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A Review on Maximum Power Point Tracking Algorithms for Photovoltaic Source

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Abstract— ***Global Warming and energy policies have become a hot topic on the International agenda in the last years. Developed as well Developing countries are trying to reduce their greenhouse gas emission. India, to at least 33 to 35 % below 2005 levels and to produce no less than 40 % of its energy consumption from Renewable sources by 2030. In this context, photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source. Solar PV systems has low efficiency and high capital cost. To maximize the photovoltaic (PV) system's output power, continuously tracking the maximum power point (MPP) of the system is necessary. MPPT algorithms are necessary because PV arrays have non linear voltage- current characteristic with a unique point where the power produce is maximum. This paper objective is to study different MPPT algorithms for photovoltaic application.***
Keywords— Maximum Power Point Tracker, Photovoltaic Cell, Perturb & Observe, Incremental Conductance.

I. INTRODUCTION

Mass production and use of electricity generated from solar energy has become very common recently because of environmental threats arising from the production of electricity from fossil fuels. The obvious benefits of solar energy are clean energy production and infinite supply of daylight. In the last decade solar energy technologies have become less expensive and more efficient, which have made it to an attractive solution, more environmentally friendly energy resource than traditional ones. Nevertheless, a PV system is still much more expensive than traditional ones, due to the high manufacturing costs of PV panels, but the energy that drives them – the light of sun is free, available almost everywhere and will still be present for millions of years, long after all non renewable energy sources have been depleted. Photovoltaic are semiconductor devices that convert solar irradiation into electrical energy. Current versus Voltage characteristics [Fig.1] of the solar cell are non linear, thus leading to technical control challenge. The power delivered by a PV system of one or more photovoltaic cells is dependent on the irradiance, temperature and the current drawn from the cells. The efficiency of PV panels is between 8-15%, increasing the efficiency of PV panel so the power generated increases is a key aspect. By operating the PV panels at Maximum Power Point [Fig.2], will certainly put the PV panel into its optimum Utilization.

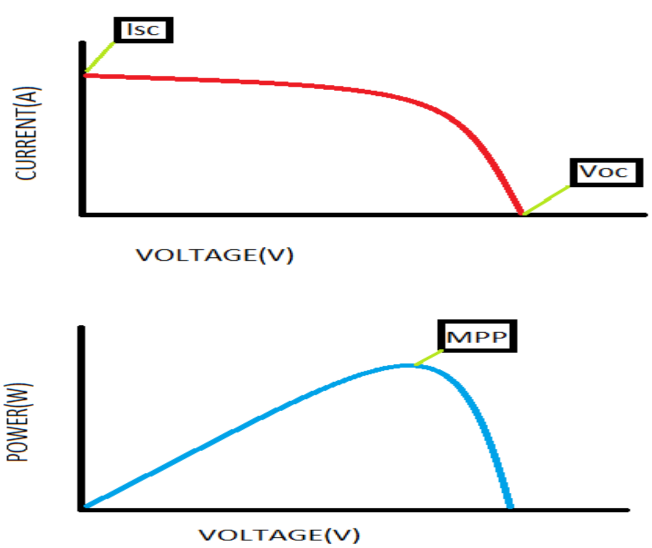

FIG.1 & 2

Two important factors that have to be taken into account are the irradiance and the temperature. They strongly affect the characteristics of solar modules. As a result MPP (Maximum Power Point) varies during the day and that is the main reason why the MPP must constantly be tracked and ensure that the maximum available power is obtained from the Panel. In the past years numerous MPPT algorithms have been published [5]. They differ in many aspects such as complexity, sensors required, cost or efficiency. However it is pointless to use a more expensive or more complicated method if with a simpler and less expensive one similar results can be obtained. A MPPT is used for extracting the maximum power from the PV module and transferring the power to the load. A DC-DC Converter (Step UP/Step Down) serves the purpose of transferring maximum power from the solar PV module to the Load. A DC-DC converter act as Interface between the PV module and load[Fig.3]. By changing the duty cycle [D], the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power.

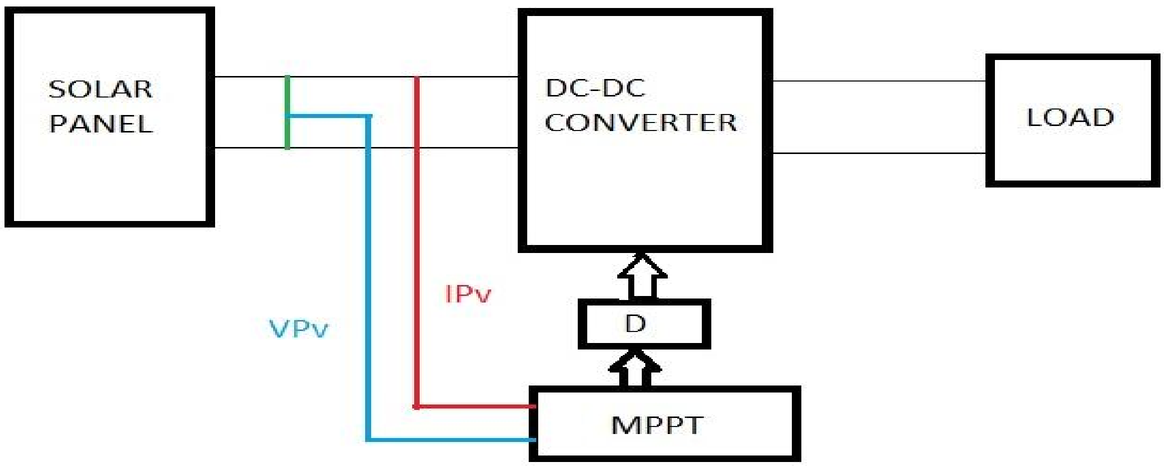

Fig. 3 Block Diagram for MPPT Scheme

II. PHOTOVOLTAIC SYSTEM

A Photovoltaic Cell or Photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon is greater than the band gap energy then electron is emitted and flow of current starts. A PV array consists of several cells connected in series and parallel combination. Cells are connected in series to increase the module voltage and in parallel to increase the current output. Typically a solar cell can be modelled by a current source and an inverted diode connected in parallel to it[Fig.4]. It has its own series resistance and parallel resistance. Series resistance is due to the hindrance in the path of flow of electrons from n to p junction and parallel resistance id due to the leakage current.

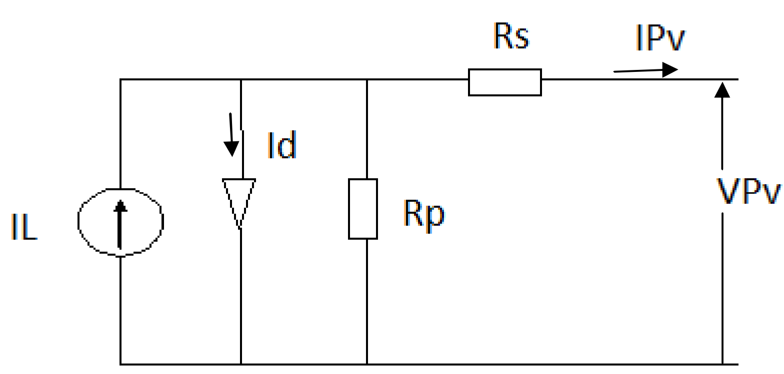

Fig. 4 Photovoltaic Equivalent Circuit

PV Output current is:

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$$IPv = IL - Io(e^{q*(VPv+IPv*Rs)\backslash a*K*T} - 1) - \frac{VPV+IPv*Rs}{Rp} \qquad \text{--- (1)}$$

Where,
IPv = PV Current output
IL = Light generated current
Io = Reverse saturation current
q = Electron Charge (1.6 $\times 10^{-19}$ C)
k = Boltzmann's constant (1.38 $\times 10^{-23}$ J/K)
a = Ideality Factor
T = Temperature (K)
Rs = Series Resistance
Rp = Parallel Resistance

Rs is the resistance offered by the contacts and the bulk semiconductor material of the solar cell. The origin of the shunt resistance Rp is more difficult to explain. It is related to the non ideal nature of the p–n junction and the presence of impurities near the edges of the cell that provide a short-circuit path around the junction [4]. In an ideal case Rs would be zero and Rp infinite. However, this ideal scenario is not possible and manufacturers try to minimize the effect of both resistances to improve their products. Two important points of the current-voltage characteristic must be pointed out: the open circuit voltage V_{OC} and the short circuit current I_{SC}. At both points the power generated is zero. V_{OC} can be approximated from (1) when the output current of the cell is zero, i.e. I=0 and the shunt resistance Rp is neglected. It is represented by equation (2). The short circuit current I_{SC} is the current at $V = 0$ and is approximately equal to the light generated current IL as shown in equation (3).

$$V_{OC} = \frac{aKT}{q} \ln\left(\frac{IL}{Io} + 1\right) \qquad \text{----- (2)}$$

$$I_{SC} = IL \qquad \text{------- (3)}$$

The photo-generated current is directly proportional to the irradiance level, so an increment in the irradiation leads to a higher photo-generated current. Moreover, the short circuit current is directly proportional to the photo generated current; therefore it is directly proportional to the irradiance. When the operating point is not the short circuit, in which no power is generated, the photo generated current is also the main factor in the PV current. For this reason the voltage-current characteristic varies with the irradiation. In contrast, the effect in the open circuit voltage is relatively small, as the dependence of the light generated current is logarithmic, as is shown in equation (3).

The temperature, on the other hand, affects mostly the voltage. The open circuit voltage is linearly dependent on the temperature, as shown in the following equation:

$$V_{OC} = V^{STC} + \frac{KV\%}{100}(T - 273.15) \qquad \text{----- (4)}$$

According to (4), the effect of the temperature on VOC is negative, because Kv is negative, i.e. when the temperature rises, the voltage decreases. The current increases with the temperature but very little and it does not compensate the decrease in the voltage caused by a given temperature rise. That is why the power also decreases. PV panel manufacturers provide in their data sheets the temperature coefficients, which are the parameters that specify how the open circuit voltage, the short circuit current and the maximum power vary when the temperature changes.

As was mentioned before, the temperature and the irradiation depend on the atmospheric conditions, which are not constant during the year and not even during a single day; they can vary rapidly due to fast changing conditions such as clouds. This causes the MPP to move constantly, depending on the irradiation and temperature conditions. If the operating point is not close to the MPP, great power losses occur. Hence it is essential to track the MPP in any conditions to assure that the maximum available power is obtained from the PV panel. In a modern solar power converter, this task is entrusted to the MPPT algorithms.

III. MPPT ALGORITHMS

Over the past decades many methods to find the MPP have been developed and published. A complete review of 19 different MPPT algorithms can be found in [5]. In this section the most popular MPPT techniques are discussed.

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A. Hill- Climbing Techniques

Hill – climbing principle consists of moving the operation point of the PV array in the direction in which power increases [4 and 6]. Hill- climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant [6]. Hill- climbing technique includes two methods, namely Perturb & Observe method and Incremental Conductance method. The advantages of both the methods are the simplicity and low computation power they need.

1) *Perturb and Observe Method:* The Perturb and Observe (P&O) algorithm is also called " hill – climbing", but both names refer to the sane algorithm depending on how it is implemented. Hill-climbing involves perturbation to the Duty Cycle of the Power Converter and P&O a perturbation in the operating voltage of the Dc link between the PV array and the Power Converter [5]. In case of the Hill-Climbing, perturbing the duty cycle of the converter implies modifying the voltage of Dc link between the PV array and the Power converter, so both names refer to the same technique. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. If there is increment in the power, the perturbation should be kept in the same direction and if the power decreases, , then the next perturbation should be in the opposite direction.

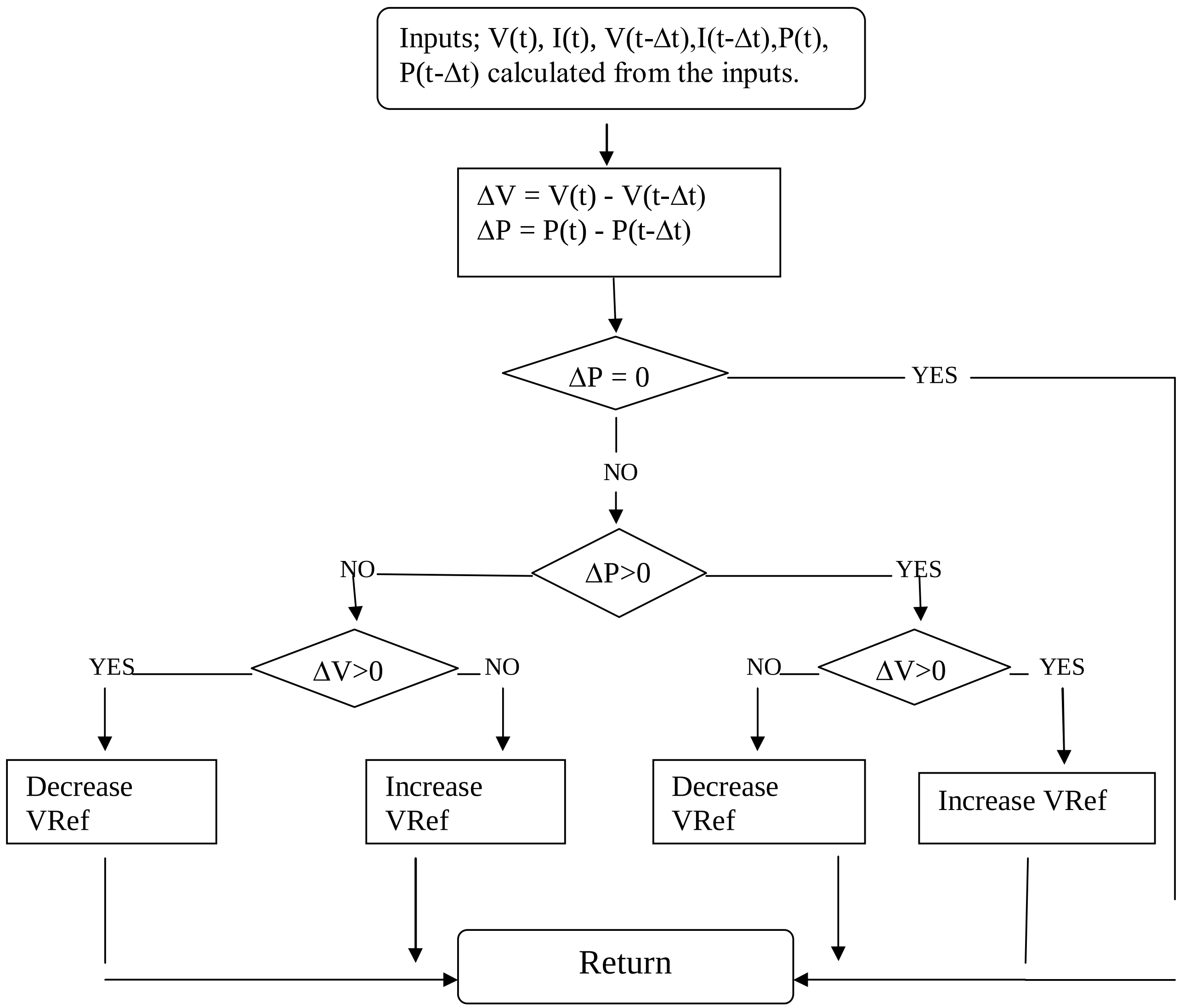

Fig.5 The flow chart of Perturb & Observe Algorithm

There is a misjudgement phenomenon for the P&O method when weather conditions change rapidly. From the diagram shown in fig 6, the starting point is point A, and a + ΔV voltage perturbation will move the operating point from A to B and cause a operating point from A to B and cause a condition is steady. According to the judgment rules of the P&O method, the next perturbation should

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be changed to $-\Delta V$ in the opposite direction. However, if the sun irradiance increases in one sampling period, the power curve will be moved from $P1$ to $P2$, and the operating point will be moved from A to C instead of A to B. This results in the power to be increased continuously, and the voltage perturbation still moves toward $+\Delta V$ direction. The operating point is then farther away from the maximum power point. If the sun irradiance continuously increases, the distance between operating point and maximum power point will be farther. Consequently, the power loss of PV modules will increase, and the efficiency of the PV system will reduce.

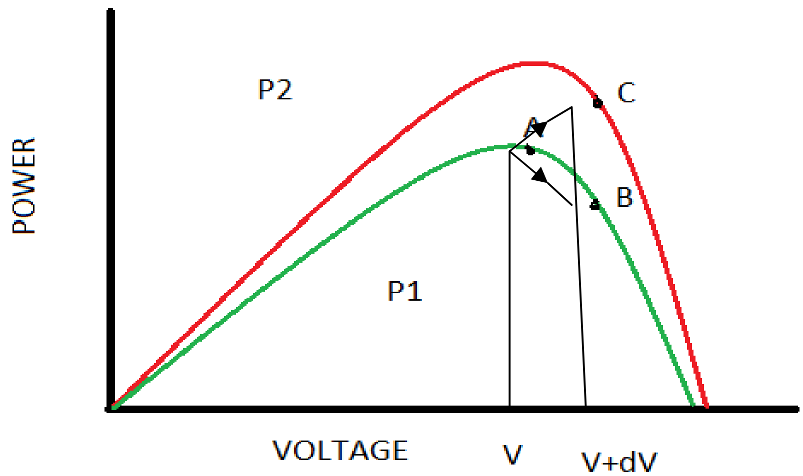

Fig.6 The separation diagram of maximum power point for the P&O method

1) *Incremental Conductance Method:* The theory of the incremental conductance method [9-13] is to determine the variation direction of the terminal voltage for the PV modules by measuring and comparing the incremental conductance and instantaneous conductance of PV modules. If the value of incremental conductance is equal to the instantaneous conductance, it represents that the maximum power point is found. The basic theory is shown in fig. 7.

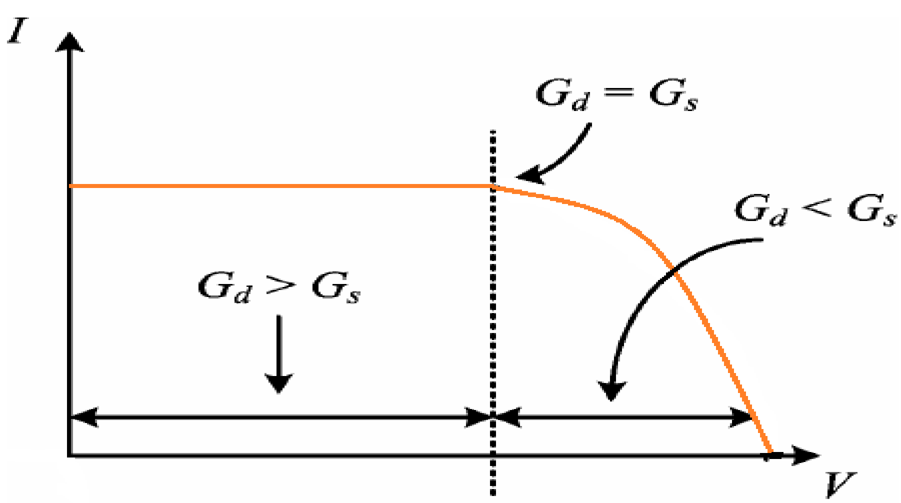

Fig. 7 The Schematic Diagram of the Incremental Conductance Method

When the operating behaviour of PV Modules is within the constant current area, the output power is proportional to the terminal voltage. That means output power increases linearly with the increasing terminal voltage of PV modules i.e. $\frac{dP}{dV} > 0$. When the operating point passes through the maximum point, its operating behaviour is similar to constant voltage. Therefore output power decreases with the terminal voltage, i.e. $\frac{dP}{dV} < 0$. When the operating point reaches to the Maximum Point, slope becomes zero, i.e. $\frac{dP}{dV} = 0$. Further as

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \qquad \text{--- (5)}$$

By the relationship of $\frac{dP}{dV} = 0$, we have $\frac{dI}{dV} = -\frac{I}{V}$

dI and dV represent the current error and voltage error respectively. The static conductance (G_s) and dynamic conductance (G_d) of PV modules is defined as

$$G_s = -\frac{I}{V} \text{ and } G_d = \frac{dI}{dV}$$

The maximum power point can be found when $G_s = G_d$.
In both P&O and Incremental conductance methods, how fast the MPP is reached depends on the size of the increment of the reference voltage.
The drawbacks of these techniques are mainly two. The first and main one is that they can easily lose track if the irradiation changes rapidly [2, 3, 6 and 7].In case of step change they track well, because the change is instantaneous and the curve does not keep on changing. The other one is the oscillations of the voltage and current around the MPP in the steady state [2, 3, 8 and 14]. This is due to the fact that the control is discrete and the voltage and current are not constantly at the MPP but oscillating around it. The size of the oscillations depends on the size of the rate of change of the reference voltage.

To overcome these drawbacks some solution has been published in recent years. Regarding the rapid change of irradiation conditions, Sera et al . published in [6 and 7] an improved P&O method, called "dp – P&O", in which additional measurement is performed without perturbation in the voltage and current.

B. Fractional Open Circuit Voltage

This method uses the approximately linear relationship between the MPP Voltage (V_{MPP}) and the open circuit voltage (V_{OC}), which varies with the irradiance and the temperature [5].

$$V_{MPP} \cong K_1 V_{OC}$$

Where K_1 is a constant depending on the characteristics of the PV array and it has to be determined beforehand by determining the V_{MPP} and V_{OC} for different levels of irradiation and temperatures. According to [5] the constant K_1 reported to be between 0.71 and 0.78.
Once the constant of proportionality K_1 is known, the MPP voltage V_{MPP} can be determined periodically by measuring $V_{OC.}$ To measure V_{OC} the power converter has to be shut down momentarily so in each measurement a loss of power occurs. Another problem of this method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of V_{MPP} is not continuous. One more disadvantage is that the MPP reached is not real one as the relationship is only an approximation.
To overcome these drawback some solutions have been proposed, as is reported in [5].

C. Fractional Short Circuit Current

There is relationship between short circuit current and the MPP current (I_{MPP}).

$$I_{MPP} \cong K_2 I_{SC}$$

The coefficient of proportionality K_2 has to be determined according to each PV array. According to [5], the constant K_2 has been reported to 0.78 and 0.92.

Measuring the short circuit current while the system is operating is a problem. It usually requires adding an additional switch to the power converter to periodically short the PV array and measure I_{SC} . Furthermore, K_2 changes if the PV array is partially shaded, which happens due to shades or surface contamination. To overcome this problem, proposes an online tuning of k2 and a periodical sweep of the PV voltage from open circuit to short circuit to update k2 and guarantee that the real MPP is reached in the presence of multiple maxima which obviously increases the complexity of the system. Most of the literature using this MPPT technique uses a DSP as controller [5].

D. Current Sweep

In this method the I-V characteristic curve is obtained using a sweep waveform for the PV array current. The sweep is repeated at fixed time intervals so the I-V curve is updated periodically and the MPP voltage (V_{MPP}) can be determined from it at these same intervals. How the I-V curve is determined and the function chosen for the sweep waveform.

With this method the real MPP is obtained. On the other hand, the sweep takes certain time during which the operating point is not the MPP, which implies some loss of available power. Strictly speaking, it is not possible to track the MPP under irradiation slopes, because the MPP varies continuously. Only if the sweep is instantaneous the global MPP could be found, but that is impossible.

E. Maximum Power Point Current and Voltage Computation

I_{MPP} and V_{MPP} computation is a technique in which the MPP is calculated based on the measurements of the irradiance and the temperature using a model of the PV module[5]. The drawbacks are the extra measurements needed, which are sometimes difficult to obtain, and the necessity of an accurate model of the PV array. On the other hand, the MPP is correctly tracked even under changing atmospheric conditions. It can be used in large plants, where the economic investment is huge and a perfect tracking is needed to obtain the maximum available power from the solar arrays.

IV. CONCLUSIONS

The main objective of this paper is to study different MPPT algorithms for PV cell model. There are many approaches to finding and tracking the maximum power point for the PV cells and group of cells. Many systems will combine methods, such as using V_{OC} to find the starting point for the iterative methods like P&O, Incremental conductance. In some cases changing from one method to another is based on the level of irradiance. At low levels of irradiance, methods like Open Circuit Voltage and Short Circuit Current may be more appropriate as they can be more noise immune. For P&O method, the basic advantage is that when it is properly optimized it can offer very high Maximum Power Point Tracking efficiency, which is highly competitive against other Maximum Power Point Tracking algorithms.

V. ACKNOWLEDGMENT

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