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Review of the modern techniques of Maximum Power Point Tracking for the solar photovoltaic systems

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ABSTRACT
The energy generation of a solar photovoltaic (SPV) system is directly dependent on solar radiation intensity and its availability. The energy generation from the PV module is also affected due to climatic parameters such as ambient temperature, humidity, rainfall, wind and dust. To extract the maximum power from PV array Maximum Power Point Tracking (MPPT) technique is applied. At varying operating conditions, MPPT algorithms automatically detect the maximum power and supply to the load. In the present paper ten different MPPT techniques have been identified and analyzed. These different techniques have been well developed in the papers individually. In the present study a comprehensive review of popular MPPT techniques is presented.
Keywords – Solar PV module, Maximum Power Point Tracking, Temperature, Converter.

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I. INTRODUCTION

Over the past several years, the climatic conditions of the earth have changed drastically. It could have direct and indirect results for electricity need in numerous regions of the globe over the several decades [1]. Moreover, the world's energy supply is still dominated by fossil fuels and they are primarily considered as rich sources in releasing greenhouse emission [2]. It is hard to both for developed and developing countries to overcome the social and economic importance of energy. Therefore, it is a key challenge in sustainably having energy supplies for extended energy consumption patterns due to human activity. In recent years, many countries have established targets for tackling the climate changes issues associated with energy use by shifting to the renewable energy power generation [3]. Among the renewable energies, solar energy has picked up momentum due to its resource availability in abundance and on the other side, accelerated depreciation in prices of solar PV electricity [4]. The government policies, rising rates of grid electricity and technological development in solar cell technology have encouraged to produce the electricity through the solar PV technology [5].

The solar photovoltaic panel directly transforms solar radiation into electricity through photovoltaic principle [6]. During on-field operation, the performance of PV panels affects by many climatic parameters such as temperature, humidity, wind velocity, soiling and cloud conditions. Due to the effect of these parameters, the output of the PV panel shows nonlinear behavior [7]. It is crucial to operate a PV panel at its maximum power point condition to achieve the maximum yield. Presently, it is achieving by apply proper tracking mechanism. Two type of tracking mechanism is available first mechanical and second electrical. In mechanical tracking, by using a mechanical system in PV system, the solar panels are always directed in such a way so that they can receive maximum solar radiation under changing positions of the sun. In an electrical tracking, to get the maximum output power the operating point is tuned to maximum power point (MPP) under changing conditions of temperature and insolation [8].

MPPT is a tracking electronic device which consist a DC to DC converter which is used for optimizing the match between the PV array and the utility grid or battery bank. In simple words, its function is to convert a higher voltage DC output from the PV panels (and a few wind generators) to the lower voltage required to charge batteries. MPPT does not move the modules physically like the mechanical tracking system to make modules more straight towards the sun. MPPT is completely an electronic system that adjusts the electrical operating point of the PV modules so that the PV modules can generate maximum power for the available solar radiation [9].

II. OUTPUT OF PV CELL

A photovoltaic cell is simulated using single diode model as shown in Fig. 1. The model consists of a current source (I_{Ph}) depends upon the solar radiation directly falling on it, diode current (I_D), and a series resistance (R_S). By applying

Kirchhoff's current law, generated current of solar cell can be expressed as [10]:

$$I_C = I_{Ph} - I_D \quad (1)$$

The diode current (I_D) of equation (1) is given by Shockley equation.

$$I_C = I_{Ph} - I_O \exp\left[\frac{(V_C + R_S T_C)}{AkT_C} - 1\right] \quad (2)$$

V_C is the output voltage of the PV module that can be expressed as:

$$V_C = \frac{AkT_C}{q} \ln\left(\frac{I_{Ph} + I_O - I_C}{I_O}\right) - I_C R_S \quad (3)$$

where Io is the reverse saturation current of the diode, R_S is the series resistance and calculates in ohm. q is the charge of the electron (1.602×10^{-19} C), A is an identity factor of the diode, T_C is the cell temperature, and k (1.38×10^{-23} J/ºK) is the Boltzman constant [11].

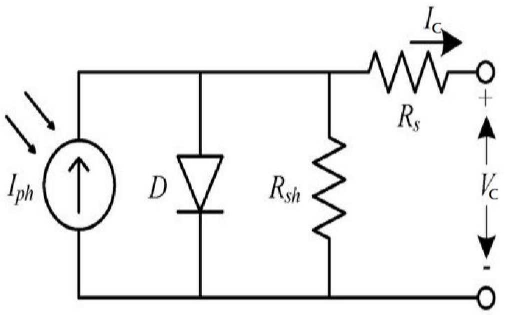
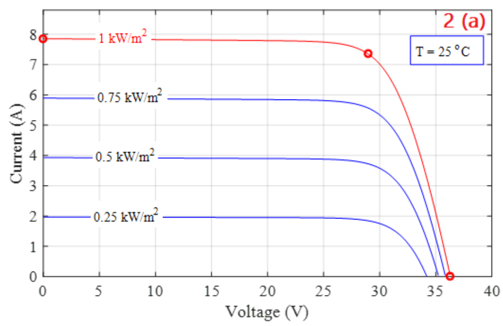


Figure 1: Equivalent circuit of solar PV cell [11].

When the ambient temperature and irradiation levels change, the cell operating temperature also changes, resulting in a new output voltage and a current value as shown in Fig. 2(a) and 2(b). These climatic parameters change the maximum power point (MPP) during the on-field operation. The maximum power point tracking mechanism shifts this operating point to the point where the module transfers the maximum power (Pmp) to load. Maximum power point tracker (MPPT) is an electronic circuit arrangement to shift the operating point to the maximum power point of the solar cell.



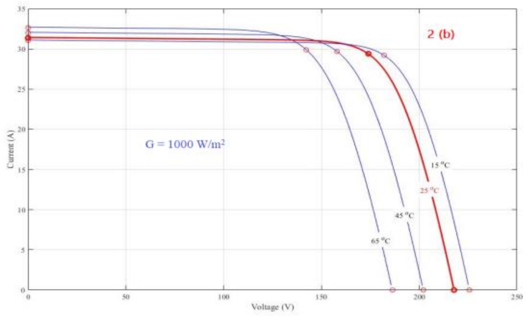


Figure 2(a), (b): I-V characteristics of solar cell at different irradiance and temperature.

III. MPPT TECHNIQUES

Numerous maximum power point tracking (MPPT) techniques have proposed to improve the energy yield of a PV system by extracting the maximum power. These methods can be distinguished on the basis of various features like the convergence speed, range of effectiveness, types of sensors needed, popularity, implementation hardware requirements, cost [12].

3.1 Constant voltage technique

To constant voltage (CV) algorithm is one of the easiest MPPT techniques (Fig. 3). In this V_{MP} is achieved by calculating open-circuit voltage and constant K i.e. V_{MP}= K.V_{OC}. The value of K depends on the material used and solar radiation, it varies from 0.72 to 0.82 from the experimental analysis [13].

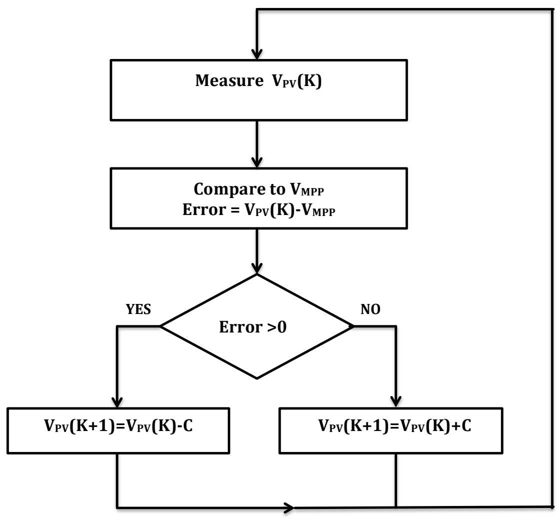


Figure 3 : Flowchart of constant voltage technique.

The value of V_{oc} depends upon the ambient condition. In this the panel voltage is compared with the reference voltage V_{ref} and V_{mp} is achieved corresponding to the reference signal. In CV techniques no additional input signal is required except for the measurement of the PV voltage which requires a PI controller to adjust the duty cycle of the converter order to maintain the PV voltage near the MPP [13].

3.2 Short circuit technique

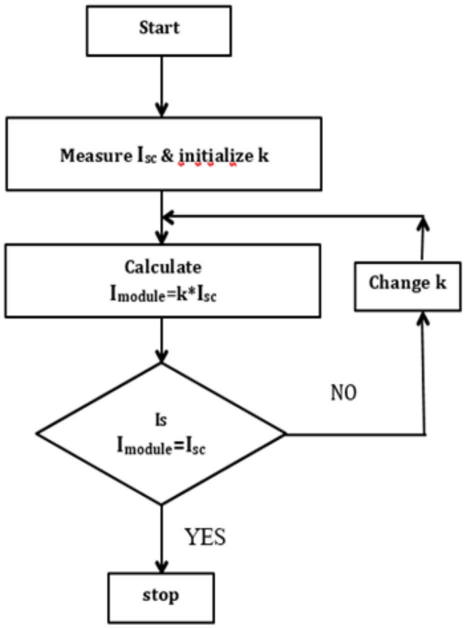


Figure 4 : Flowchart of short circuit technique.

In short circuit current pulse method technique, the non-linear characteristic of PV system is modeled using mathematical equation. Based on those V-I characteristic the mathematical relationship between I_{mpp} and I_{SC} is constructed as $I_{MPP} = k*I_{SC}$. I_{SC} denotes the short circuit current of the PV panel and the proportionality constant k primarily depends on the property of the solar cell, environmental condition, and fill factor. Here the value of k is always less than 1. It seems very easy but computing the best value of k is very strenuous and the value of k may vary from between 0.78 and 0.92.

3.3 Open circuit voltage method

In the open-circuit voltage methods, the panel is disconnected from the load momentarily to measure the open-circuit voltage (V_{oc}). The measured V_{oc} is stored and used for calculation of the reference voltage as shown in Fig. 5. The main drawback of this method is that the power delivered to the load falls to zero during the sampling period. Moreover, the ambient conditions may change between the different sampling intervals and the PV panel may operate at a voltage other than the MPP voltage.

Both these factors contribute to a reduced energy output from the PV panel. To overcome the above-mentioned disadvantages, an analog MPPT was proposed, wherein a small pilot PV panel is used to measure the open-circuit voltage [13].

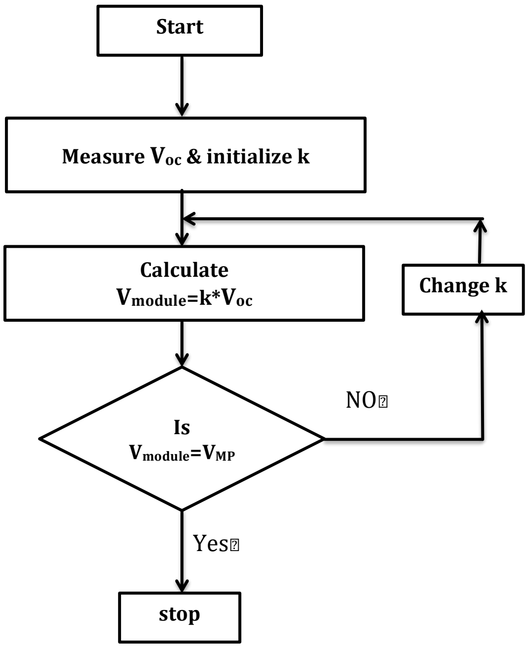


Figure 5 : Flowchart of open circuit voltage method.

3.4 Perturb and observe method

Perturb and Observe (P&O) technique is one of the commonly used MPPT techniques. In this, we calculate the voltage and current at a particular temperature and radiation and corresponding power P1 is obtained. And then power P2 is calculated corresponding to the small perturbation of voltage (ΔV) or duty cycle (Δd) as shown in Fig. 6.

Then both the power is compared. If P2 is greater than P1 then perturbation is in a positive direction but when P2 is smaller than P1 then perturbation is in a negative direction. The maximum power (P_{mp}) is achieved then. The major disadvantage of this deviates in case of rapid change in environmental condition. To overcome this drawback variable steps adaptive hill climbing techniques are used [14].

3.5 Incremental conductance technique

Incremental conductance (Inc-Cond) method is similar to P&O techniques. P&O method fails in rapidly changing environmental condition. At maximum power when, dP/dV=0 incremental conductance (dP/dV) is equal to the negative of instantaneous conductance (I/V).

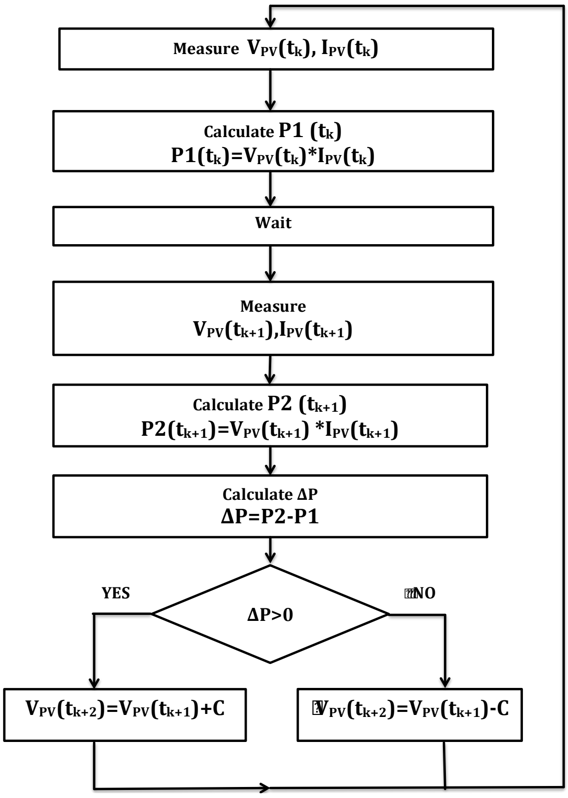


Figure 6 : Flowchart of perturb and observe technique.

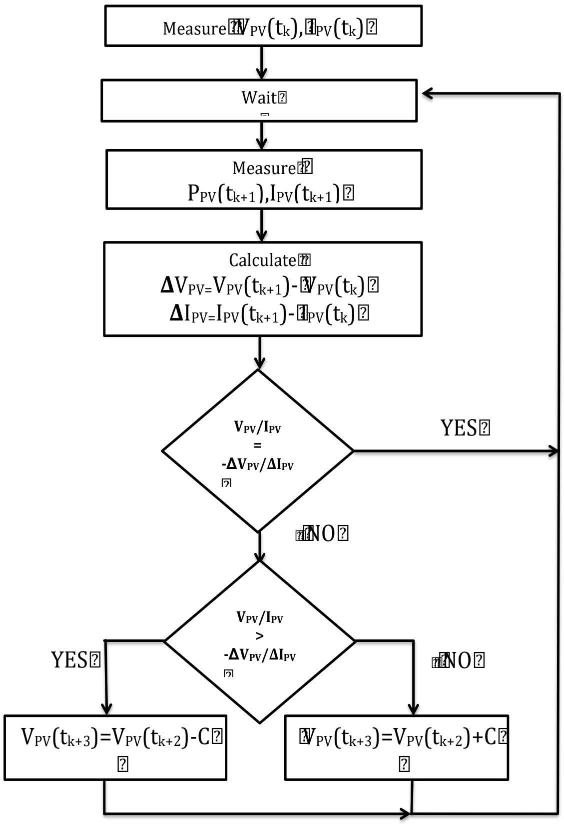


Figure 7 : Flowchart of Inc-Cond method.

The sign determines the variation of operating points. When it shows the negative sign (-) then current increases and when it shows the positive sign (+) current decreases [15]. The variation of current is also depending on the ambient condition. When the PV output voltage is constant but the output current increases, the perturbation should be kept in the same direction. If the current decreases with the constant voltage, the perturbation direction become reversed [16].

3.6 Current sweep technique

This technique determines the derivative of the PV module output power with respect to the PV module current while the module current is operated as a decaying exponential sweep function. For this purpose, a sweep waveform is used for the PV module current to obtained the I-V characteristics, which is continuously updated after some definite time intervals. Then from the I-V characteristic curve, computation of V_{MPP} can also be done for the same time interval. The PV module current (I_{PV}) can be calculated as a function of time.

$$I_{PV}(t)= f(t) \quad (4)$$

The PV module power along this sweep waveform, as a function of time will be:

$$P_{PV}(t) = V_{PV}(t)\, I_{PV}(t) = V_{PV}(t)\, f(t) \quad (5)$$

At the maximum power point, the derivative of $P_{PV}(t) = 0$.

$$\frac{dP_{PV}(t)}{dt} = V_{PV}(t)\frac{df(t)}{dt} + f(t)\frac{dP_{PV}(t)}{dt} = 0 \quad (6)$$

The above equation can be simplified by choosing the sweep waveform directly proportional to its derivative.

$$f(t) = m_1 \frac{df(t)}{dt} \quad (7)$$

where m_1 is a real constant. Now further simplification of MPP eq.

$$\frac{dP_{PV}(t)}{dt} = \frac{df(t)}{dt}\left(m_1 \frac{dP_{PV}(t)}{dt} + V_{PV}(t) \right) = 0 \quad (8)$$

If it is assumed that the derivative of f(t)≠ 0 in the range of the sweep waveform, after dividing the above eq. both side by df(t)/dt, equation becomes:

$$\frac{dP_{PV}}{df(t)} = \frac{dP_{PV}}{dI_{PV}} = m_1 \frac{dP_{PV}(t)}{dt} + V_{PV}(t) \quad (9)$$

The maximum power point condition given in the equation 9 can be investigated by only using the voltage V_{PV} and its derivative.

$$m_1 \frac{dP_{PV}(t)}{dt} + V_{PV}(t) = 0 \qquad (10)$$

The solution of the differential equation 8 is unique and is given as:

$$f(t) = c_1 * e^{t/m_1} \qquad (11)$$

where c_1 is the arbitrary constant of the general solution. It is notable in Eq. 11, if m_1 is chosen as a negative real number, the sweep waveform corresponds to an exponentially decreasing function with a time constant $\tau = -m_1$, in this condition, c_1 corresponds to the maximum current I_{max} when t=0. The choice of the constants $m_1<0$ and $c_1=I_{max}$ simplifies the generation of the sweep waveform. At the moment when the test condition is fulfilled, the voltage of the PV module can be held by an analog hold circuit as the fixed point of the chopper's controller of the chopper for the duration when power is delivered the load and batteries. This method is found feasible in the condition when the power consumed by the tracking unit is less than the increment in the power that it can bring to the entire PV system [17,18].

3.7 Fuzzy logic based MPPT method

Fuzzy logic based tracking is a smarter way to track maximum power point (MPP) than conventional tracking techniques. Without using accurate mathematical models, it tracks MPP by using fuzzy inputs. Fuzzy logic works on the basis of fuzzy set theory, in this theory a variable is a member of one or more sets, having a specified degree of membership (Fig. 8).

ΔE / E	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Figure 8 : Fuzzy logic table [17].

Fuzzy logic enables us to mimic the human reasoning process in computers, evaluate imprecise information, make decision-based on fuzzy and inadequate data. This is a three-step process as fuzzification, rule base lookup table and defuzzification. The process, which convert the input/output variable to linguistic levels is called as fuzzification. A set of rules governed the nature of the control surface, which relates the input and output variables of the system. The third stage is the defuzzification where the fuzzy logic controller output is converted from linguistic variable to numerical variable using the membership functions [20].

3.8 Artificial Neural Network (ANN) based MPPT

The neural network technique is one of the promising smart techniques to track the MPP in used PV system. This is inspired by the behavior of neurons. As this algorithm is based on the artificial intelligence, ANN is capable to think of its own. But then, the method requires more knowledge to train the neurons present in the algorithm.
This method consists of three layers:

1. Input layer
2. Hidden layer
3. Output layer

The pictorial view of all the above mentioned layers is shown the Fig. 9. In this method different parameters of PV module like V_{OC} and I_{SC}, atmospheric variables (irradiance and temperature) or any combination of the mentioned parameters can be used as input variables. The output denotes the duty-cycle signal that directs the converter to search the MPP, on the basis of the algorithm used in the hidden layer.

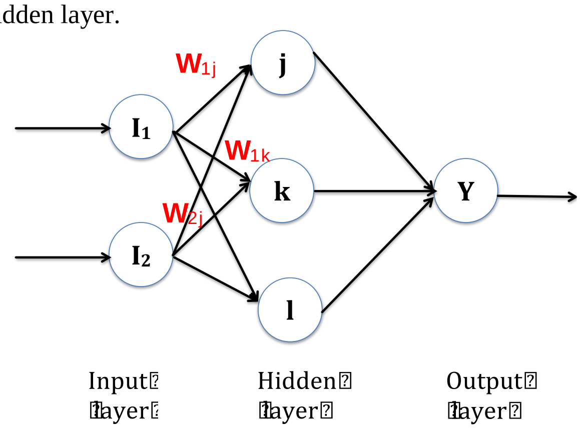


Figure 9 : Layers of artificial neural network [17].

The neural network technique is based on weighting the links between nodes based on some training process, where the PV parameters are tested and recorded over months or years to get the right weight for every node. There is a problem with this method that every time the neural network has to be trained properly, when PV module in use, otherwise it cannot be generalized to work on several types at the same time. Furthermore, with time the characteristics of the PV panel vary, implying a periodical training of the neural network to precisely track the MPP [21].

3.9 Ripple correlation method

Ripple correlation method uses the signal ripples for tracking MPP, which are automatically present in power converters due to the switching action of power converter when connected to the PV array [22]. The ripple correlation control (RCC) method considered ripple as a perturbation that can ascertain gradient ascent optimization by correlating the ripple with the switching function [23].

3.10 Biological swarm changing technique

The biological swarm chasing algorithm is another recent development among the artificial intelligence techniques widely used for tracking maximum power point (MPP) proposed in the paper and is based on the concept of Particle Swarm optimization technique (PSO). Particle Swarm optimization technique is one of the well known artificial intelligence technique, which is commonly used to deal with the maximum power point tracking problem [23]. The PSO technique is a popular choice because it has fast computation capability, uncomplicated structure and simple implementation.

Swarm intelligence technique is motivated by perceiving the organized flying pattern of a group of birds and fish schooling [24]. This technique simply shows the collective nature of a group, chasing some simple rules to achieve the common goal. In the suggested Bio-MPPT-based PV power system, each PV module is considered as a particle, and the MPP is treated as the moving target. Bio-MPPT algorithm works in such a way that it makes every PV module to follow the MPP automatically in-spite of change in environmental conditions. Thus, in this method to achieve the MPP, all the PV module in photovoltaic array are treated as servants working under one master module and each module of this PV array communicates with master module to chase the MPP. The study in the paper shows the improvement of 12.19% in the efficiency when compared to the P & O method [25].

IV. CONCLUSION

The efficiency of the photovoltaic system is generally poor. MPPT is a very essential component of any PV system to extract the maximum power from the PV panels. In order to augment the efficiency of the solar PV system, many MPPT methods have been developed and implemented. Some of the MPPT techniques, which are popular in the solar PV field have been reviewed and analyzed in this paper comprehensively. There are some merits and demerits of every MPPT technique. But the popularity and use of any MPPT technique depend on its overall performance like response time, accuracy, design consideration, cost-effectiveness, hardware implementation process, the capability of handling dynamic variation in irradiation conditions etc. The review will provide the deep insight to the readers about the discussed MPPT methods.

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