2018
Accepted 24 September 2018
Published 30 September 2018

ABSTRACT

Power-Voltage (P-V) characteristics of PV module are non-linear but it has a unique maximum power point. Maximum power point tracking (MPPT) techniques are used to maximise or to increase the output power of photovoltaic system for all time. These techniques give maximum output power, irrespective of the irradiation condition, temperature and electrical characteristics of loads. For the purpose of tracking the maximum power, MPPT techniques use some electronic converters. In this paper, an improved perturbation and observation (P&O) technique has been modeled and simulated in MATLAB/Simulink. The proposed technique is a modification of conventional P&O method. In the conventional P&O technique, the perturbations of the module operating point introduce with a fixed magnitude.

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Keywords: Boost converter; Maximum Power Point Tracking (MPPT); Perturb and Observe (P&O); photovoltaic.

1. INTRODUCTION

The photovoltaic cell converts the sunlight into electricity. Since, the generation from PV systems has two major problems: its low efficiency of conversion of electric power and a high cost of PV cell. The generation of PV system depends on the weather condition. The photovoltaic cell V-I characteristic is non-linear and changes with a change in irradiation, temperature and load impedance where irradiation and temperature are dynamic [1,2]. The maximum power point location continuously changes and also it is difficult to find an accurate operating point, but this point can be exactly pointed by search algorithms. Hence the MPP tracking is a technique which leads the module towards the higher output. There are so many Maximum Power Point Tracking Techniques that have been already discussed and proposed in the research papers; e.g. Perturb and Observe (P&O), Incremental Conductance (IC), Fractional open-circuit voltage (FV_{OC}), Fractional short-circuit current (FI_{SC}), Neural network (NN), Fuzzy logic control (FLC) [3-16].

2. MATHEMATICAL EQUATION OF SOLAR CELL

A solar cell is nothing but a p-n junction modeled in a thin wafer of semiconductor. Due to the photovoltaic effect, the electromagnetic radiation from the sun can be a change in to electricity.

The equivalent circuit of a PV cell is as shown in Fig. 1.

The current source is cell photocurrent denoted by I_{ph}. The intrinsic shunt and series resistances are denoted by R_{sh} and R_s respectively. The value of shunt resistance (R_{sh}) is very large and the value of series resistance (R_s) is very small. Usually the value of R_{sh} is very large and that of R_s is very small.

The PV module can be modeled mathematically as given in equations below.

Module photo-current:

$$I_{ph} = [I_{scr} + K_i(T - 298)] \times \frac{G}{1000} \quad (1)$$

Module's reverse saturation current:

$$I_{rs} = I_{scr}/[\exp\left(\frac{qV_{oc}}{N_s kAT}\right) - 1] \quad (2)$$

The module saturation current:

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_{g0}}{Bk}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \quad (3)$$

The current output of PV module is:

$$I_{pv} = N_p \times I_{ph} - N_p \times I_0\left[\exp\left\{\frac{q \times (V_{pv} + I_{pv}R_s)}{N_s AkT}\right\} - 1\right] \quad (4)$$

Where,

$N_p = 1$ and $N_s = 36$
I_{pv} is cell current in (A).
q is the charge of electron = 1.6×10^{-19} (coulomb).
K is Boltzmann constant (j/K) = 1.3805×10^{-23}.
T is operating temperature of module in Kelvin.
T_r is reference temperature in Kelvin.
N_p is the number of cell in parallel.
N_s is the number of cell in series.
R_s, R_{sh} are series and shunt resistance (ohms) respectively.
I_{sc} is the short circuit current (A) at reference temperature.
V_{oc} is the open circuit voltage (volts).
I_o is the diode saturation current.
K_i is temperature coefficient of short circuit current.
A is the ideal factor of the PN junction.

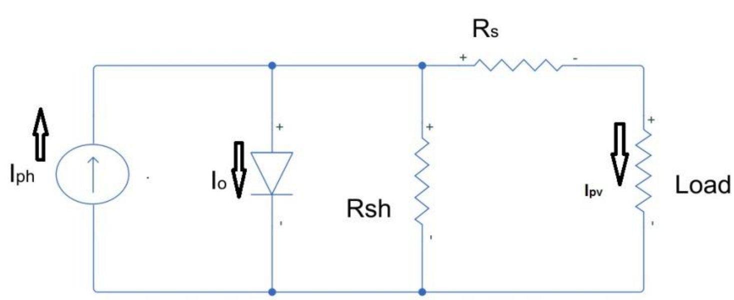

Fig. 1. PV cell modeled as diode circuit

3. REFERENCE PV MODULE

A PV module of 36 W is taken as the reference module for simulation and comparison. The specification of PV module is given in Table 1.

Table 1. Electrical characteristics data of reference Photovoltaic module

Rated Power	36.75 W
Voltage at Maximum power (V_m)	17.71 V
Current at Maximum power (I_m)	2.07 A
Open circuit voltage (V_{oc})	21.17 V
Short circuit current (I_{scr})	2.25 A
Total number of cells in series (N_s)	36
Total number of cells in parallel (N_p)	1
Series Resistance (R_s)	0.221ohm
Parallel Resistance (R_p)	415 ohm

Note: The electrical specifications given in Table 1 are under the standard test conditions (STC) i.e. at irradiance of 1000 W/m^2 and cell temperature of 25°C

4. MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking is commonly written as MPP tracking or MPPT. MPP tracking is an electronic system which operates the Photovoltaic (PV) modules to deliver maximum capable power for all operating time. The physical movement of module towards the sun to deliver maximum power comes under mechanical tracking which is different from MPPT techniques as this is electronic system of tracking the maximum power by varying the electrical parameters of the PV module [17-20].

The output current of PV panels varies depending on the status of the load. Fig. 2 shows current (I)-voltage (V) and power (P)-voltage (V) characteristics of a certain PV panel. Over a wide range of I and V, it is very essential to find a point that maximises the output power. The power is calculated by the product of V and I. The point maximising the power consequently enables for users to extract maximum capable power from the PV cell. The point is called the Maximum Power Point (MPP) and the technique of finding this point is called Maximum Power Point Tracking (MPPT) [21-30].

The MPPT controlled PV system is shown in Fig. 3. The output of PV array is to be given to MPPT controller from which the duty cycle generated. This duty will be converted in the form of pulses using PWM and then these pulses are given to switching converter. The load is connected to the output terminal of converter [16].

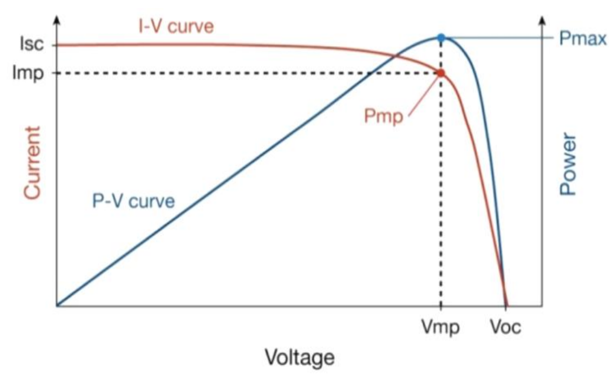

Fig. 2. Power-voltage and current-voltage characteristics

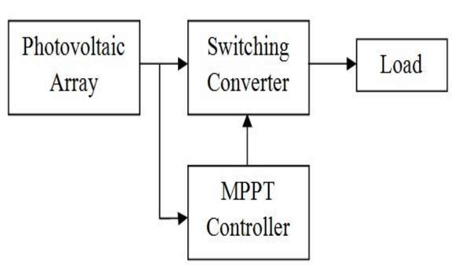

Fig. 3. Block diagram of a MPPT controlled PV system

4.1 Perturb and Observe (P&O) Algorithm

The P&O algorithm for MPP tracking is the simplest techniques among all the MPP tracking techniques in literatures [19,25] and [28]. It is based on the simple mathematical condition, i.e. dP/dV = 0, where P and V are power and voltage at output of PV module respectively.

In this algorithm a small perturbation is introduced in the system. It causes the change in output power of the photovoltaic module. The perturbation introduced will be continued in the same direction if the delivered power increases. The perturbation will be reverse at the next instant of maximum power point as the power decreases after MPP. After some time the output power of PV module reached in the steady state and oscillate near the MPP. In order to minimise the oscillation in power the perturbation size should be made very small. The algorithm is developed to set a reference voltage (V_{REF}) of the PV module corresponding to the maximum voltage (V_{MAX}) of the PV module. A Proportional Integral controller then moves the operating point of the PV module to that particular voltage level. At last it is observed that the PV system with Perturb and Observe MPPT technique have some power loss and also the P&O technique fails to accurately track the maximum available power under fast varying atmospheric conditions. But still the P&O algorithm is very popular because of its simplicity.

From Fig. 2, it can be seen that increase in voltage increases power when the PV array operates in the left of MPP and power decreases on increasing voltage when the same is operates in the right of MPP. The position of operating point with respect to MPP has been summarised in Table 2. Hence if dP/dV > 0, the perturbation should be same and if dP/dV < 0, the perturbation should be reversed. The process should be repeated periodically until dP/dV = 0 (maximum power point) reached. Flow chart of conventional P&O algorithm is shown in Fig. 4.

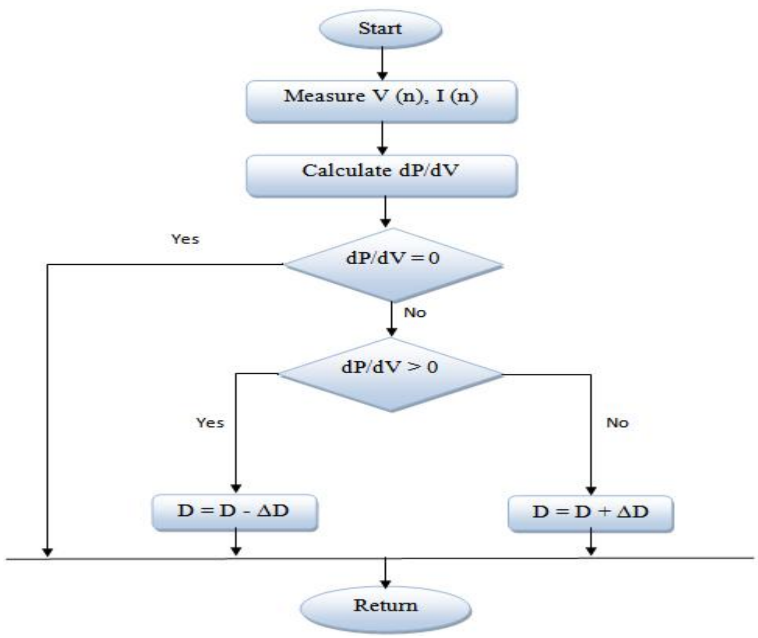

Fig. 4. Flow chart of conventional P&O algorithm

Table 2. Operating point with change in sign of power and voltage

Change in power	Change in voltage	dP/dV	Operating point
Positive	Positive	Positive	Left of MPP
Negative	Negative	Positive	Left of MPP
Positive	Negative	Negative	Right of MPP
Negative	Positive	Negative	Right of MPP

Simulink model of conventional P&O algorithm is shown in Fig. 5. Under sudden changing atmospheric conditions P&O method does not respond well as illustrated in Fig. 6. Due to small perturbation of ΔV in the PV voltage V under constant atmospheric conditions the operating point moves from A to B. Since power decreases to B so according to P&O algorithm the perturbation should be reversed. And when the power curve shifts from P_1 to P_2 due to increase in irradiance the operating point will change from A to C. Now there is an increase in power so again according to P&O algorithm the perturbation should be kept same which results in the divergence of operating point from Maximum Power Point. So the P&O technique need some change to track MPP correctly even under rapid change in irradiance.

4.2 Improved Perturb and Observe (P&O) Algorithm

The limitation of the Perturb & Observe algorithm of tracking under rapidly changing irradiation is addressed and a simple improvement is proposed. This improved algorithm performs an additional measurement of power in the middle of the MPPT sampling period without any perturbation.

This algorithm takes three different voltages (V_a, V_b, V_c) and corresponding three different current (I_a, I_b, I_c), and then obtains three different power (P_a, P_b, P_c) by multiplying the corresponding voltage and current. At the points A, B, C, if insolation level get changed then according to the location of operating point (location may be at left of MPP, right of MPP or at MPP), the MPPT algorithm again decide the three points A, B, C and then the module voltage may be increased or decreased or remains same to get maximum power.

In this algorithm if perturbation value is taken very high, the steady state steps will have a large oscillation in the output power of PV module which leads to decrease the efficiency. Also if the perturbation value is taken very small then it will respond very slowly to change in irradiance. It will also reduce the efficiency of PV module. The flow chart and Simulink model of improved perturb and observe algorithm is shown in Figs. 7 and 8 respectively. Tracking concept of improved P&O algorithm is illustrated in Fig. 9.

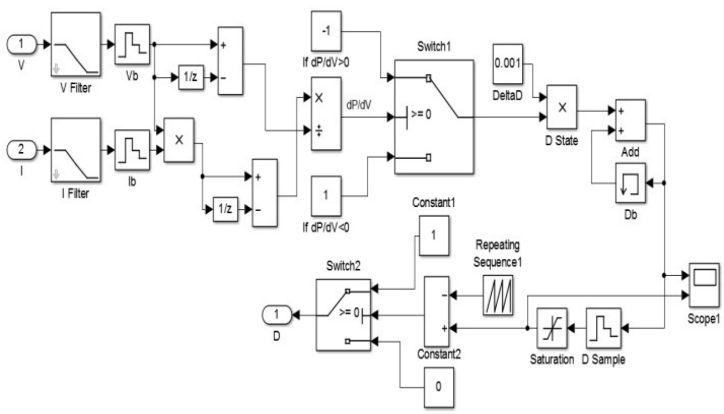

Fig. 5. Simulink model of conventional P&O algorithm

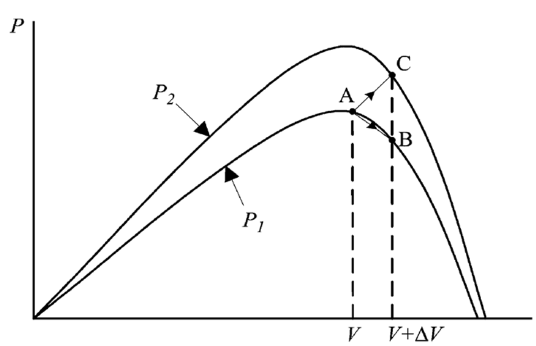

Fig. 6. Divergence of P&O from MPP

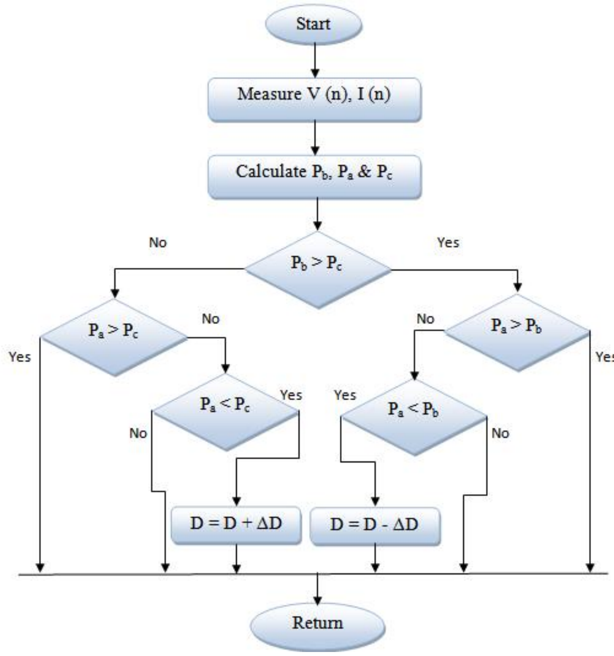

Fig. 7. Flow chart of improved P&O algorithm

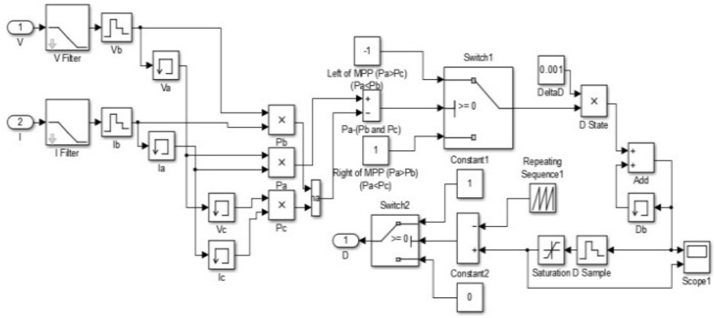

Fig. 8. Simulink model of improved P&O algorithm

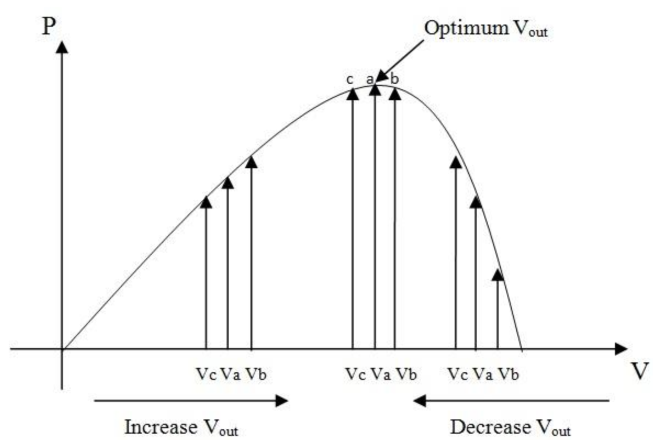

Fig. 9. Tracking technique of the improved P&O algorithm

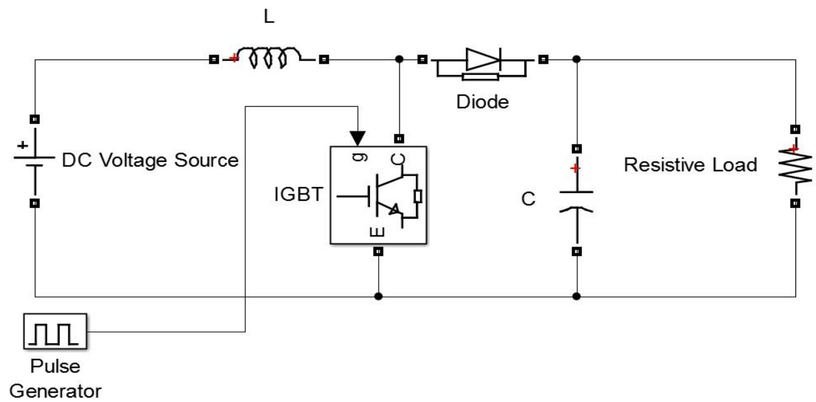

Fig. 10. Boost converter circuit

5. BOOST CONVERTER

Boost converter is basically used to deliver higher output than that of input. In the proposed method of MPP tracking technique, a boost converter (DC to DC) is chosen to vary the electrical parameters of PV module to get maximum available power for all operating time [4]. Boost converter circuit is shown in Fig. 10. It delivers the higher output than the given input as per the following formula:

$$V_{out} = \frac{V_{in}}{1-D} \tag{5}$$

Here, D is the duty cycle of the boost converter. This duty cycle (D) is being controlled by the output of PWM which is controlled by the MPPT algorithm.

The duty cycle of this DC-DC converter is controlled in compliance with the varying solar irradiation by using a MPP tracking algorithm. In this paper the modified Perturbation and Observation method is being used to precisely track the maximum power point with minimum possible oscillations at the time of rapid change in irradiance.

6. SIMULATION RESULTS

The behaviour of power generation from PV system on rapid change in irradiance has been discussed in this section. Corresponding the time of tracking (tracking speed) of maximum power has also been discussed. An irradiation pattern is taken for rapid change in irradiation for both (conventional and improved perturb and observe) technique. The irradiation pattern is given in Table 3.

Table 3. Irradiation pattern for rapid change

Irradiation (W/m^2)	Time range (sec)
700	0.00 – 0.73
1000	0.73 – 1.11
700	1.11 – 1.50
1200	1.50 – 1.87
800	1.87 – 2.18
1000	2.18 – 2.63
400	2.63 – 2.80

6.1 PV System with Conventional P&O Algorithm

Power curve of PV module with conventional P&O algorithm at rapid change in irradiance is shown in Fig. 11. At starting the irradiation is 700 W/m^2 for 0.00 to 0.73 sec. After 0.73 sec irradiation is 1000 W/m^2. Here at the time of change in irradiation, a large oscillation can be seen in power curve. Similarly, on every sudden change in irradiation, a large oscillation occurs till the steady state reached.

Range of variation in power on sudden change in irradiation and range of time to settle the oscillation is given in Table 4.

6.2 PV System with Improved P&O Algorithm

Power curve of PV module with improved P&O algorithm at rapid change in irradiance is shown in Fig. 12. At starting the irradiation is 700 W/m^2 for 0.00 to 0.73 sec. After 0.73 sec irradiation is 1000 W/m^2. Here at the time of change in irradiation, a large oscillation can be seen in power curve. Similarly, on every sudden change in irradiation, a small oscillation occurs till the steady state reached.

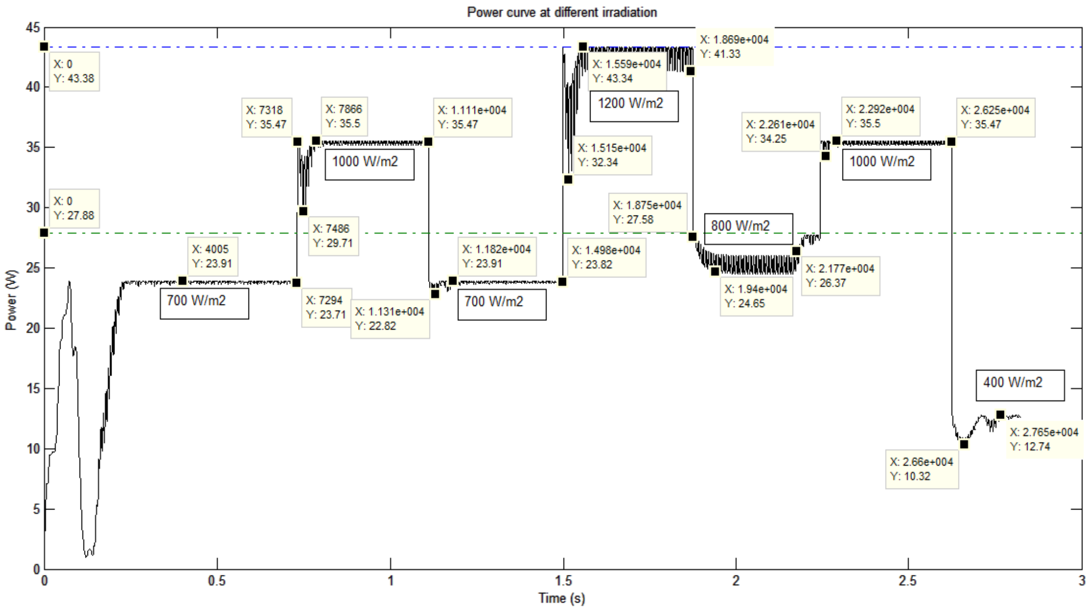

Fig. 11. Power curve on rapid change in irradiation with conventional P&O algorithm

Table 4. Oscillation in power and time taken to settle for conventional P&O algorithm

Change in Irradiation (W/m^2)	Range of variation in Power (W)	Range of time (sec) to settle
700 – 1000	29.71 - 35.47	0.732 - 0.787
1000 – 700	22.28 - 23.91	1.131 - 1.182
700 – 1200	32.34 - 43.34	1.498 - 1.559
1200 – 800	24.65 - 27.58	1.875 - 1.940
800 – 1000	26.37 - 35.50	2.177 - 2.292
1000 – 400	10.32 - 12.74	2.625 - 2.765

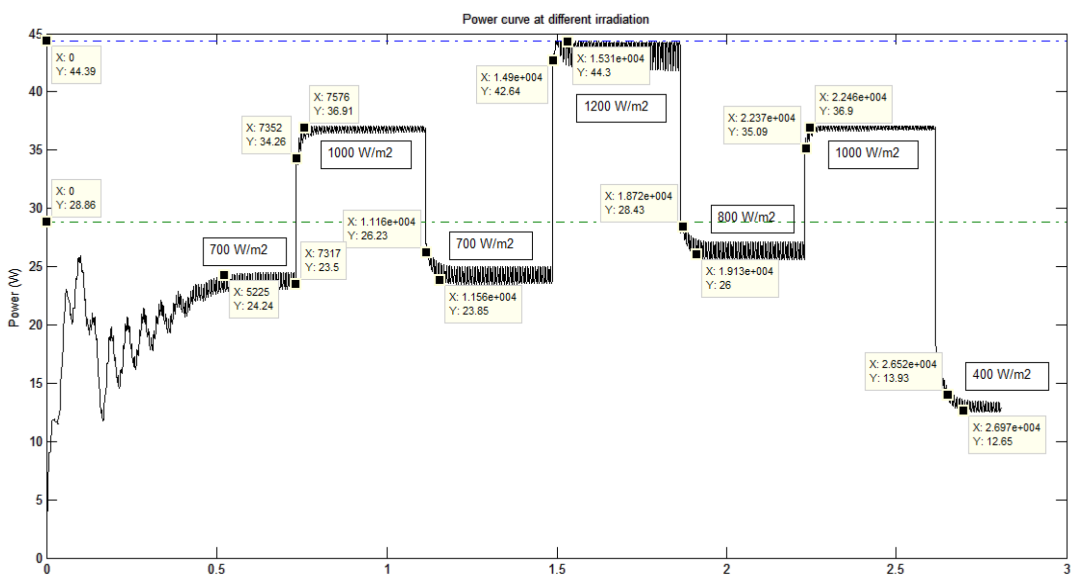

Fig. 12. Power curve on rapid change in irradiation with improved P&O algorithm

Range of variation in power on sudden change in irradiation and range of time to settle the oscillation is given in Table 5.

The comparison of dynamic response of both techniques is given in Table 6.

M. Killi and S. Samanta, reported the time to track the peak due to change in power level is 0.08 sec with adaptive conventional P&O and 0.05 sec with adaptive drift free modified P&O due to change in isolation from 270 W/m^2 to 480 W/m^2 (shown in Fig. 13) [31]. C. Hua and Y. Chen, also reported the time 0.05 sec to track the peak due to change in power level (shown in circle in Fig. 14) [32].

Table 5. Oscillation in power and time taken to settle for improved P&O algorithm

Change in Irradiation (W/m^2)	Range of variation in Power (W)	Range of time (sec) to settle
700 – 1000	34.26 - 36.91	0.735 - 0.758
1000 – 700	24.22 - 25.81	1.118 - 1.157
700 – 1200	42.06 - 44.30	1.488 - 1.531
1200 – 800	25.70 - 27.76	1.879 - 1.929
800 – 1000	35.09 - 36.90	2.237 - 2.246
1000 – 400	12.65 - 13.93	2.652 - 2.697

Table 6. Summary of oscillations and settling time of power for both conventional and improved P&O algorithm

Change in Irradiation (W/m^2)	Conventional P&O algorithm		Improved P&O algorithm	
	ΔP (W)	ΔT (s)	ΔP (W)	ΔT (s)
700 – 1000	5.76	0.055	2.65	0.023
1000 – 700	1.63	0.051	1.59	0.039
700 – 1200	11.00	0.061	2.24	0.043
1200 – 800	2.93	0.065	2.06	0.050
800 – 1000	9.13	0.115	1.81	0.009
1000 – 400	2.42	0.140	1.28	0.045

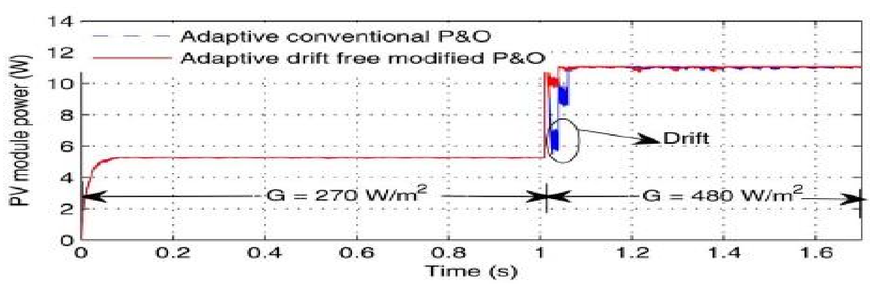

Fig. 13. Adaptive technique for conventional and drift-free modified P&O MPPT for one time insolation change [31]

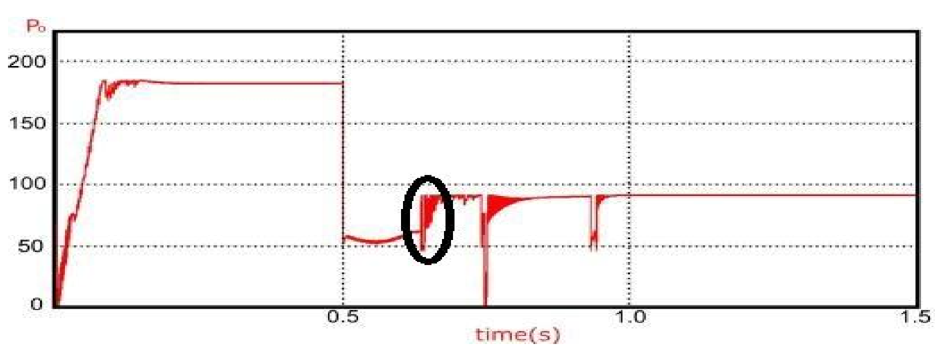

Fig. 14. MP&O tracks GMPP under partial shading condition [32]

7. CONCLUSION

The range of variation in power on a sudden change in irradiation and range of time to settle the oscillation in case of conventional and improved P&O technique is given in Tables 4 and 5 respectively. Summary of comparison of dynamic response for both techniques is given in Table 6. From Table 6, it can be seen that the improved P&O algorithm have small oscillation on a sudden change in irradiation and take less time to settle the oscillations in power than conventional P&O algorithm. The simulation results are obtained for 0 to 2.80 sec at six time sudden change in irradiation. Average power output of PV module recorded in case of conventional P&O is 27.88 W and the same in case of improved P&O is 28.86 W.

Hence, it can be concluded from the results that the improved P&O technique of maximum power point tracking of PV module in case of sudden change in irradiation responds much better than conventional P&O technique.

8. FUTURE WORK

The proposed modified technique can be implemented on hardware and tested for online photovoltaic generation systems. It can also be extended like the proposed technique can also be added with the algorithms to reduce the partial shading effects. Also, the performance of proposed technique can be extended by improving the converter topologies.

ACKNOWLEDGEMENT

We are very thankful to you for accepting our manuscript for publication in your journal. We have read full galley proofed paper, it was formatted in very good format. I am very much thankful to all the reviewer and all the members of publishing house for their precious time and help to improve the manuscript. Everything has been completed form our end.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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