# MODIFIED PERTURB AND OBSERVE MPPT CONTROL FOR AVOID DEVIATION IN PHOTOVOLTAIC SYSTEMS

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**Abstract** *Maximum power point tracking (MPPT) techniques are used in photovoltaic (PV) systems to extract maximum power from the PV module. Many MPPT techniques have been published such as perturb and observe (P&O). Perturb and Observe (P&O) maximum power point tracking (MPPT) algorithm is widely applied due to its simplicity, costless and easy implementation. However, P&O tracking algorithm suffers from deviation due to change of irradiance. In order to avoid the deviation, in this paper we have proposed a modified P&O technique. This modified technique is proposed to avoid the problem of irradiance variation by incorporating the information of voltage, current and power in the decision process for updating the duty cycle of the converter. Simulation result showed that the proposed algorithm accurately tracks the maximum power and avoid the deviation in fast changing irradiation. The effectiveness of proposed MPPT algorithm is verified using MATLAB/Simulink.*
**Key words:** *boost converter, P&O algorithm, maximum power point tracking, photovoltaic module*.

## 1.  Introduction

Solar photovoltaic (PV) is envisaged to be a popular source of renewable energy due to several advantages,  notably low operational cost, almost maintenance free and environmentally friendly [1,2,24].

Despite the high cost of solar modules, PV power generation systems, in particular the grid-connected type, have been commercialized in many countries because of its potential long-term benefits [25–30].

Photovoltaic (PV) modules are utilized to convert sunlight energy into electrical energy and they are defined as a nonlinear DC power source [3].

The dependency of environmental factors and p-n junction structure makes PV modules an unreliable power source for electricity continuity.

Furthermore, there is one unique point on the voltage-current (V-I) curve, which is defined as maximum power point (MPP). PV modules should be operated under MPP condition for the purpose of obtaining highly efficiency.

A number of different MPPT algorithms have been proposed [4-6], including the P&O algorithm.

Among all mentioned methods, the P&O algorithm is the most popular and widely used due to its simplicity, ease of implementation and low cost.

However the algorithm fails tracking MPP during rapid change of weather and its tracking performance has steady state oscillations around MPP according to step size [24], [31-33]. The sudden variation in atmospheric conditions causes this P&O algorithm to deviate away from MPP [5], and the analysis of this deviate problem is given in [34] and [35]. This paper presents a clear analysis of deviate such as when the deviation can come, the movement of the operating point, and the effect of deviation in case of tow times irradiations changes, as well as rapid change in irradiation. The deviation phenomena in case of the adaptive P&O technique are also incorporated in this paper.

## 2. Modeling and characteristic of solar panel
## 2.1. PV cell model and characteristics

The model of solar cell can be categorized as p-n semiconductor junction, when exposed to light, the DC current is generated. The PV cell equivalent circuit can be represented as an ideal current source, diode, parallel resistance and series resistance as shown in Fig.1, where the current source is the light generated current which is directly proportional to the solar irradiation. The series and the shunt resistances represent a voltage loss on the way to the external contacts and the leakage current in the shunt path respectively.
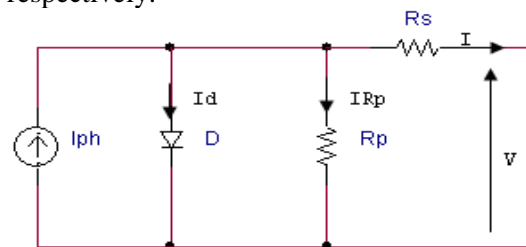


**Fig.1.** Equivalent circuit of a photovoltaic cell

The mathematical model which relates the output current to the output voltage is given by the Eq (1) [36].

$$I = I_{ph} - I_0 \times \left[ exp\left( \frac{(V + I \times R_s)}{a \times V_{th}} \right) - 1 \right] - \frac{V + I \times R_s}{R_P} \qquad (1)$$

Where $I$ and $V$ are the output current and output voltage of the photovoltaic cell, respectively, $I_0$ is

the diode's reverse saturation current, **a** is the diode ideality factor, $R_s$ and $R_P$ are the series and parallel resistance, respectively. $V_{th}$ is the thermal voltage of the cell, which is expressed as,

$$V_{th} = \frac{K_b \times T}{q} \tag{2}$$

Where $q$ is the electron charge $(1.6 \times 10^{-19} C)$, **T** is the junction temperature in Kelvin (K), and $K_b$ is the Boltzmann constant $(1.38 \times 10^{-23}$ J/K). $I_{ph}$ is the generated photocurrent; it depends mainly on the radiation and cell's temperature, which is expressed as,

$$I_{ph} = [I_{SC_{STC}} + K_i(T - T_{STC})\frac{G}{G_{STC}} \tag{3}$$

Where $I_{SC\_STC}$ (in Ampere, A) is the short-circuit current at standard test conditions (STC), $T_{STC}$ $(25°C$ ) is the cell temperature at STC, **G** (in watts per square meters, $W/m^2$ ) is the irradiation on the cell surface, $G_{STC}$ $(1000 \ W/m^2)$ is the irradiation at STC, and $K_i$ is the short circuit current coefficient, usually provided by the cell manufacturer. In addition, the saturation current **Io** is influenced by the temperature according to the following Eq (4) [16,17]

$$I_0 = \frac{I_{SC\_STC} + K_i(T - T_{STC})}{\exp[(V_{OC\_STC} + K_V(T - T_{STC}))/a \times V_{th}] - 1} \tag{4}$$

Where $V_{OC\_STC}$ (in Volt, V) is the open circuit voltage at STC; $K_V$ is the open circuit voltage coefficient.

## 2.2. Series/parallel grouping
The output power from a single PV cell is relatively small. To produce the required voltage and power, PV cells are connected in series and parallel. They are grouped into modules. Modules are combined to form panels. These panels are connected together to build up the entire PV array.

Then, any desired current–voltage (V-I) and power–voltage (V-P) characteristic could be generated [17]. Therefore, the V-I characteristic equation of a PV array (arranged in $N_P$ parallel and $N_S$ series solar cell) can be expressed as,

$$I = N_P \times I_{ph} - N_P \times I_0 \left[ \exp\left( \frac{V + I \times \left(\frac{N_S}{N_P}\right) \times R_S}{N_S \times a \times V_{th}} \right) - 1 \right]$$

$$- \frac{V + I \times \left(\frac{N_S}{N_P}\right) \times R_S}{\left(\frac{N_S}{N_P}\right) \times R_P} \tag{5}$$

Where connecting cells in series will increase the output voltage and connecting them in parallel will increase the output current. Fig.2 shows the I-V and P-V characteristic of the PV module at a fixed cell temperature T and at a certain solar radiation, G. In this figure (I-V curve), there are three remarkable points:

- The short circuit point $(0, I_{SC})$, (the point where the I-V curve meets the voltage axis). Where $I_{SC}$ is the short circuit current that can be drawn by connecting the positive and negative terminals of PV module. It is the greatest generated current value when the voltage is zero (V=0).
- The open circuit point $(V_{OC}, 0)$, (the point where the I-V curve meets the current axis). Where $V_{OC}$ is the open circuit voltage of PV module. It reflects the voltage of the module in the night. In this case, no current is generated (I=0).
- The maximum power point, MPP $(V_{mpp}, I_{mpp})$: at this point, the PV module is said to operate at maximum efficiency and produces its maximum output power $(P_{max})$ given by:

$$P_{max} = V_{mpp} \times I_{mpp} \tag{6}$$

Where $I_{mpp}$ and $V_{mpp}$ are the optimal operating current and voltage of PV module, respectively. When a PV module is directly connected to a load, the operating point will be at the intersection of the I-V curve of the PV module and the load curve.

Most of the time, this operating point does not meet the maximum power point (MPP) of PV module. Furthermore, as the maximum power point depends on solar radiation and cell temperature, which vary randomly, the MPP position is continuously changing [18].

Therefore, it is very important to ensure that the module operates at maximum efficiency because the main problem with PV energy generation systems is low efficiency [19]. In order to overcome this problem, specific circuits, called maximum power point trackers (MPPT), are used [18].
The MPPT is achieved by interposing a DC–DC converter between the PV array and the load, the MPPT algorithm generates the optimal duty ratio (D) in order to maintain the electrical quantities (V, I and P) at values corresponding to the maximum power point

## 2.3. Characteristic I-V and P-V of PV module
The PV module used for simulation consists of 36 series PV cells where the PV cell, is the single diode ( $I_{ph} = 3,25A$ , $a = 1,2 I_0 = 8,225.10^{-12}A$, Rs= 0,015 Ω, and $Rp = 30$ Ω, $K = 1,38.10^{-23}J/K$, $q = 1,6.10^{-19}c$ ).
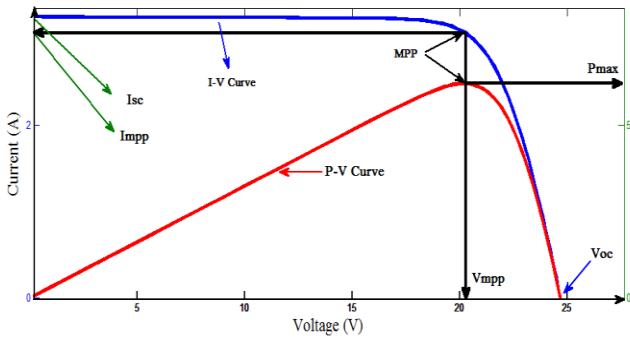
**Fig.2.** I-V and P-V characteristics of a PV module

## 2.4. Effect of solar radiation and cell temperature

The V-I characteristics of a PV cell strongly depend on solar radiation and temperature [20–22]. Fig.3a shows that the output current I of a PV module is widely influenced by the variation in solar irradiance G, whereas the output voltage V stays almost constant. In the other hand, for a changing temperature one can see that the voltage varies widely while the current remains almost unchanged (Fig.3b). Fig.4a and b shows how the dependency of output current (I) and output voltage (V) on solar irradiance and cell temperature translate into a dependency of the output power (P) on the same two parameters. Fig.4a confirms the expected behavior of a device that converts solar energy into electricity: the output power of a PV generator is largely reduced for a decreasing irradiance.

Furthermore, Fig.4b shows that the output power decreases by an increase in cell temperature. This can be explained by the dependency of the open circuit voltage ($V_{OC}$) on the cell temperature as follows [23]

$$V_{OC} = V_{OC\_STC} + K_V(T - T_{STC}) \tag{7}$$
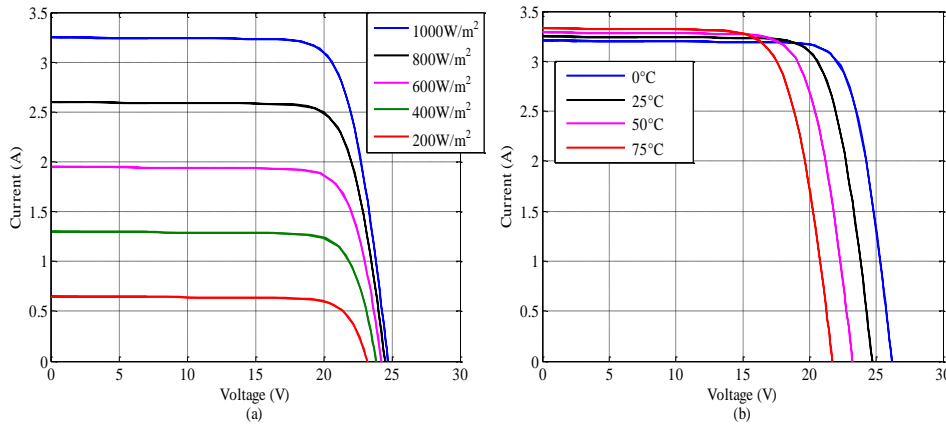


**Fig.3.** I–V characteristics of a PV array: (a) for various values of irradiance G at a temperature of $25^0C$; (b) for various values of temperature T at an irradiance of $1000W/m^2$.
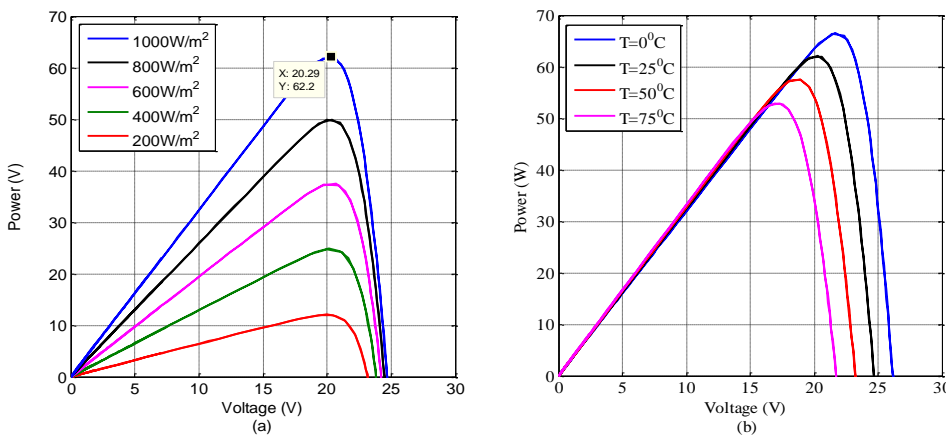


**Fig.4.** P–V characteristics of a PV array: (a) for various values of irradiance G at a temperature of $25^0C$; (b) for various values of temperature T at an irradiance of $1000W/m^2$.

## 3. MPPT model

The circuit diagram of the energy conversion system is shown in Fig.5. The system consists of photovoltaic panel, a DC-DC boost converter. The PV array consists of 36 series PV cells. The I-V characteristic of array depends on the temperature and solar irradiation level. The photovoltaic array operation depends on the load characteristics to which it is connected. So when connected to load directly, the output of the PV array seldom works at MPP. However, to adapt the load and extract maximum power from a PV module, a DC-DC boost

converter is utilized by adjusting its duty cycle under control of selected based MPPT controller so that the maximum solar panel output power is extracted under all operating conditions [7].
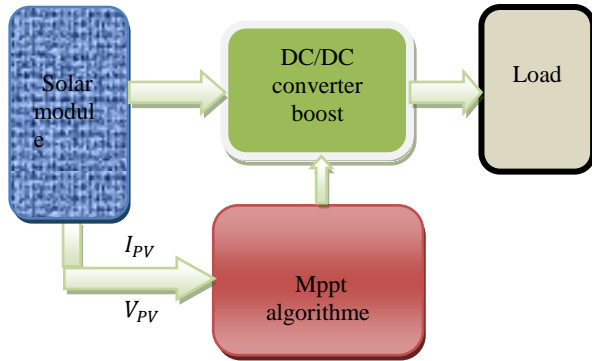


**Fig.5.** MPPT system

## 4. DC-DC converter

Boost converters are more significant and have several advantages, such as simple construction, and higher efficiency and performance; it is a step-up DC-DC power converter [11]. Fig.6 shows the boost converter circuit using MOSFET switch. The converter operation can be divided into two modes. Mode 1 begins when the transistor is switched ON, the current in the boost inductor increases linearly, and the diode is OFF state, mode 2 begins when the transistor is switched OFF, the energy stored in the inductor is released through the diode to the load.

The power flow is controlled by varying the on/off time of the MOSFET. The relationship between input and output voltages is given by Eq (8) [8].

$$\frac{V_o}{V_i} = \frac{1}{1-D} \tag{8}$$

Where $V_i$ is the PV output voltage, $V_o$ voltage of boost converter, D is duty cycle that can be expressed by Eq (9).

$$D = \frac{T_{on}}{T} \tag{9}$$

Where $T_{on}$ is time when MOSFET is switched on, T is cycle period time. The transistor operates as a switch; it is turned on and off depending on pulse width modulated (PWM) control signal. PWM operates at constant frequency; T is constant and $T_{on}$ is varying, so D can be varied from 0 to 1.
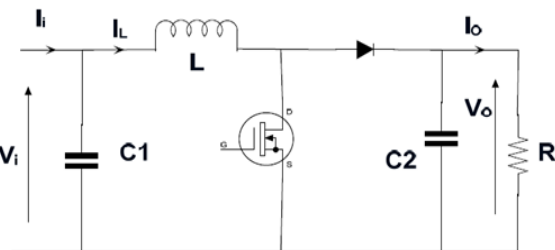


**Fig.6.** Boost converter circuit diagram

## 5. Conventional P&O method

Conventional P&O algorithm is the simplest, costless, popular and almost applicable in practice with efficiency up to 96.5%. However, it is not robust in tracking the right MPP at rapid changes of weather. The algorithm obtains its information from the actual operating point of the PV module or array (i.e., voltage, Vpv and current, $I_{PV}$) to scan the P-V curve in order to obtain MPP as shown in Fig.7. The scanning of the P-V curve is done by changing the operating point (Vpv or $I_{PV}$, which is known as perturbation step, and then measuring the change in PV power (dP), that is known as observation step.

The resulting change of PV power is observed as follow:

- If $\frac{dP}{dV}$ is positive, the perturbation of voltage should be increased from point "A" towards MPP as shown at the left side of Fig.7.
- If $\frac{dP}{dV}$ is negative, the perturbation of voltage should be decreased from point "B" towards MPP as shown at the right side of Fig.7.
- The previous process is repeated until is reached to MPP where $\frac{dP}{dV}$ is closely to zero; this is satisfied condition is called steady state.
- The P&O keeps perturbing the system in order to detect a change in the MPP (caused by a change in the environmental conditions or load), which triggers a new scan.

Normally, this process causes the operating point of the PV system to oscillate around MPP. The flowchart of conventional P&O algorithm is shown in Fig.8.
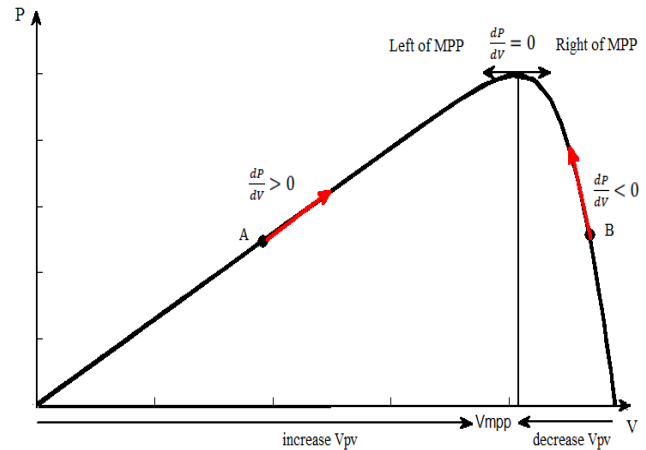


**Fig.7.** Perturb and observe on P-V curve

## 5.1. Conventional perturb & observe algorithm and weather variations

The successive rapid increasing and decreasing of irradiance causes the deviation problem due to conventional P&O algorithm is unable to recognize the change in power either is coming from weather or perturbation change. Suppose there is an increase in irradiance level, whiles the PV system operates at point MPP1 at perturbation j as shown in Fig.9 then,

the operating point will be moved to a new point 2 in corresponding irradiance curve during the same perturbation j which results positive change in both power (dP) and voltage (dV). The information of positive change during perturbation j+1 will make algorithm to increase voltage perturbation instead of decreasing and move operating point from point 2 to point 3 as shown in Fig.9. This wrong decision causing the operating point of PV system is far away from MPP as a result of successive change of irradiance as shown in Fig.9. Also, the successive rapid decreasing of irradiance deviate the operating point of PV system away from MPP as shown in Fig.10.
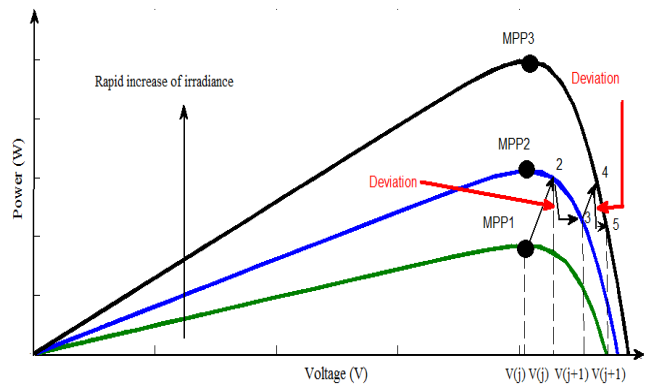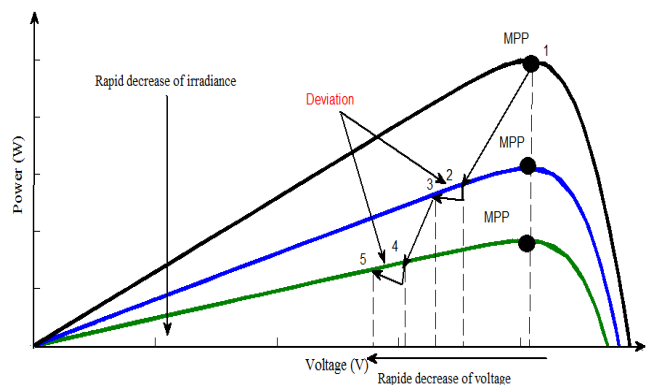


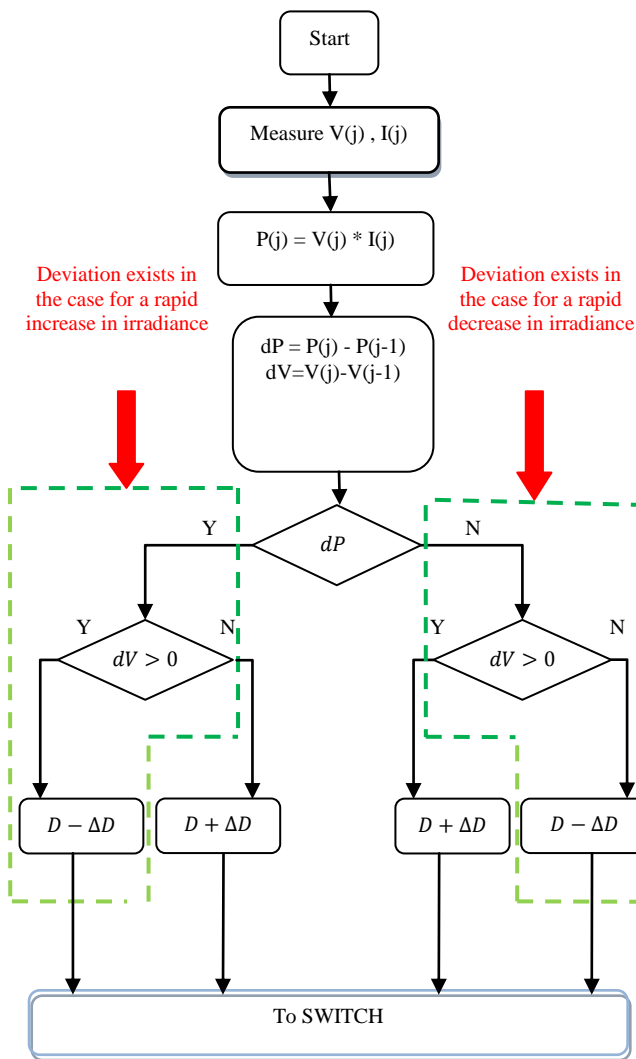**Fig. 9.** Rapid increase of irradiance



**Fig.10. Rapid decrease of irradiance**

A simulation of the conventional P&O algorithm has been implemented by using MATLAB; Figs.11 and 12 shows the simulation results.





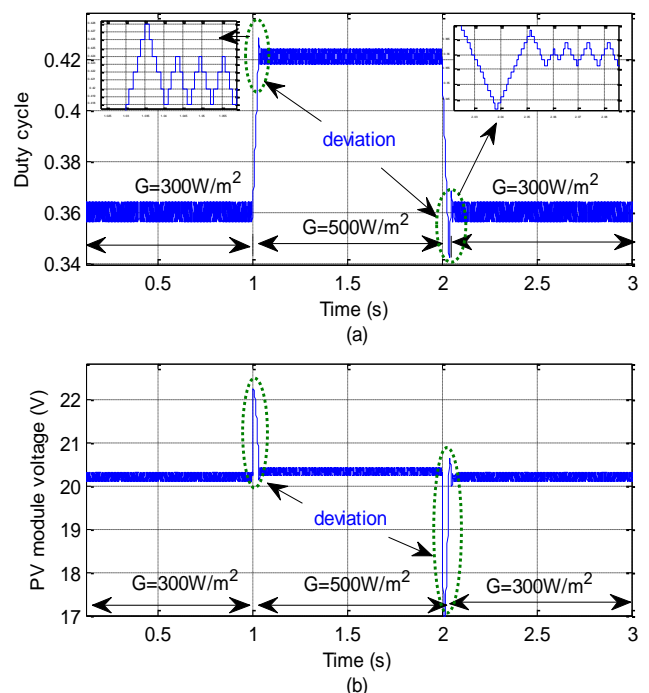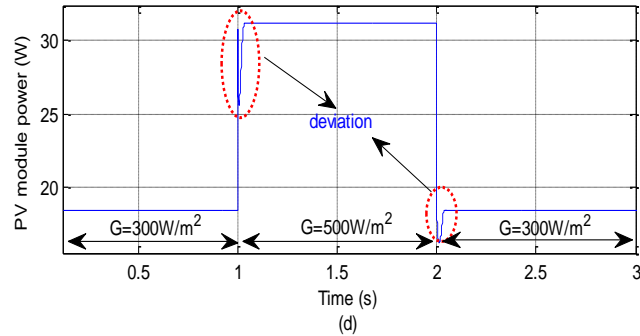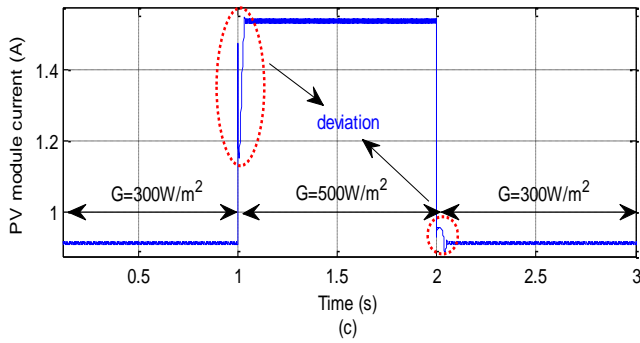**Fig. 11.** Conventional P&O MPPT for both times irradiation change. (a) Duty cycle variation. (b) Voltage.



**Fig.8.** P&O flowchart

**Fig.12.** Conventional P&O MPPT for both times irradiation change. (c) Current. (d) .Power

## 6. Modified P&O MPPT technique

The conventional P&O MPPT is developed based on the observation of dP and dV by considering the P–V characteristics of the PV module. As said previously, conventional P&O has a suffer of deviation in case of a change in irradiation due to confusion, and this confusion can be eliminated by evaluating another parameter dI (change in current).

With the information of dV, dP and dI, the deviate phenomena can be avoided by detecting the change in irradiation.

The I–V characteristics of the PV module and the change in operating point due to a change in irradiance are shown in Fig.13. As shown in Fig.13, supposing that there is a decrease in irradiance while operating at point 2, then the operating point will settle to a new point 3 in the new irradiance curve.

Now, the decision has to be taken by the algorithm at point 3, where dI < 0 as shown in Fig.13. At the same time on the P−V characteristics at point 3, both dP < 0 and dV < 0 as shown in Fig.13 Thus, all three parameters dP, dV, and dI are negative at point 3 as shown in Fig.13 and 14 . Thus, the negatives value of dP is due to whether perturbation or due to decrease in irradiance can be detected by using the additional parameter dI. Both dP, dV and dI will be negative only for an decrease in irradiance as shown in Fig.13. Thus, an decrease in irradiance can be detected by using the additional parameter dI, and thereby, decreasing the duty cycle by new variable step size $\Delta$D ($\Delta D_n$) where can eliminate the deviation problem by moving the operating point closer to the MPP as shown in

Fig.14. And in the same way in the case of an increase in irradiance the modified P&O control detected that dP, dV and dI are negative and therefore increase the duty cycle by $\Delta D_n$. $\Delta D_n$ is variable step size that can be expressed by Eq (10).

$$\Delta D_n = \pm M|\Delta G| \qquad 10$$

M is a constant parameter and $\Delta G$ represents the change of irradiance. The flowchart of this modified P&O MPPT technique is shown in Fig.15 and The MATLAB/Simulink model of the proposed modified P&O algorithm is shown in Fig.16.
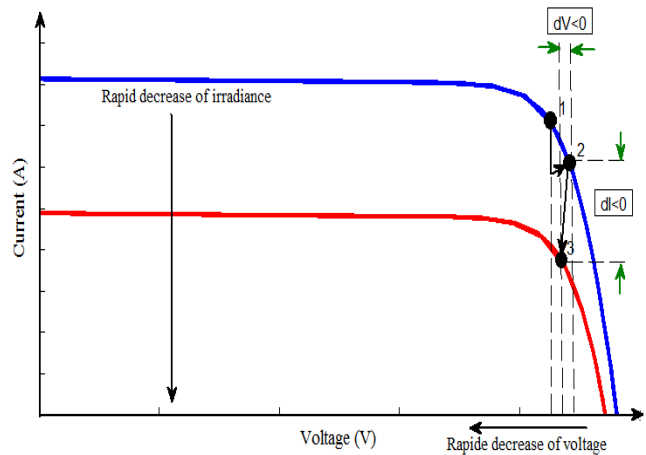


**Fig.13. Observation of change in current**
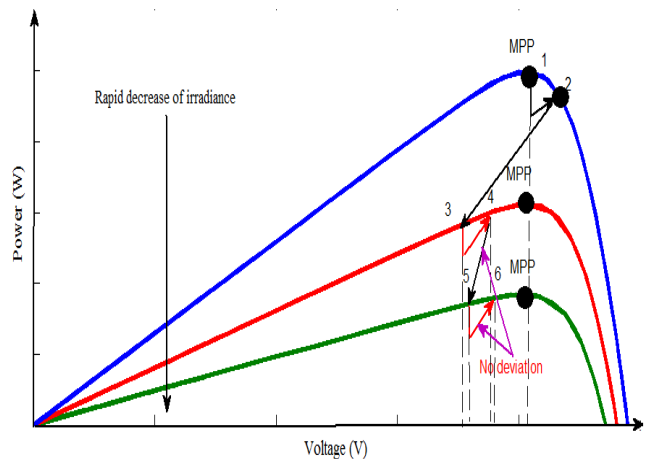


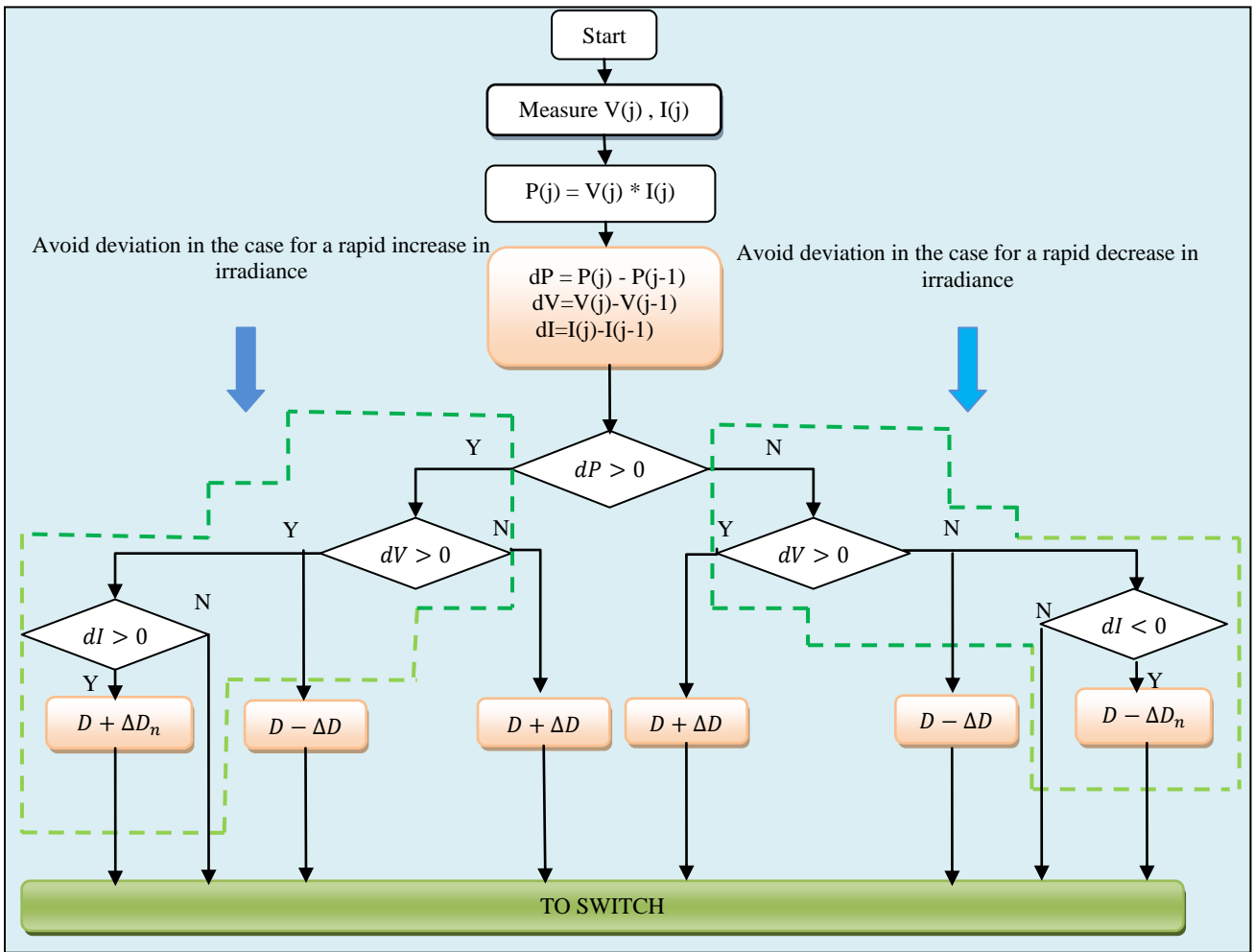**Fig.14.** both times increase in irradiance

**Fig.15.** Flowchart of modified P&O MPPT algorithm.
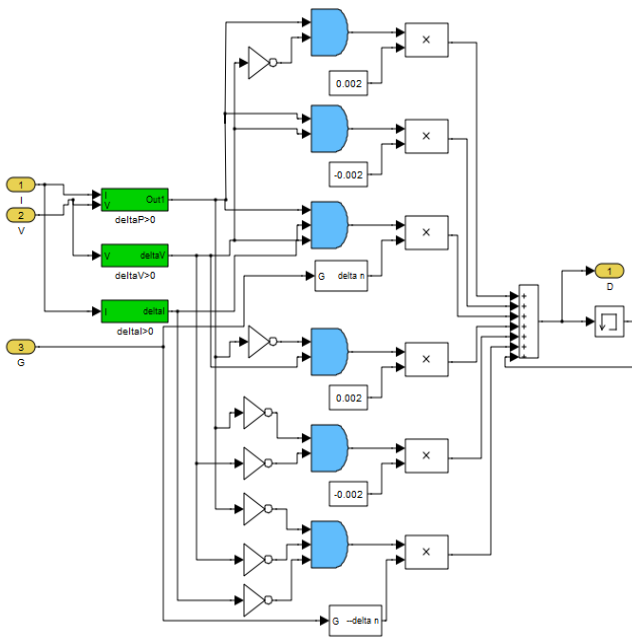


**Fig.16.** MATLAB/Simulink model of modified P&O MPPT algorithm**.**

## 6.1. Analysis the deviation for tow Step Change in irradiance

The proposed MPPT algorithm has been tested for a step change in irradiance level from 300 to 500 w/m$^2$ at 1s and from 500 to 300 w/m$^2$ at 2s as shown in Fig.17.

The perturbation time (T) and the perturbation step size ($\Delta D$) are chosen as 1 ms and 2 ms, respectively.
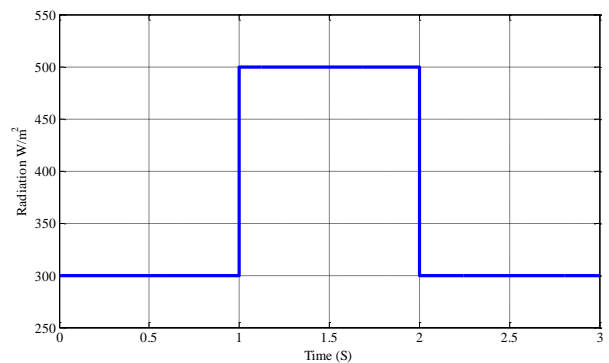


**Fig.17.** Variation of solar irradiance.

The solar irradiance level is stepped from low to high and then to low again as shown in Fig.17. The initial level is set at G=300 w/m$^2$ at t=1sec, the irradiance is suddenly stepped up to G=500 w/m$^2$.

Finally at t=2sec, it is stepped down to G=300w/m$^2$. The temperature is kept constant at $25^0 C$ for all irradiance levels. Fig.18 show the simulation results of duty cycle, voltage, current and extracted maximum power, respectively as compared with conventional P&O algorithm. It can be seen from fig.18 that, the modified P&O algorithm is more accurate, powerful to avoid the deviation than conventional P&O algorithm.
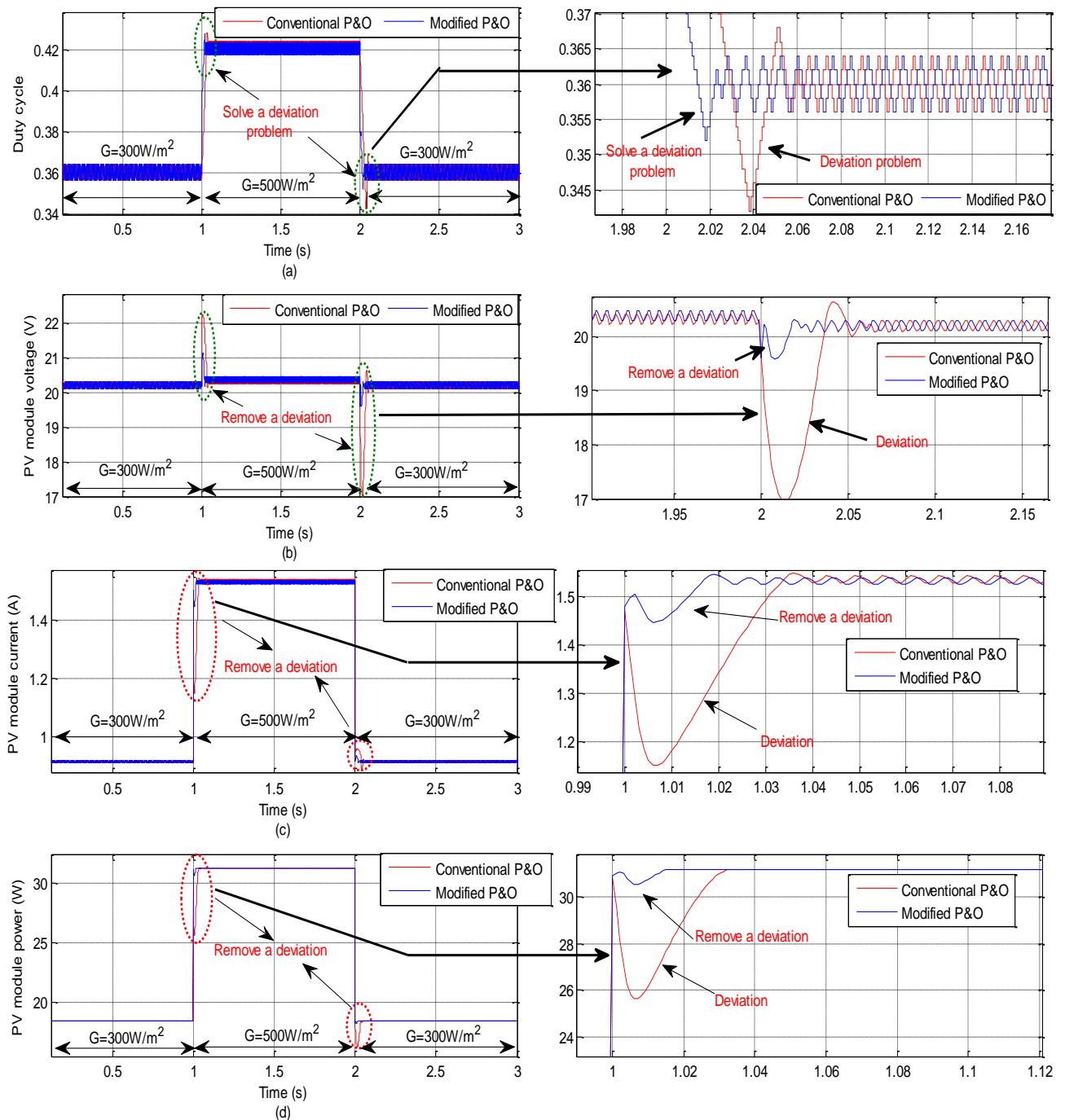


**Fig.18**. Conventional and modified P&O MPPT for both times irradiation change.(a) Duty cycle. (b) Voltage. (c) Current. (d) Power.

## 7. Conclusion

Maximum power point tracking techniques extract the maximum output power of the PV systems at certain weather conditions to maximize its efficiency and minimize the overall system cost. Regrettably, MPPT techniques deviate from MPP location as a result of irradiance variations. The most conventional technique is P&O algorithm due to it's easily, costless and has minimum controlled parameters. The conventional P&O algorithm has many inconveniences such as failure to extract MPP during fast change of irradiance. In this paper, a new modified P&O algorithm is proposed to improve the conventional P&O algorithm for overcoming previously inconveniences. This proposed algorithm is based to use another parameter dI and variable step size $\Delta D_n$ to enable conventional P&O algorithm to recognize the cause of deviation coming from rapid change of irradiance. The results of proposed P&O algorithm show good excellent maximum power tracking due to rapid variations in irradiance as compared with simulation. The modified proposed P&O algorithm satisfies extracting maximum power with high efficiency due to fast change of irradiance and finally increasing stability of PV system.

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