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Maximum Power Point Tracking Techniques for Photovoltaic Systems - A Review

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Abstract - *Photovoltaic energy has become one of the popular area in the field of electrical power system, due to rapid developments in the field of power electronics. The solar energy is clean, easily available, pollution free and unlimited. But there are two main drawbacks with PV plants, the high cost of PV cells and their conversion efficiency. In the I-V characteristics of PV module which is non-linear but has a unique maximum power point. To increase or to maximize the output power of photo-voltaic system Maximum power point tracking (MPPT) techniques are used. These techniques give maximum output power, irrespective of the irradiation condition, temperature and load electrical characteristics. For the purpose of tracking the maximum power the MPPT techniques use some electronic converters. In this paper, various algorithms used in MPPT for Photovoltaic (PV) systems has been studied and compared.*

Key Words: **Photo-voltaic (PV), Maximum power point tracking (MPPT), Perturb and observe (P&O), Incremental conductance (INC), Fractional open circuit voltage (FVOC).**

1. INTRODUCTION

PV solar cell converts sunlight into electricity. Since, the generation from PV systems has two major problems: the low efficiency of conversion of electric power and high cost of PV cell. As the generation of PV system depends on the weather condition so under low irradiation conditions the efficiency of conversion is 9-16% [2]. The solar cell V-I characteristic is nonlinear as shown in fig. 1 and changes with irradiation, temperature given in fig. 3 & fig. 4 and load impedance where irradiation and temperature are dynamic. The maximum power point location continuously change and not known, but can be located by calculation models or by search algorithms. Hence Maximum Power Point Tracking (MPPT) techniques are basically used to maintain the PV array's operating point at the Maximum Power Point [3].

There are so many MPPT techniques that have been already proposed in the literature; for example the Perturb and Observe (P&O), the Incremental Conductance (IC), Fractional open-circuit voltage (FVOC), fractional short circuit current (FSC), Neural network, Fuzzy logic control, etc.

Usually, The PV modules used commercially are having efficiency between 6 to 16% and the variation in their efficiency depends on the technology used [1], [2], [10]. There are mainly two techniques to get high conversion efficiency. The first one is based on both electrical and mechanical (electro-mechanical) equipments also known as sun trackers which are helpful to track the best position for solar PV module during the operating time. And the second one is totally based on electrical equipments which are helpful to vary the electrical parameters at the output of the solar PV module because of which the PV module allows to operate in the optimal operating point [1]. Fig. 2 shows a basic MPPT system.

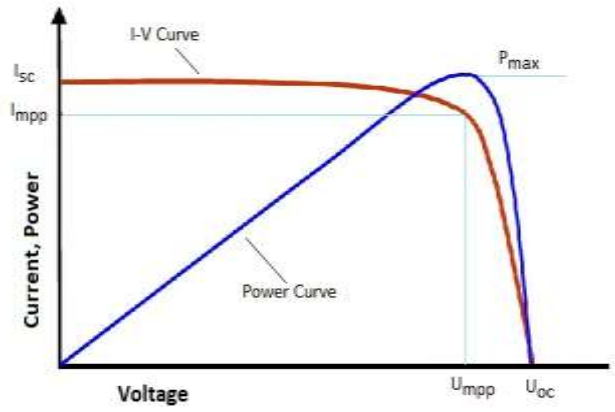

Fig -1: Power-voltage and current-voltage curve.

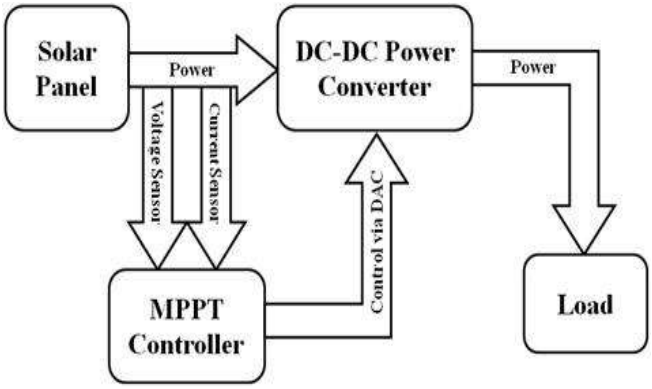

Fig -2: Block diagram of a MPPT controlled PV system.

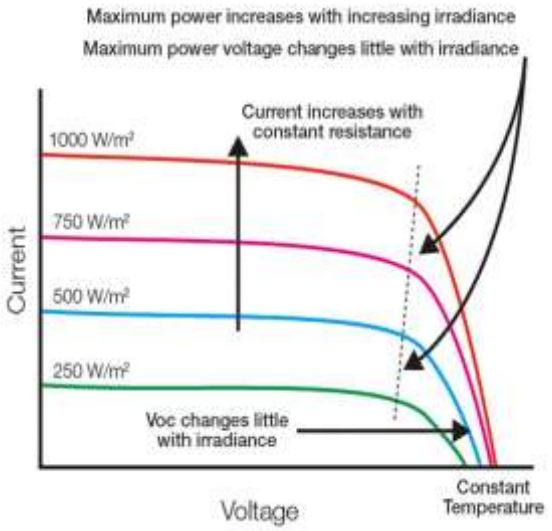

Fig -3: Current–voltage characteristics of a PV module for different radiation levels at constant cell temperature.

It is clear from fig. 3, the output power of PV module is directly proportional to the irradiation and fig. 4 shows that the output power of PV array is inversely proportional to the temperature.

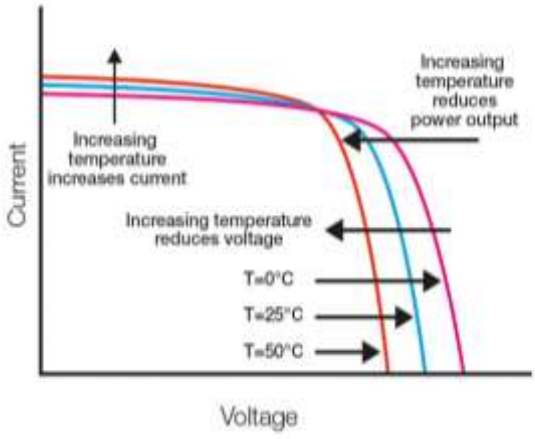

Fig -4: Power–voltage and current–voltage characteristics of a PV module for different cell's temperature at constant radiation level.

2. MPPT TECHNIQUES - AN OVERVIEW

The main aim in MPPT system is to control the duty cycle (D) of the converter used source side. In the source side we use a convertor that is connected to a solar panel in order to enhance the output voltage and by changing the duty cycle of the converter appropriately the source impedance can be matched with the load impedance.

Among all MPPT techniques, the MPPT techniques which are to be discussed in this paper are:

1. Hill climb search,
2. Incremental conductance,
3. Fractional open circuit voltage,
4. Fractional Short Circuit Current,
5. Other Intelligent Control Methods.

2.1 Hill climb search (HCS) MPPT algorithm

The Hill climb search (HCS) MPPT algorithm is also called perturbation and observation (P&O) MPPT algorithm. In Perturb-and-observe algorithm method, we only use one sensor and hence it is very easy to implement. Voltage sensor used, senses the PV array voltage and so the cost of implementation is less among all other MPPT algorithm.
The Perturb-and-observe algorithm for maximum power point tracking is simplest techniques among all the MPPT techniques in literatures. 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.
From fig. 1, 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. 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 $dP/dV = 0$ reached (maximum power point) [1], [3], [4], [9].

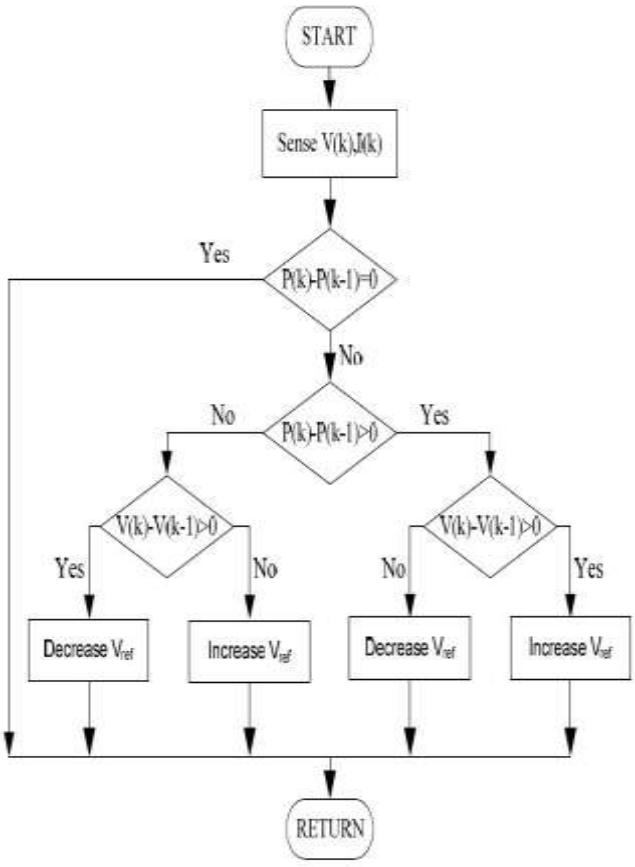

Fig -5: Flowchart of P&O method.

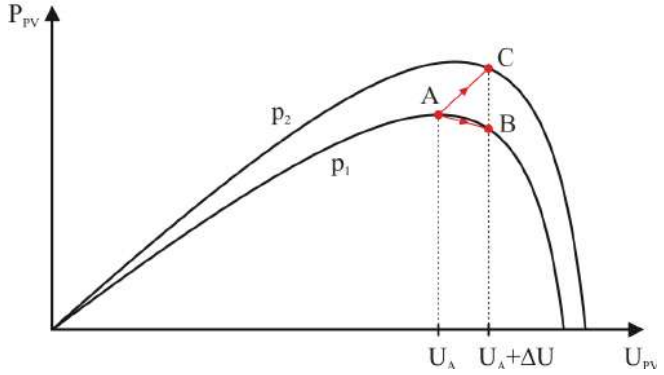

Fig -6: Divergence of P&O from MPP.

Under sudden changing atmospheric conditions P&O method does not respond well as illustrated in figure 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 P1 to P2 due to increase in irradiance the operating point will change from A to C. Now there is 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 [3], [4] and hence calculates the wrong MPP. To avoid this problem we can use incremental conductance method to track MPP correctly even under rapid change in irradiance.

2.2 Incremental conductance (INC) MPPT algorithm

INC is commonly used for solar PV MPPT. The incremental conductance method is based on the fact that the slope of the P vs. V (I) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right of MPP. This technique deals with the sign of dP/dV without a perturbation which overcome the limitations of P&O technique [5].

dP/dV > 0 left side of the curve
dP/dV < 0 right side of the curve
dP/dV =0 peak of the curve

The above expressions can be expressed as (shown in fig. 8):

$$\frac{dP}{dV} = \frac{d\,(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \qquad (1)$$

For MPP by putting $\frac{dP}{dV} = 0$, we get,

$$I + V\frac{\Delta I}{\Delta V} = 0$$

Hence,

ΔI/ΔV= -I/V , At MPP
ΔI/ΔV > - I/V, Left of MPP
ΔI/ΔV < - I/V, Right of MPP

Where,

I/V is instantaneous conductance,
ΔI/ΔV is incremental conductance,
VREF is reference voltage at which PV array is to be operated.

According to above equations the maximum power point of PV array can be tracked by comparing the I/V to ΔI/ΔV as shown in the flow chart (fig. 7).

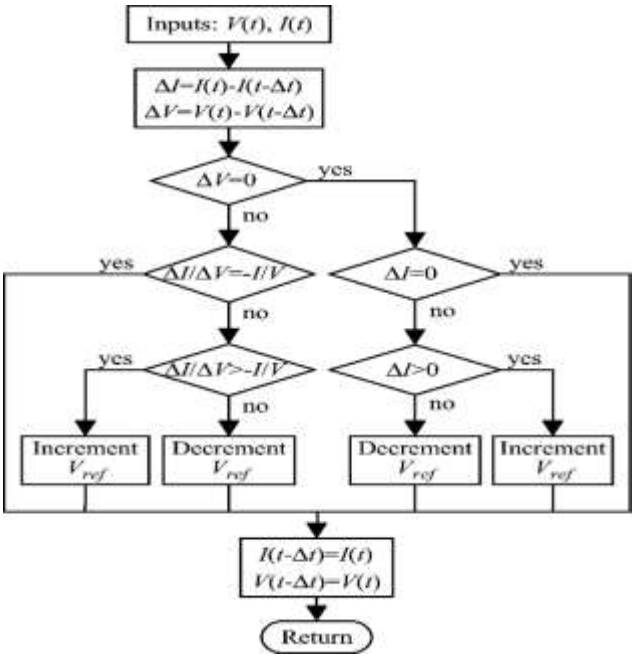

Fig -7: Flow chart of Incremental Conductance method.

When the MPP is achieved at that instant VREF must be equal to VMPP. And once it happens the operation is maintained at MPP until a change in ΔI is occur or the change in atmospheric conditions. The INC algorithm is continuously decreases or increases the VREF to maintain the new MPP. This method has advantages over P&O method like INC technique can track rapid change in atmospheric conditions. Also this technique determines when it has reached the MPP whereas the P&O technique oscillates around the same point [1], [2], [4]-[6], [11].

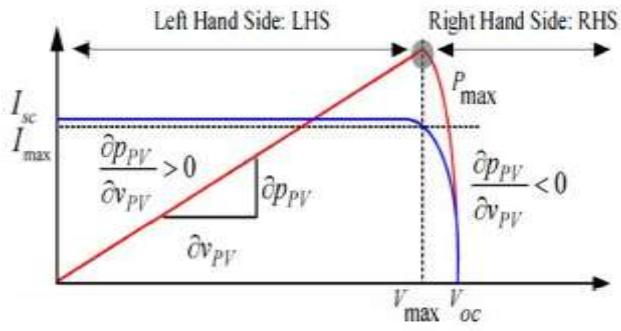

Fig -8: I-V and P-V curve and maximum power point of PV module.

2.2 Fractional open circuit voltage (FVOC) MPPT algorithm

The Fractional open circuit voltage (FVOC) method of maximum power point tracking based on the near linear relationship between the maximum power point voltage (VMPP) and open circuit voltage (VOC) PV array [4].

$$V\_MPP \approx K\_1 V\_OC \quad (2)$$

Where, k1 is proportionality constant and the value of k1 is dependent on the characteristics of the solar cell being used. Its value is usually between 0.71 and 0.78 i.e. the ratio VMPP/VOC will be up to 78% [5].

VMPP can be calculated easily using the known value of k1 with the help of (2) with measured value of VOC periodically by shutting down the converters for a very short time which results the temporary loss of power.

The problem of power loss can be overcome by using pilot cells from which VOC can be taken. The major problem with FVOC algorithm is the wastage of available energy when the power converter is getting disconnected from load. And another problem is value of k1 is not constant, it varies according to the PV parameters [4], [5].

2.3 Fractional Short Circuit Current MPPT algorithm

It is same as fraction open circuit, but here the relationship is between MPP current (IMPP) and short circuit current (ISC) for varying atmospheric conditions.

$$I\_MPP \approx K\_1 I\_sC \quad (3)$$

The coefficient of proportionality k' is obtained according to each PV array. Its value varies between 0.78 and 0.92. To measure ISC, an additional switch to power converter is required to periodically short the PV array.

2.4 Other Intelligent Control Methods

Neural network and fuzzy logic based control are used for complex nonlinear systems. Therefore, these intelligent control approaches are frequently used to represent complex plants and construct advanced controllers [12]. The fuzzy logic controller (FLC) does not require any mathematical modelling and instead its operation is based on a set of rules derived from the system behaviour. The rules are designed such that the controller always traces maximum power point without any knowledge of system. Thus, FLC is a suitable tool for small PV system. Some other notable advantages of the fuzzy logic controller are its simplicity, robustness and computational speed [13].

Over the classical controllers for maximum power extraction Artificial Neural Network (ANN) based controller is a fast and reliable option. Neural network and fuzzy logic comes under Soft Computing. The logic of neural network is motivated by the sophisticated functionality of human brain where hundreds of billions of interconnected neurons process information in parallel.

The input variables can be the parameters of the PV array such as VOC and ISC, atmospheric data such as temperature and irradiation or combination of all these. The output is usually one or more reference signals like the DC-link reference voltage or the duty cycle. The performance of the NN depends on the functions used by the hidden layer and how well the neural network has been trained. The weights are adjusted in the training process. For this, data is recorded for a period of time, so that the MPP can be tracked accurately.

The main disadvantage of this MPPT technique is that as the characteristics of the PV array vary depending on the model and the atmospheric conditions depend on the location, the data needed for the training process has to be acquired for every PV array and location.

3. COMPARISON OF MPPT TECHNIQUES

Table -1: Comparison of MPPT techniques according to several parameters

Parameters	Techniques						
	P&O	***INC***	***FVOC***	***FIsc***	***Fuzzy logic control***	***Neural network***	***Particle Swarm Optimization***
Convergence speed	Varies	Varies	Medium	Medium	Fast	Fast	Fast
Implementation complexity	Low	Medium	Low	Medium	High	High	Medium
Periodic tuning	No	No	Yes	Yes	No	No	No
Efficiency (%)	Medium	Medium	Low	Low	Very High	Very High	High
Sensed parameters	V & I	V & I	V	I	Varies	Varies	Varies

Analog or Digital Control	Both	Digital	Both	Both	Digital	Digital	Digital
True MPPT	Yes	Yes	No	No	Yes	Yes	Yes
Cost	Moderate	Moderate	Cheap	Cheap	Expensive	Expensive	Expensive
Control Strategy	Sampling	Sampling	Indirect	Indirect	Probabilistic	Probabilistic	Probabilistic
Stability	Not Stable	Stable	Not Stable	Not Stable	Very stable	Very stable	Very stable

4. CONCLUSION

From many years researchers and scientists are working on renewable energy sources. MPPT is the technique for increasing the output efficiency and mainly used for solar system and play vital role in electrical energy generation. In this study, general classification and descriptions of the most widely used seven MPPT techniques are analyzed and compared to point out the advantages and drawbacks of various MPPT methods. This paper is helpful for selecting a MPPT technique depending upon various constraints as given in the table. In practice, the most widely used techniques are P&O and INC due to their simple structures and low cost.

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