

# Analysis and Simulation of Modified Adaptive Perturb and Observe MPPT Technique for PV Systems

J. Suryakumari and G. Sahiti

**Abstract:** Solar energy is a clean and renewable energy resource for power generation. The power output from a solar photovoltaic system mainly depends on the nature of the connected load because of non-linear I-V characteristics. In the past years, PV power generation system has attracted more attention due to the energy crisis and environment pollution. Photovoltaic (PV) power generation systems can mitigate effectively environmental issues such as the green house effect and air pollution. Photovoltaic (PV) offers an environmentally friendly source of electricity, which is however still relatively costly today. PV power generation systems have one big problem that the amount of electric power generated by PV module is always changing with weather conditions i.e., irradiation and temperature.. Therefore, a maximum power point tracking (MPPT) control method to achieve maximum power (MP) output at real time becomes indispensable in PV generation systems. The maximum power point tracking (MPPT) of the PV output for all sunshine conditions is a key to keep the output power per unit cost low for successful PV applications. Several techniques have been proposed for maximum power tracking. The most commonly used techniques for MPPT, are the Hill Climbing Techniques. These include Perturb & Observe method Adaptive P&O and modified adaptive P&O techniques. It is known that the P&O method exhibits erratic behavior under rapidly changing irradiance level that causes incorrect or slow maximum power tracking. The Modified P&O (MP&O) method was proposed to solve this problem by decoupling the PV power fluctuations caused by hill-climbing process from those caused by irradiance changing.

**Keywords:** MPPT (Maximum Power Point Tracker), P&O (Perturb and Observe), Photovoltaic system, Boost Converter, Hill-Climbing, Adaptive.

## 1. INTRODUCTION

As fossil energy becomes more expensive and causes growing environmental concerns, energy from natural resources such as sunlight and wind are globally welcomed to replace the fossil fuel. Among methods of generating electric power by alternative resources, photovoltaic (PV) has grown steadily in recent decades as a carbon-free technology alternative PV converts sunlight directly into current electricity by means of the photovoltaic effect. Since common solar cells are made from silicon-based semiconductors, the photovoltaic effect is involved with the p-n junction of the solar cells. First, sunlight produces

electron-hole pairs (EHPs) into the cell. Then, the electrons move to the n-region and the holes move to the p-region as a result of the electric field created by the junction. The electric charges collected in both regions finally flow as electric current into a connected load. A PV system is a power system that generates direct current (DC) from sunlight and processes it requiring DC or alternating current (AC) electricity. Instead of solar cells, the PV system generally uses PV panel-interlinked packages with solar cells-or PV arrays-combined assemblies of PV panels-due to the low voltage of a single solar cell.

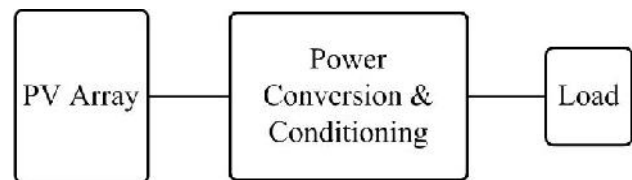


Figure 1: Block diagram of PV system

As shown in Figure 1, the PV system consists of three stages: power generation, power conversion & conditioning, and power distribution. In the power generation stage, the PV array generates DC electricity directly from sunlight. The generated DC must be controlled and conducted in the power conversion & conditioning stage to suit distribution requirements. This stage uses power electronic devices such as DC-DC converters and/or DC-AC inverters for processing DC from the array. The output power of PV module is nonlinear function of temperature, isolation, and thus linear control theory is not suitable for MPPT. There are a few MPPT methods presented. The “perturbation and observation” (P&O) method with fixed perturbation step, which is well known as the “hill-climbing method,” is widely applied. P&O algorithms have drawbacks such as slow response and high oscillations around MPP. However, power oscillations always appear in this method under steady state and reduce the efficiency of PV module. Some methods for avoiding the problems of the P&O method have been proposed.

This paper proposes a new method for the MPPT control of PV systems. Adaptive P&O utilizes perturb as varying perturb. Even though varying perturb is used, but still there exists oscillation around MPP. These are overcome by modified adaptive technique in which automatic tuning mechanism and control mode switching is used. Owing to changes in the solar radiation energy and the cell operating temperature, the output power of a solar array

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is not constant at all times. Consequently, during the design process a simulation must be performed for system analysis and parameter settings.

## 2. HOW A PV CELL WORKS

Solar cell consists of a p-n junction fabricated in a thin wafer or layer of a semiconductor material. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. . The commercial solar cell is made of wafer-based technology of semiconductor materials, such as Crystalline Si (C-Si) and thin film. Different types of silicon can be used to fabricate the solar cell i.e. mono-crystalline silicon, poly-crystalline silicon, and amorphous. The variation between these types is distinguished by the conversion efficiency of the PV cell. Fig. 1 roughly illustrates the

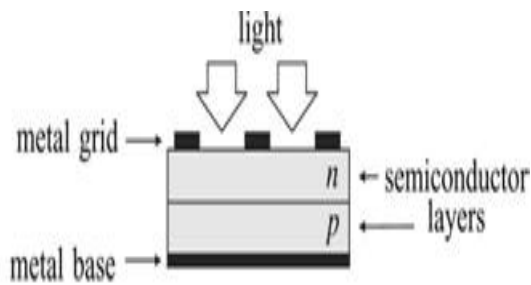


Fig.2. Structure of a PV cell

physical structure of a PV cell. . When photons from the solar energy hits the solar cell, with energy greater than band gap energy of the semiconductor, electrons are knocked loose from the atoms in the material, creating electron-hole pairs. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. The rate of generation of electric carriers depends on the flux of incident light and the capacity of absorption of the semiconductor. The capacity of absorption depends mainly on the semiconductor band gap, on the reflectance of the cell surface (that depends on the shape and treatment of the surface), on the intrinsic concentration of carriers of the semiconductor, on the electronic mobility. The solar radiation is composed of photons of different energies. Photons with energies lower than the band gap of the PV cell are useless and generate no voltage or electric current. Photons with energy superior to the band gap generate electricity, but only the energy corresponding to the band gap is used—the remainder of energy is dissipated as heat in the body of the PV cell. Semiconductors with lower band gaps may take advantage or a larger radiation spectrum, but the generated voltages are lower.

## 3. MODELLING OF PV ARRAY

PV arrays are built up with combined series or parallel combinations of PV solar cells, which are usually

represented by a simplified equivalent circuit model such as the one given in Fig. 2 and/or by an equation as in (1). A photovoltaic cell is basically a semi-conductor diode whose p–n junction is exposed to light [5], [6]. Modeling is basic tool of the real system simulation. For modeling, it is necessary to analyze the influence of different factors on the photovoltaic cells. The mathematical models for photovoltaic cells are based on the theoretical equations that describe the operation of the photovoltaic cells and can be developed using the equivalent circuit of the photovoltaic cells. The most common one is as follows.

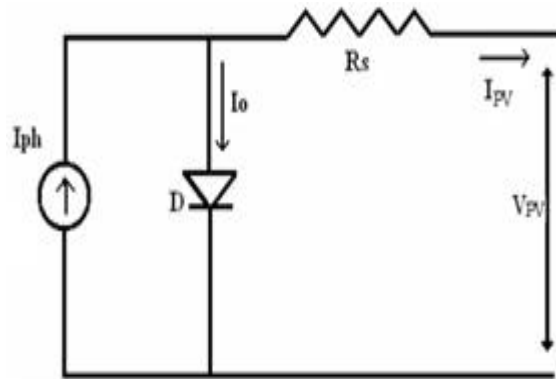


Fig.3. Equivalent circuit of PV cell

Solar cell generated current depends on the characteristic of material, age of solar cell, irradiation and cell temperature. A double exponential equation may be used for the polycrystalline silicon cells.

$$I = I_{ph} - I_s \left( \frac{\exp(q \cdot (V + IR_s))}{N \cdot K \cdot T} - 1 \right) - \frac{(V + IR_s)}{R_{sh}} \quad (1)$$

Equation (2) represents output voltage of a PV cell

$$V_{pv} = \left[ \frac{N_s A K T}{q} \right] \ln \left[ \frac{N_p \times I_{ph} - I_{pv} + N_p \times I_o}{I_o} \right] - I_{pv} R_s \quad (2)$$

Output current of a PV cell

$$I_{pv} = N_p \times I_{ph} - N_p \times I_o \left[ \exp \left\{ \frac{q \times (V_{pv} + I_{pv} R_s)}{N_s A K T} \right\} - 1 \right] \quad (3)$$

Where,

$$I_{ph} = [I_{scr} + Kt(T - 298)] \times \frac{\lambda}{100} \quad (4)$$

$$I_o = I_{or} \left[ \frac{T}{T_r} \right] \exp \left[ \frac{q \times E_{go}}{BK} \left\{ \frac{1}{T_r} - \frac{1}{T} \right\} \right] \quad (5)$$

The PV array power can be calculated using the following equation

$$P_{pv} = V_{pv} \times I_{pv} \quad (6)$$

$$P_{pv} = V_{pv} \times N_p \times I_{ph} - V_{pv} \times N_p \times I_o \left[ \exp \left\{ \frac{q \times (V_{pv} + I_{pv} R_s)}{N_s A K T} \right\} - 1 \right] \quad (7)$$

Where,

$V_{pv}$  is output voltage of a PV cell (V)

$I_{pv}$  is output current of a PV cell (A)

$N_s$  is the number of modules connected in series

$N_p$  is the number of modules connected in parallel

$I_{ph}$  is the light generated current in a PV cell (A)

$I_o$  is the PV cell saturation current (A)

$R_s$  is the series resistance of a PV cell ( $\Omega$ )

$A=B$  is an ideality factor =1.6

$K$  is Boltzmann constant = $1.3805e-23$ Nm/K

$T$  is the cell temperature in Kelvin =298K

$Q$  is electron charge = $1.6e-19$  Coulombs

$T_r$  is the reference temperature =301.18K

$I_{sc}$  is the PV cell short circuit current

$N$  = No of cells

$R_{sh}$  is shunt resistance of a PV cell

$\lambda$  is the PV cell illumination (MW/cm<sup>2</sup>)

$I_{or}$  is the saturation current at  $T_r$

$E_{go}$  is the energy band gap (ev)

Both  $k$  and  $T$  should have the same temperature unit, either Kelvin or Celsius. The curve fitting factor  $A$  is used to adjust the I-V characteristics of the cell obtained from the actual characteristics obtained by testing. Eq. (2) gives the voltage of a single solar cell which is then multiplied by the number of the cells connected in series to calculate the full array voltage. Since the array current is the sum of the currents flowing through the cells in parallel branches, the cell current  $I_C$  is obtained by dividing the array current by the number of the cells connected in parallel before being used in (1), which is

only valid for a certain cell operating temperature  $T$  with its corresponding solar irradiation level  $S_c$ . If the temperature and solar irradiation levels change, the voltage and current outputs of the PV array will follow this change. Hence, the effects of the changes in temperature and solar irradiation levels should also be included in the final PV array model. The complete behavior of PV cells are described by five model parameters ( $I_{ph}$ ,  $N$ ,  $I_s$ ,  $R_s$ ,  $R_{sh}$ ) which is representative of the physical behavior of PV cell/module. These five parameters of PV cell/module are in fact related to two environmental conditions of solar isolation & temperature. The determination of these model parameters is not straightforward owing to non-linear nature of equation.

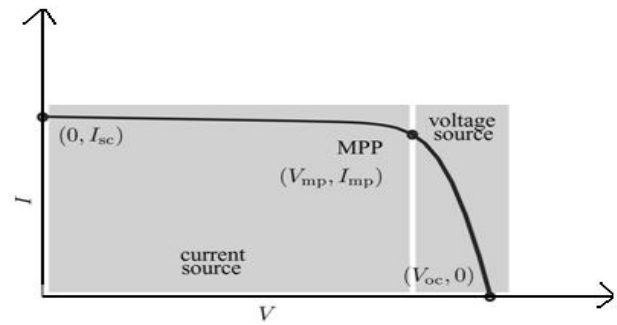


Fig.4. Maximum Power Point ( $V_{mp}$ ,  $I_{mp}$ )

Characteristic I-V curve of a practical PV device and the three remarkable points: short circuit ( $0, I_{sc}$ ), MPP ( $V_{mp}, I_{mp}$ ), and open circuit ( $V_{oc}, 0$ ). The short circuit current slightly increases with cell temperature. For practical use, PV cells can be ampere curve electrical connected in different ways: series or parallel. PV cells are first connected in series in most manufacturing methods to form PV module. Modules can be connected in different ways to form PV array. This is done for the sake of voltage/current requirement of the power conditioning units (PCU's) of the PV system.

(A) Simulation model of PV cell Based on Matlab / Simulink

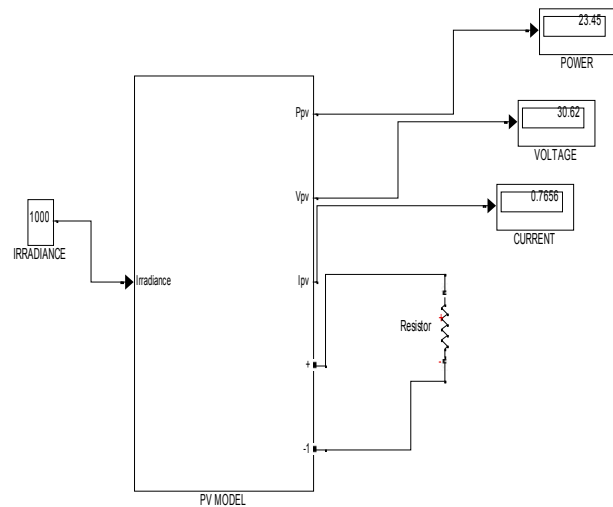


Fig.5. Simulation model of PV cell

The output characteristic of a photovoltaic (PV) array is nonlinear and is influenced by solar irradiance level, ambient temperature, wind speed, humidity, pressure, etc. The irradiation and ambient temperature is two primary factors. To study the output characteristics of PV cell, some experiments based on simulation of PV cell have been done.

For constant temperature (25°C) and different intensity (400-1000W/m<sup>2</sup>) The PV array current constant up to some voltage level and then it will be decreased. The PV array current always increases with intensity

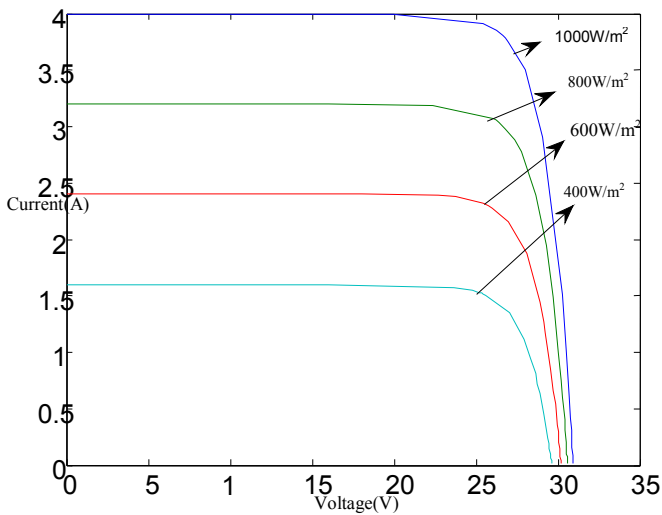


Fig6(a). I-V characteristics of Solar array for various irradiance at a constant temperature of 25°C . For constant temperature (25°C) and different intensity (400-1000W/m<sup>2</sup>) The PV array power increases up to some voltage level and then it will be decreased. The PV array power always increases with low to high intensity.

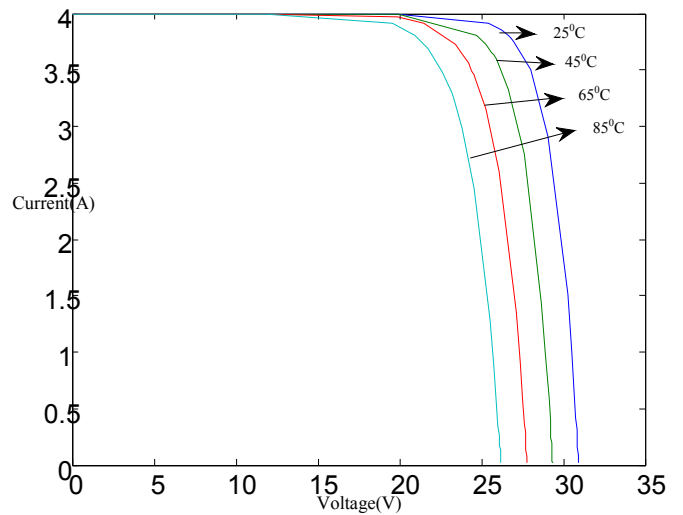


Fig7(a). I-V characteristics of Solar array for various temperature at constant irradiance of 1000W/m<sup>2</sup>.

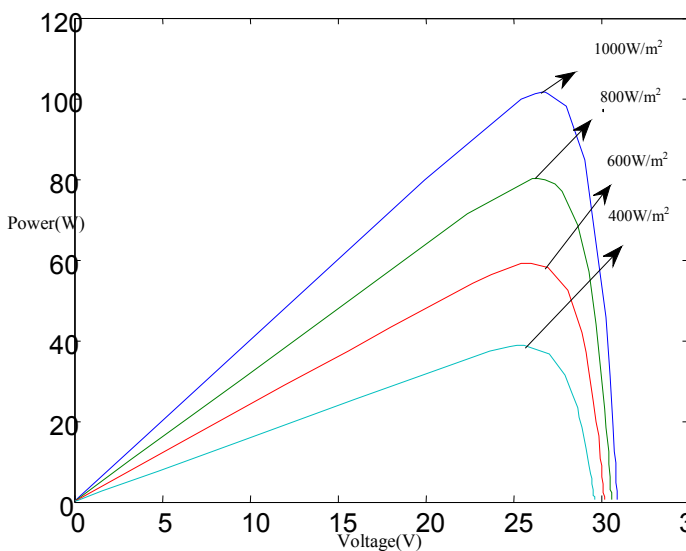


Fig 6(b). P-V characteristics of Sola array for various irradiance at a constant temperature of 25°C.

From figure.7 (a) I-V characteristics for different temperature and constant irradiance the generated power is gradually decreased and maximum power available more at low temperature.

From figure.7 (b) P-V characteristics for different temperature and constant irradiance the current is constant up to some voltage and then it will decrease gradually.

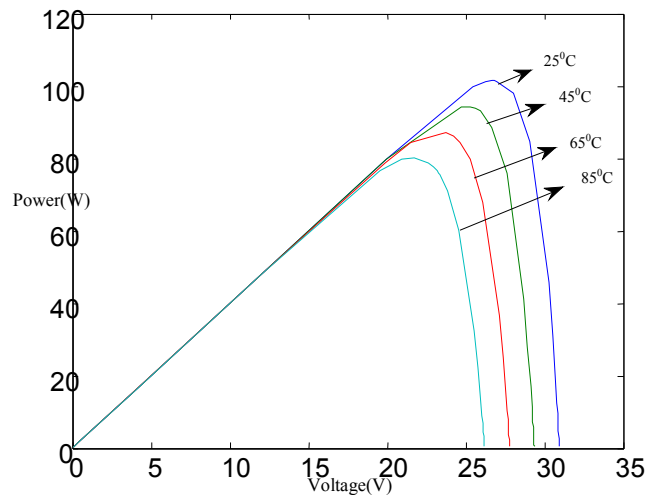


Fig7(b). P-V characteristics of Solar array for various temperature at a constant irradiance of 1000W/m<sup>2</sup>.

### 3. BOOST CONVERTER

The output voltage can be greater than the input voltage  $V_{in}$  (solar array voltage).The switch S operates at high frequencies to produce a chopped output voltage [12]. The power flow is controlled by adjusting the on/off duty cycle of the switching. The average output voltage is determined by the equation,

$$\frac{V_o}{V_{in}} = \frac{T}{T_{off}} = \frac{1}{1 - D} \tag{8}$$

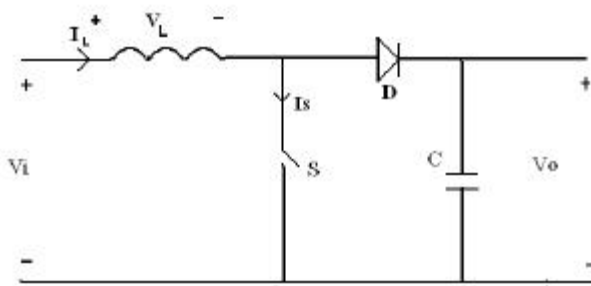


Fig.8. Boost Topology

Boost converter which boosts the voltage to maintain the maximum output voltage constant for all the conditions of temperature and solar irradiance variations. A simple boost converter is as shown in Figure9.

#### 4. MPPT TECHNIQUES

##### 4.1. Open Circuit Voltage method

This method uses  $V_{OC}$  to calculate  $V_{MP}$ . Once the system obtains the VOC value, VMP is calculated by the equation 9.

$$V_{MP} = k \times V_{OC} \quad (9)$$

The k value is typically varies from 0.70 to 0.80. It is necessary to update VOC occasionally to compensate for any temperature changes. It uses fraction of open circuit voltage to determine the modules voltage at the maximum power point. The open circuit voltage algorithm is based on the observation from V-I curves that the ratio of the array's maximum power voltage ( $V_{mp}$ ) to its open circuit voltage ( $V_{oc}$ ) is approximately constant. Here the factor is always  $<1$ . The solar array is temporarily isolated from the MPPT and a  $V_{oc}$  measurement is taken.

##### 4.2 Short Circuit Current method

The short circuit current method uses a value of ISC to estimate IMP.

$$I_{MP} = k \times I_{SC} \quad (10)$$

This method uses a short load pulse to generate a short circuit condition. During the short circuit pulse, the input voltage will go to zero, so the power conversion circuit must be powered from some other source. One advantage of this system is the tolerance for input capacitance compared to the VOC method. The k values are typically close to 0.9 to 0.98

##### 4.3 Perturb and Observe (P&O) method

A P&O method is the most simple, which moves the operating point toward the maximum power point periodically increasing or decreasing the PV array voltage by comparing power quantities between in the present and past. The block diagram of P&O method is illustrated in Fig. 9.

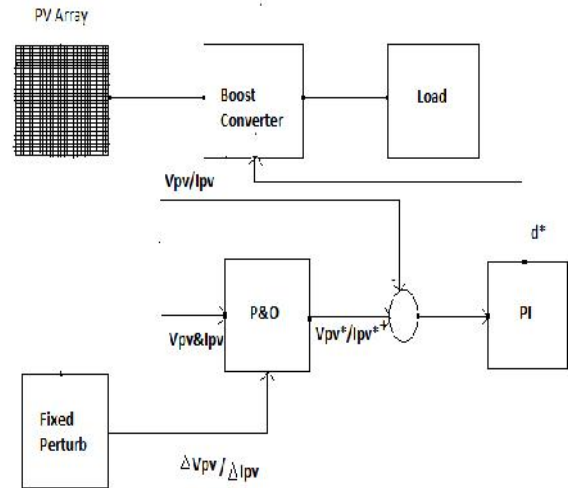


Fig.9. Block diagram of P&O MPPT

If the power increased, the perturbation is continuous in the same direction in the next perturbation cycle, otherwise the perturbation direction is reversed. This way, the operating point of the system gradually moves towards the MPP and oscillates around it in steady-state conditions. Large perturbation step sizes yield fast tracking of the MPP under varying atmospheric conditions but result in reduced average power conversion in steady state due to large oscillations around the MPP. It was proved that the P&O MPPT control system sometimes deviates from the maximum operating point in case of rapidly changing atmospheric conditions, such as broken clouds. Another disadvantage is that this simple tracking method has difficulty in providing good performance in both dynamic and steady-state responses. Hence the famous tradeoff problem between faster response and steady-state oscillations is inherent. Moreover, the perturbation is not generic. In order to overcome all this, high performance P&O technique is proposed.



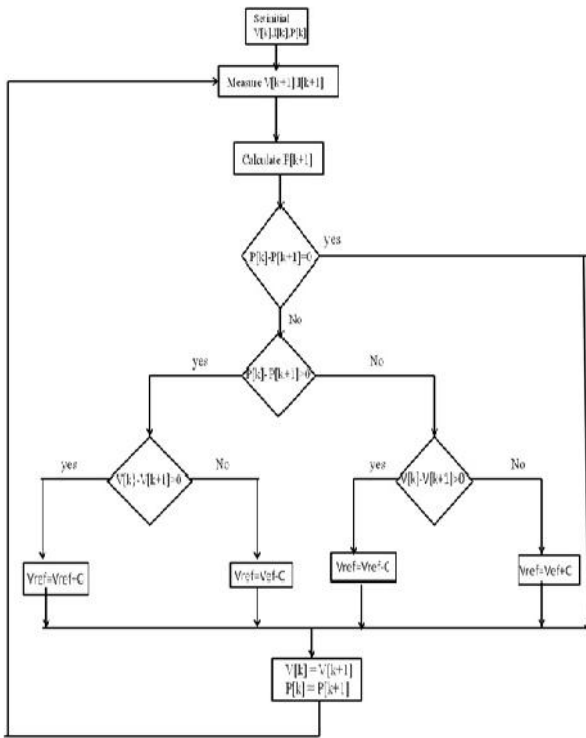


Fig10.Flow chart diagram of P&O MPPT method

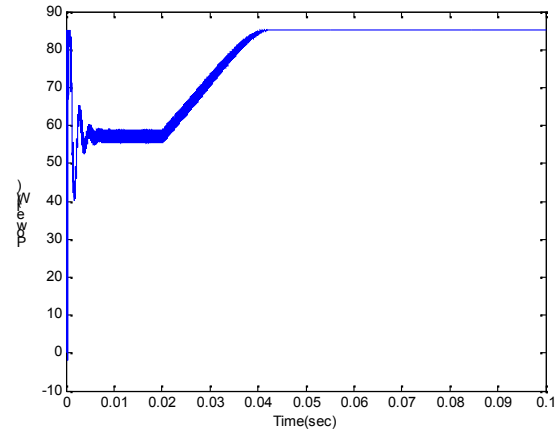


Fig11(c). PV array output power for P&O MPPT technique

The response with perturbation and observation (P&O) MPPT Technique waveforms are 11(a) PV array output current 11(b) PV array output voltage 11(c) PV array output power at temperature=25°C and solar irradiation =1000W/m<sup>2</sup>.

**4.4 Adaptive Perturbation and Observation method (AP&O)**

The main idea behind this technique is that at the start of any hill climbing technique, large perturb steps are needed to quickly reach the MPP, and as the MPP is approached, the perturb value needs to be decreased to avoid large oscillations around this maximum output power operating point. This adaptive technique utilizes the error between two successive array power signals calculated from the measured array voltage and current signals to create an adaptive perturb.

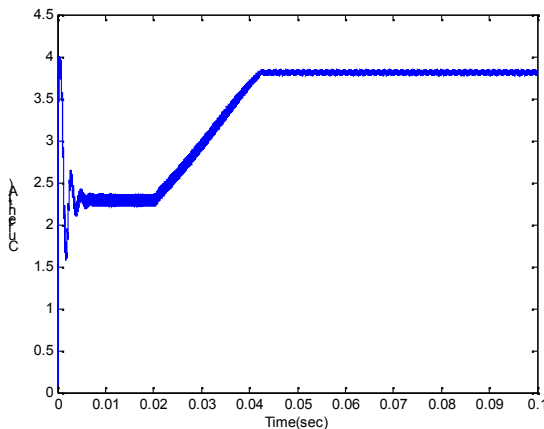


Fig11(a). PV array output current for P&O MPPT technique

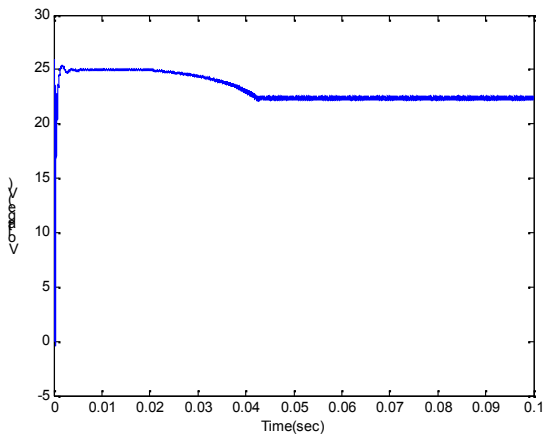


Fig11(b). PV array output voltage for P&O MPPT technique

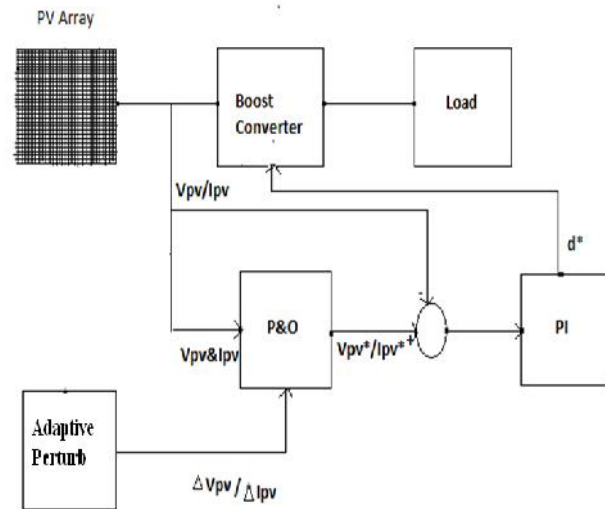


Fig. 12. Block diagram of Adaptive P&O MPPT

Basically, at the start of the hill climbing process, this error is large and decreases as the maximum power operating point is approached at steady state. Therefore, this error can

be treated like an error signal in a closed-loop system that needs to be minimized at steady state, prevented from overshoot at startup, and free from steady-state oscillations. The simplest clue to achieve all these targets is to treat this error signal using a conventional PI controller, which is the main core of this technique. Even though perturbation is adaptive, still there exists oscillations around MPP and gives slow response. The flowchart of Adaptive P&O is shown in fig (13)

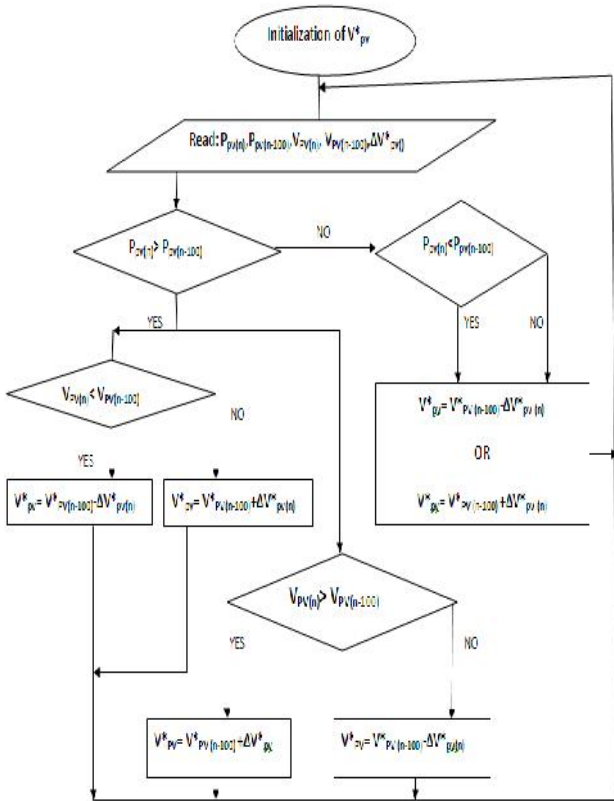


Fig13.Flow chart diagram of AP&O MPPT method

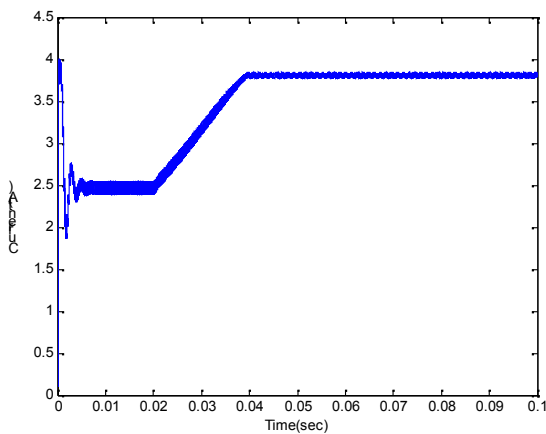


Fig14(a). PV array output current for AP&O MPPT technique

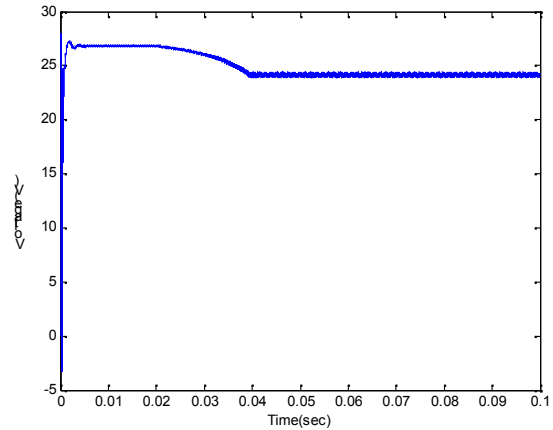


Fig14(b). PV array output voltage for AP&O MPPT technique

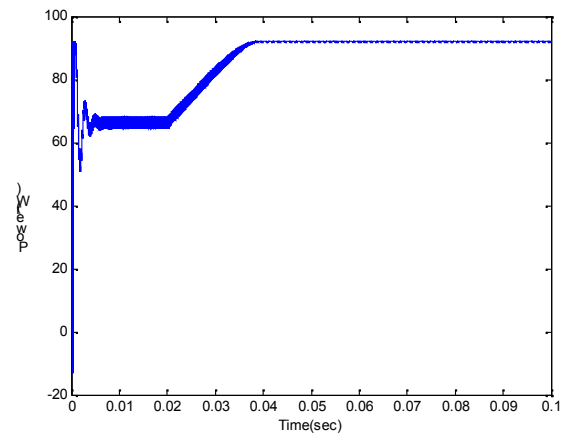


Fig14(c). PV array output power for AP&O MPPT technique

### 4.5 Modified Adaptive Perturbation and Observation method (AP&O)

A modified adaptive hill climbing (MAHC) MPPT control method is introduced based on the previous research and detailed analysis of the characteristics of PV power systems. The modifications to the traditional hill climbing method include automatic parameter tuning and Control mode switching.

#### 4.5.1 Proposed MPPT Technique

There is a tradeoff between dynamic response and steady state performance due to the selection of the incremental step of switching duty cycle. Through analysis, it is ideal to make large switching duty cycle during transient stage and small in steady state. In the proposed MAHC method, this problem is solved by the automatic tuning of parameter on-line. When the power changes in a large range primarily due to environmental variation, this tuner will change the switching duty cycle to a large value to satisfy the fast response requirement during the transient stage. When the power change is small, the controller assumes that the system enters the steady-state stage and the value of "a" becomes small to keep control signal change smooth. With this tuning mechanism, both dynamic and steady-state requirements can be considered in the controller design, because the critical parameter is updated and adjusted

adaptively. . In some specific cases, it was shown that the P&O method could cause the operating point to deviate from the optimal point during the period of rapid isolation changes. This problem could be avoided by switching the control mode. The control algorithm can be demonstrated in flow chart format shown in Fig.8, where "P" and "D" represent the PV power level and the duty cycle value respectively.

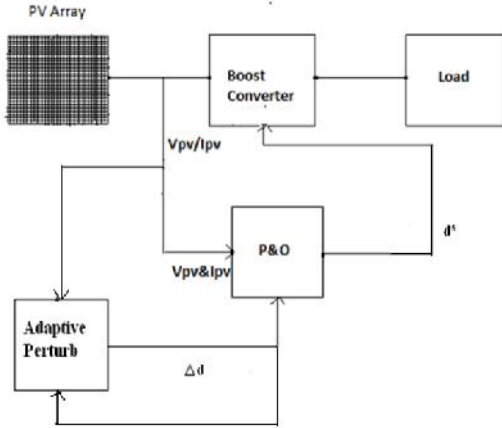


Fig15. Block diagram of MAP&O MPPT

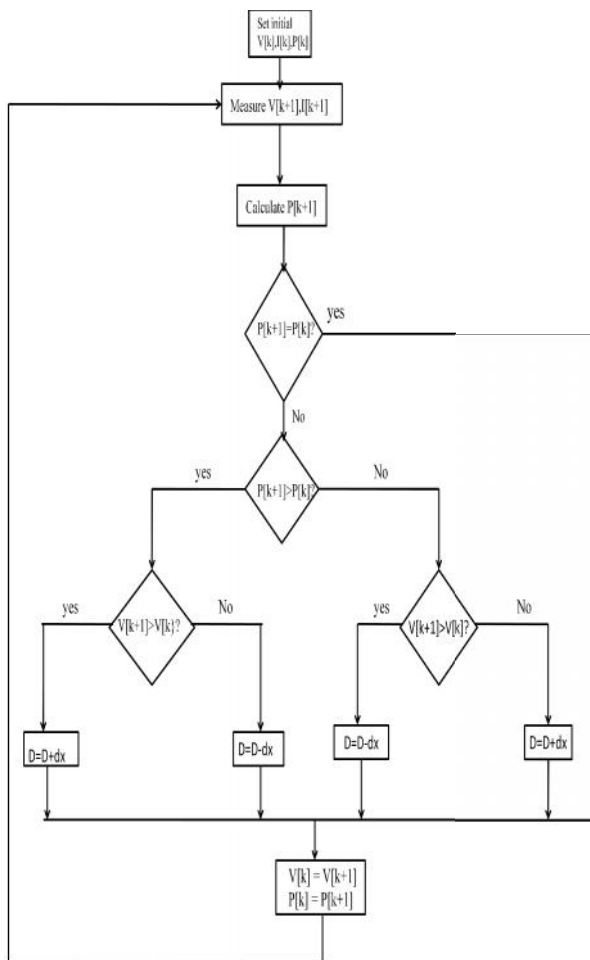


Fig16. Flow chart diagram of MAP&O MPPT method

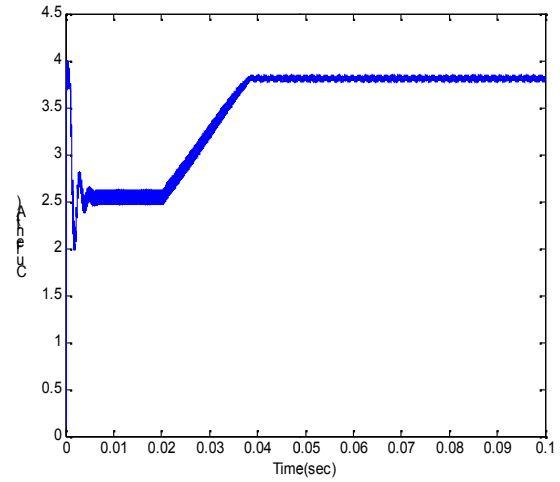


Fig17(a). PV array output current for MAP&O MPPT technique

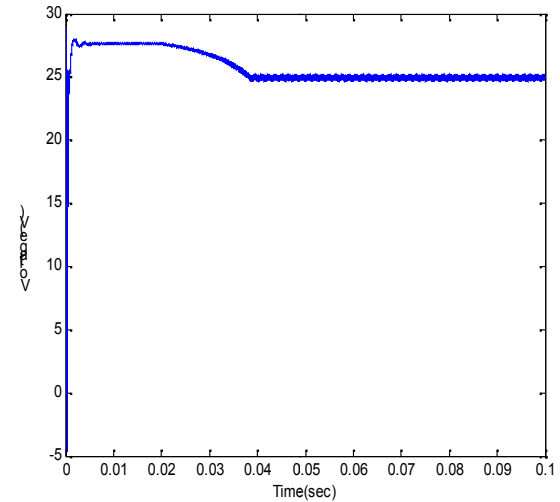


Fig17(b). PV array output voltage for MAP&O MPPT technique

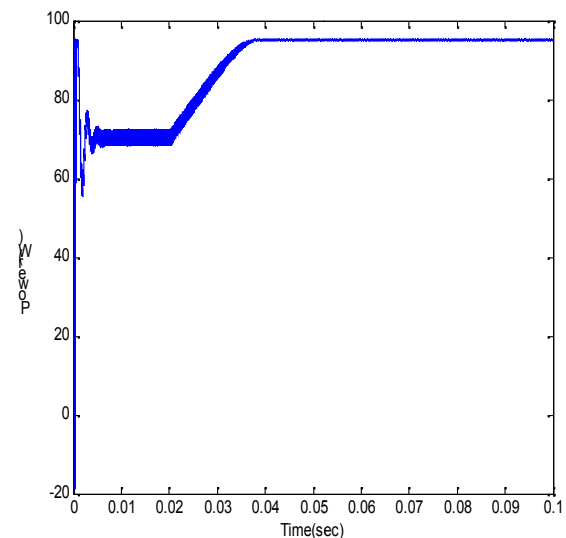


Fig17(b). PV array output voltage for MAP&O MPPT technique



S. No	MPPT Technique	Voltage (V)	Current (A)	Power (W)	Efficiency (%)
2	P & O	22.45	3.795	85.22	83.96
3	AP&O	22.42	3.801	92.05	90.68
4	MAP&O	25.03	3.799	95.09	93.68

Table5. Comparison of MPPT Techniques at a temperature of 25°C and irradiance of 1000W/m<sup>2</sup>

## 6. CONCLUSION

This paper proposes design and modeling of photo voltaic system, simple boost converter and Modified Adaptive P&O MPPT Technique. The PV cell output voltage varies with atmospheric parameters such as temperature and irradiation. In order to operate PV array at MPP, we need an interface system between PV array and load called MPPT. The OC, SC and P&O methods are simple and mostly used methods, but do not accurately track the MPP. In order to overcome the drawback of above methods Modified Adaptive P&O MPPT method is proposed, in which switching duty cycle is used as control parameter.

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