A review of MMPT methods for solar pv systems

Pravin D. Patel[1], Dr. Jatin J. Patel[2]
Assistant Professor, Department of EE, Goverrment Engineering College, Godhra, Panchmahal, Gujarat, India[1]
Associate Professor, Department of EE, G.H.Patel College of Engineering and Technology,Anand, Gujarat, India[2]
pravin07in@gmail.com[1], jjpatelgcet@gmail.com[2]

Abstract— The purpose of this paper is to study and compare different maximum power point tracking (MPPT) methods in a photovoltaic system. Many maximum power point tracking techniques for photovoltaic systems have been developed to maximize the produced energy. There are different techniques for MPPT such as Perturb and Observe, Incremental conductance, Fractional Short Circuit Current, hill climbing method, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. These techniques are vary in many aspects as: simplicity, convergence speed, digital or analogical implementation, sensors required, cost, range of effectiveness, and in other aspects. This paper presents a comparative study of different widely-adopted MPPT algorithms. 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.

Index Terms— Minimum Solar Photo voltaic (SPV) system,maximum power point tracking (MPPT), P&O algorithm

1 INTRODUCTION

THE need for renewable energy sources is on rise because of the severe energy crisis in the world today. The use of solar energy is emphasizly increasing and an important resource of energy in the 21st century. India plans to produce 20 Gigawatts Solar power by the year 2020.[5]

The Solar cells represent the fundamental power conversion unit of a photovoltaic system. As the power supplied by solar arrays depends upon the insolation, temperature and array voltage, it is s necessary to draw the maximum power from the solar array.

1.1 Characteristics of PV cell

An ideal PV cell is modelled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the figure 1. RS is the intrinsic series resistance whose value is very small. RP is the equivalent shunt resistance which has a very high value [1].
Applying Kirchhoff's law to the node where IPh, diode, RP and RS meet,

$I_{Ph} = I_D + I.\,R_P + I$ …………… (1)

We get the following equation for the photovoltaic Current:
$I = I_{Ph} - I.R_P - I_D$ …………………………………… (2)

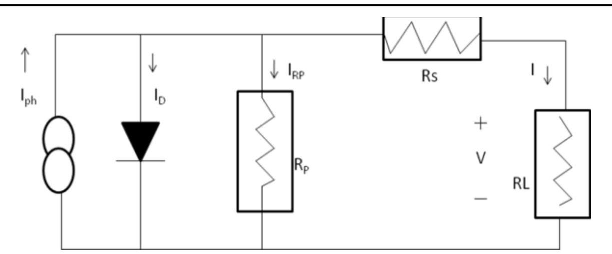

Fig. 1. Simplified equivalent circuit of a solar cell

$I = I_{Ph} - I_o\,[\exp\,(V+I.R_s)/V_T)-1]-[V+I.R_s)/R_P]$……. (3)

Here, IPh is the insolation current, I is the Cell current, Io is the Reverse saturation current, V is the Cell voltage, RS is the Series resistance, RP is the Parallel resistance, VT is the Thermal voltage (K.T/q), K is the Boltzmann constant, T is the Temperature in Kelvin, q is the Charge of an electron The short circuit current (ISC) equal to the cell current(I) depends on Iph, the insolation current Mathematically write as:

$$I_{SC} \propto I_{ph}$$

Open circuit voltage is the voltage at which the cell current is Zero.The expression for the open circuit voltage can be ob tained by substituting I = 0 in eq. 3 and obtained the following expression

$V_{OC} = V_T \ln\,[(I_{ph}/I_O) - (V_{OC}/I_O.R_P) + 1]$……….(3)

The efficiency of a PV cell is defined as the ratio of peak power to input solar power.

$\eta = (V_{mp}.I_{mp}) / I\,(KW/m^2)\,A\,(m^2)$……….. (4)

Where, Vmp is the voltage at peak power, Imp is the current at peak power, I is the solar intensity per square metre, A is the area on which solar radiation fall.
The efficiency will be maximum if we track the maximum power from the PV system at different environmental condition such as solar irradiance and temperature by using different methods for maximum power point tracking[1]

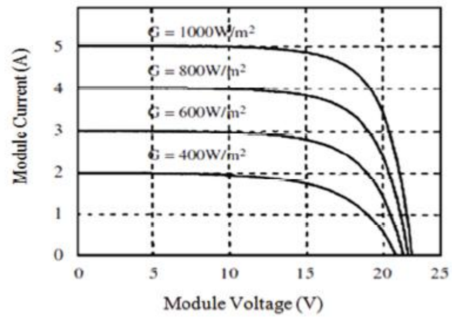

Fig. 2. I-V characteristics of PV with variation of Irradition

Fig. 2.shows that the current of the PV module increased linearly by increasing the solar energy, while the voltage of the PV module increased in a logarithmic pattern as the solar radiation increases shown in fig.2

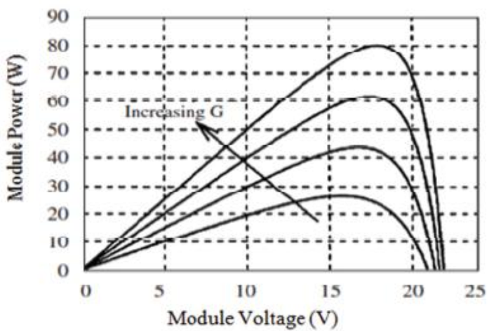

Fig. 3. Power Vs Voltage characteristics of PVA with Variation of Irradiation

From figure 4, the voltage of the PV module decreases as far as the ambient temperature value increases, while the current of the PV increases in logarithmic pattern by the decrease in the ambient temperature [4].
From figure (3), it is noted that the power of the PV module increases as the solar radiation value increased. Besides that, figure (5) shows that the voltage of the PV module decreases as the ambient temperature value decreased.

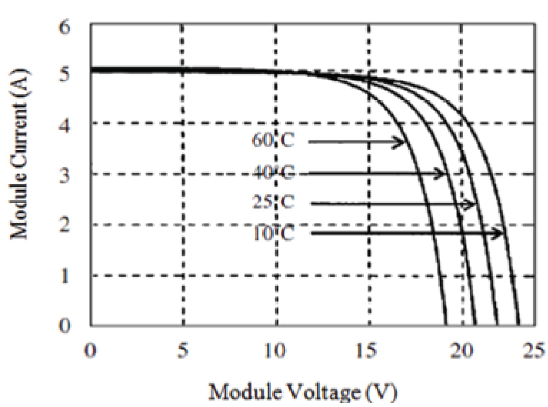

Fig. 4. Current (I) Vs Voltage(V) characteristics of PVA with Variation of Temperature

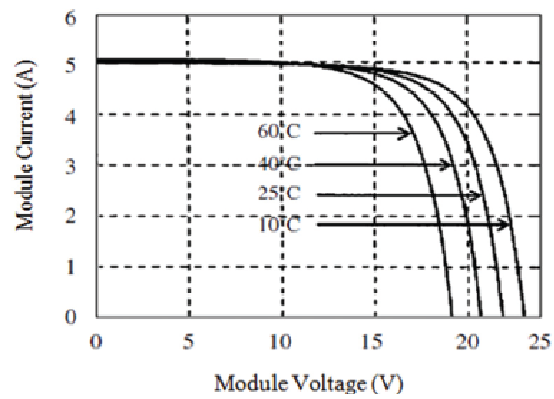

Fig. 5. Current (I) Vs Voltage(V) characteristics of PVA with Variation of Temperature

2. DIFFERENT TECHNIQUES FOR MPPT

There are different techniques for MPPT such as Perturb and Observe, Incremental conductance, Fractional Short Circuit Current, voltage feedback method, hill climbing method,Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation,lesser time to track the MPP and several other economic reasons.[5]

Perturbation and Observation method (P&O) and Incremental conductance are most commonly used because of their simple implementation,lesser time to track the MPP and several other economic reasons.[5] The purpose of this paper is to study and compare advantages, shortcomings and execution efficiency for three power-feedback type MPPT methods, including perturbation & observation (P&O), incremental conductance (INC) and hill climbing (HC) methods. Although the incremental conductance method offers good performance under rapidly changing atmospheric conditions, but four sensors are required to perform the computations .If sensors or system require more conversion time then it will result in a large amount of power loss. On the contrary, if the execution speed of the perturbation and observation method is increased, then the system loss will be decreased. Moreover, this method only requires two sensors, which results in the reduction of hardware requirement and cost. Therefore, the Perturbation and Observation method was used in this paper to control the output current and voltage of the solar arrays.Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (9-16%), especially under low irradiation conditions and the amount of electric power generated by solar arrays changes continuously with weather conditions. Moreover, the solar cell V-I characteristic is nonlinear and changes with irradiation and temperature. In general, there is a point on the V-I or V-P curve only, called the Maximum Power Point (MPP), at which the entire PV system operates with maximum efficiency and produces its maximum output power [4].The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. Maximum Power Point Tracking (MPPT) techniques are used to maintain the PV array's operating point at its MPP. Among the various techniques proposed, the Incremental Conductance(IC) maximum power point tracking algorithm is the most commonly used method due to it performs precise control under rapidly changing atmospheric conditions without steady state oscillation. [1]. Maximum power point trackers (MPPTs) play a main role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions,and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. They vary in complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima and their applications . Some MPPTs are more rapid and accurate and thus more impressive which need special design and familiarity with specific subjects such as fuzzy logic or neural network methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibits better performance in contrast with P&O control method [8]; however the main disadvantage of this method is that its effectiveness is highly dependent on the technical

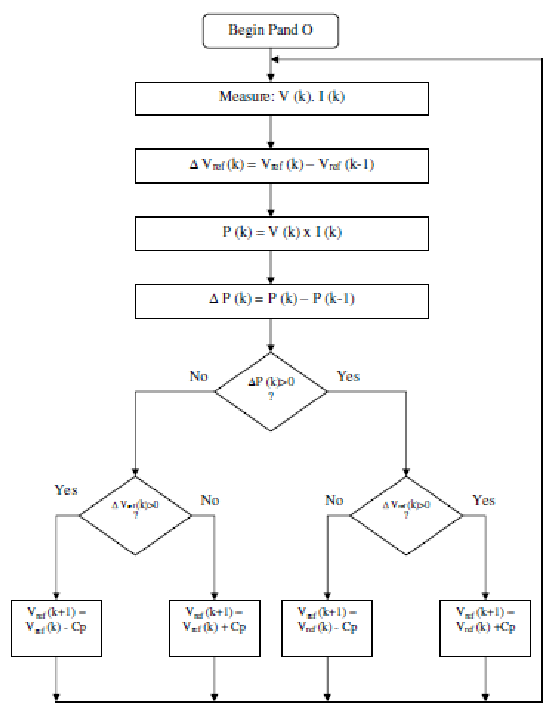

Fig. 6. Flow chart of the PandO MPPT algorithm, Cp is the perturbation step width

knowledge of the engineer in computing the error and coming up with the rule base table. It is greatly dependant on the how designer arranges the system which requires skill and experience. [1].

2.1 THE PERTURBATION AND OBSERVATION METHOD (P AND O):

The P and O method is a widely used approach to MPPT. It employs a microprocessor with the values for panel voltage V and panel current I as its input values and the desired operating voltage Vref as its output value. With this algorithm the operating voltage V is perturbed with every MPPT cycle. As soon as the MPP is reached, V will oscillate around the ideal operating voltage Vmp. This causes a power loss, which depends on the step width of a single perturbation. If the step width is large, the MPPT algorithm will be responding quickly to sudden changes in operating conditions with the tradeoff of increased losses under stable or slowly changing conditions. If the step width is very small the losses under stable or slowly changing conditions

will be reduced, but the system will be only able to respond very slowly to rapid changes in temperature or insolation. The value for the ideal step width is system dependent and needs to be determined experimentally. Assuming that the system has been oscillating around the MPP, it can be seen in figure that a continuous perturbation in one direction will lead to an operating point far away from the actual MPP.

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In a situation where the irradiance changes rapidly, the MPP also moves on the right hand side of the curve. The algorithm takes it as a change due to perturbation and in the next iteration it changes the direction of perturbation and hence goes away from the MPP as shown in the figure 6.[5]

However, in P&O algorithm we use only one sensor, that is

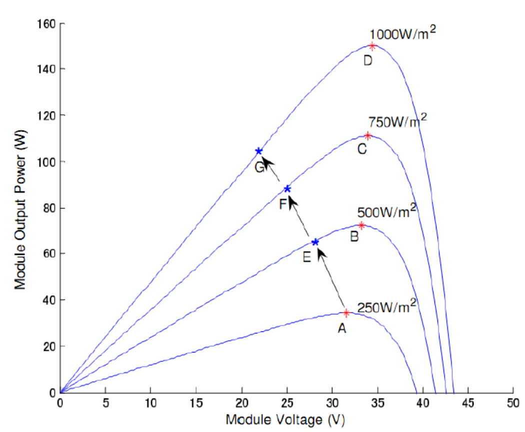

Fig. 7. Curve showing wrong tracking of MPP by P&O algorithm under rapidly varying irradiance

the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing in both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm.

2.2 The Incremental Conductance Method (IncCond):

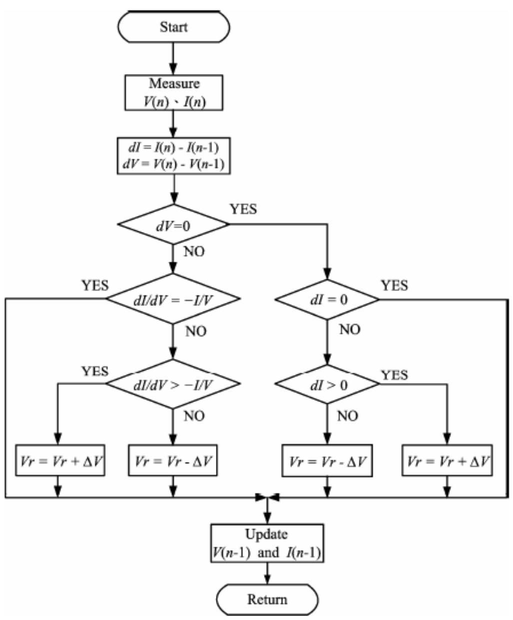

Fig. 8. Flow chart of Inc Cond MPPT algorithm

To avoid the drawbacks of the PandO MPPT method, Hussein and others developed the incremental conductance MPPT algorithm (IncCond). It is based on the fact that the derivative of the output power P with respect to the panel voltage V is equal to zero at the maximum power point (MPP). The solar panel's P-V characteristics in figure 4 show further that the derivative is greater than zero to the left of the MPP and less than zero to the right of the MPP. This leads to the following set of equations:

$dP/dV = 0$ for $V = V_{mp}$, (5)
$dP/dV > 0$ for $V < V_{mp}$, (6)
$dP/dV < 0$ for $V > V_{mp}$. (7)

The fact that $P = V I$ and the chain rule for the derivative of products yields

$$dP/dV = d(VI)/dV = I\,dV/dV + V\,dI/dV = I + V\,dI/dV \quad (8)$$

Combining equations (1) and (4) leads to the MPP condition ($V = V_{mp}$) in terms of array voltage V and array current I:

$$dI/dV = -I/V. \text{ ------ } (9)$$

This shows that with equations (5) and (8) enough information is gathered to determine the relative location of the MPP by measuring only the incremental and instantaneous array conductance dI dV and I V, respectively.

2.3 Fractional open circuit voltage

The near linear relationship between VMPP and VOC of the PV array, under varying irradiance and temperature levels, has given rise to the fractional VOC method.

$$V_{MPP} = k1 . V_{oc} \quad ….(10)$$

where k1 is a constant of proportionality. Since k1 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining VMPP and VOC for the specific PV array at different irrdiance and temperature levels. The factor k1 has been reported to be between 0.71 and 0.78. Once k1 is known, VMPP can be computed with VOC measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power. [5].

2.4 Fractional short circuit current

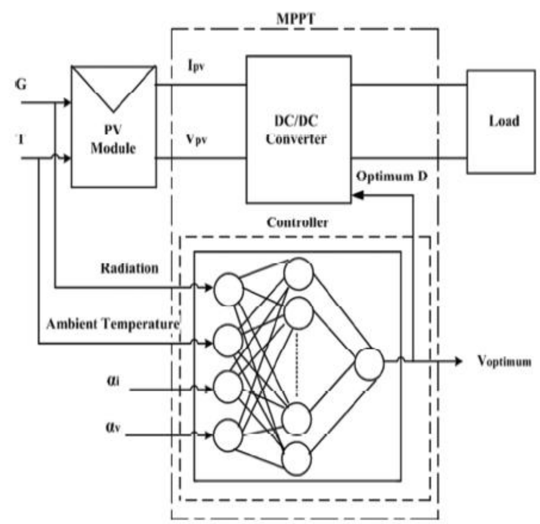

Fig. 9. Flow chart of ANN MPPT algorithm

Fractional ISC results from the fact that, under varying atmospheric conditions, IMPP is approximately linearly related to the ISC of the PV array.

$$I_{MPP} = k2\ I_{sc} \quad ….(11)$$

where k2 is a proportionality constant. Just like in the fractional VOC technique, k2 has to be determined according to the PV array in use. The constant k2 is generally found to be between 0.78 and 0.92. Measuring ISC during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that ISC can be measured using a current sensor[5].

2.5 Fuzzy Logic Control

Microcontrollers have made using fuzzy logic control popular for MPPT over last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity [14].

2.6 Neural Network

Another technique of implementing MPPT which are also well adapted for microcontrollers is neural networks. Neural networks commonly have three layers: input, hidden, and output

TABLE 1
COMPARISION OF DIFFERENT MPPT TECHNIQUES

MPPT technique	Convergence speed	Implementation complexity	Periodic tuning	Sensed parameters
Perturb & observe	Varies	Low	No	Voltage
Incremental conductance	Varies	Medium	No	Voltage, current
Fractional V_{oc}	Medium	Low	Yes	Voltage
Fractional I_{sc}	Medium	Medium	Yes	Current
Fuzzy logic control	Fast	High	Yes	Varies
Neural network	Fast	High	Yes	Varies

layers. The number nodes in each layer vary and are user-dependent. The input variables can be PV array parameters like VOC and ISC, atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signals like a duty cycle signal used to drive the power converter to operate at or close to the MPP [14].

TABLE 2
APPLICATION OF DIFFERENT MPPT TECHNIQUES

Application	Space and Orbital station	Solar Vehicle	Residence Use	Street Light
Need of system	Cost and Complexity are not an issue, high reliability and performance	Fast convergence to MPP	Partial shading issuespayback time should less	Charging of Battery during day , easy and cheap implementation
Method suggested	Hill climbing and P&O,Inc	Fuzzy logic control, Neural Network,Load current,Load volt maximization	Two stage Inc, Current sweep method, OCC MPPT	Fractional VOC, Fractional ISC

Figure 9. shows the proposed ANN algorithm.The algorithm starts by obtaining solar radiation and ambient temperature, and then the optimum voltage is predicted using the developed ANN. Here, a comparison between the predicted optimum voltage and the operating voltage is done to find whatever the system is optimally operated or not. Eventually, and in the case of non optimal operation the optimum duty cycle is calculated using the predicted voltage using eq.(12). [10].
The output voltage is supposed to be the PV output voltage (Vpv), while the input voltage is supposed to be the optimum voltage (Vpv optimum) of the PV module.

$$\frac{\text{Vpv}}{\text{Vpv optimum}} = D \quad \text{--------------(12)}$$

Table1. shows comparision of different MPPT techniques as per their conversion speed implementation complexity,Periodic tuning,senced parameters.[5]Also Table 2 shows application wise most suitable techniques.[13]

CONCLUSION

A MPPT techniques are used for extracting the maximum power from the solar PV module and transferring that power to the load. P&Q MPPT algorithm possesses fast dynamic response and well regulated PV output voltage, and deterministic process of INC algorithm is complicated but accurate. A most suitable MPPT technique may be selected based on the implementation cost, number of sensors required, complexity. The comparison table is shown in Table 1and Table 2 made as per their characteristics and application respectivly.

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