A Review on Solar MPPT Techniques

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Abstract- With the depletion of non-renewable resources, harnessing of energy from renewable resources has become a necessity. Among the different types of renewable sources of energy, solar energy is one of the most sustainable, pollution free and abundant source of energy. Solar photo voltaic (PV) systems are employed for the conversion of solar energy into electrical energy directly. The major drawbacks of these systems are low power conversion efficiency and power losses due to factors like changing weather conditions and rate of solar irradiation. So, for these systems to operate and produce the maximum power output, a Maximum power point tracker (MPPT) is implemented. This paper will give an access to the researchers about the pros and cons regarding the various MPPT techniques and will help them implement the most effective one as per their system requirements.

Index Terms : Maximum power point tracker (MPPT), maximum power point (MPP), solar photo voltaic (PV) system.

I. INTRODUCTION

Non-renewable energy sources such as fossil fuels are limited and with the threat to a sustainable future and increasing demand in electrical power, these energy sources will need to be replaced with renewable alternatives such as solar energy, wind energy, tidal energy, etc. As compared to other energy sources, solar energy is clean, inexhaustible, free and abundant [14] [15]. Although having some demerits, conversion of solar energy into electrical energy is convenient and easy to harness. These systems also have a high installation cost. For operation of these PV systems at an optimal point to extract the maximum output power, mechanical tracking or electrical tracking methods are implemented. Maximum power point tracking (MPPT) is an automatic electrical tracking method whose purpose is to achieve the best efficiency and help a PV system to always operate in the maximum power point (MPP) at any operating condition taking into account various parameters like voltage and current.

The application of power electronics and soft skills are used in accordance for the development of various MPPT algorithms and supporting electrical hardware. Taking into account various journals and papers developed by researchers we have been able to come up with the following techniques of MPPT which will be of assistance to the fellow researchers and engineers for further development and improvement in the efficient harnessing of solar energy.

II. MAXIMUMPOWER POINT TRACKING

Maximum power point tracking (MPPT) is a technique used commonly with PV solar systems and wind turbines to maximize power extraction under all conditions. In PV systems the maximum power produced is dependent on the characteristics of the load of the system, solar irradiance and surrounding temperature [21] [2]. The basic theory of MPPT revolves around the concept of maximum power transfer, which states that the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance or in other words, matching of the load impedance with the PV array impedance [8]. For this a DC-DC converter is used which will vary the duty cycle eventually matching the load – source impedance.

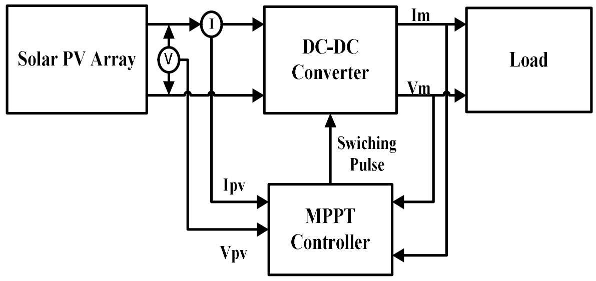

Fig.1 Block diagram of MPPT for a PV system

III. MPPT TECHNIQUES

Numerous algorithms and techniques have been developed for tracking of the MPP of a PV system till date [16] [17]. Each method have different logic for tracking the MPP and can be implemented depending upon the requirement of the system. Some of the trending and effective techniques have been discussed herewith for better understanding and choice of the correct technique to be implemented for further research and development programs [7] [12].

A. Perturb and Observe method

Perturb and Observe (P&O) is the simplest method[2]that can be implemented for maximum power point tracking [4]. This method states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in the power(ΔP) is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If ΔP is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed [18] [19].

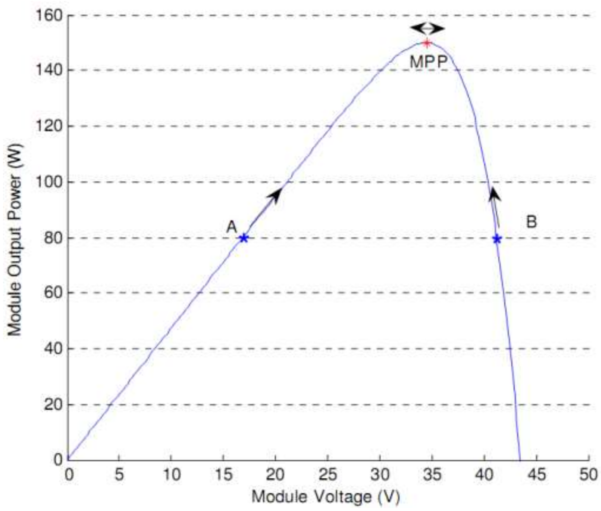

Fig.2 Power v/s Voltage characteristics of a PV module

Fig.2 depicts the PV module output power versus voltage characteristics at a particular irradiance. The point MPP refers to the Maximum power point. Two operating points A and B are taken as shown in the figure above. The point A is on the left hand side of the MPP, so to reach to the MPP from point A, a positive voltage perturbation needs to be provided.When we apply a positive perturbation considering point B which is on the right hand side of the MPP, we get a negative value for ΔP. So, we need to reverse the perturbation direction to reach the MPP [20].

This method is simple to implement as mentioned earlier and is also cost effective. However, the major drawbacks of this method is that the output will oscillate near the MPP and is inaccurate when it comes to tracking of MPP during varying weather conditions [10].

B. Incremental Conductance method

This algorithm measures and compares incremental changes in the current and voltage of the PV array to predict the effect of a voltage change. The slope of the PV curve is equal to zero at MPP, positive (increasing) on the left of MPP and negative (decreasing) on the right of MPP [8]. Present and past values of voltage and current are compared at regular time intervals to check if the slope is zero which indicate that the system is operating on its MPP. When the system is not operating at the MPP, this algorithm performs two morechecks for adjusting the voltage and current parameters so that the system operates at its maximum efficiency. At first the incremental change in current is checked and if it is not equal to zero ($\Delta I \neq 0$) then depending on the value of ΔI, adjustments are made i.e. if ΔI is positive, voltage is increased and vice versa. One more check is carried out by comparing the incremental conductance$\left(\frac{dI}{dV}\right)$with the array conductance $\left(\frac{I}{V}\right)$ and if these two values are equal, we will know that the system is operating at MPP else the algorithm will adjust the array voltage to move towards the MPPfor optimum power output [4] [8] [22].

$$\left(\frac{dp}{dv}\right)=0; \text{ at MPP} \quad (1)$$

$$\left(\frac{dp}{dv}\right)>0; \text{ left side of MPP} \quad (2)$$

$$\left(\frac{dp}{dv}\right)<0; \text{ right side of MPP} \quad (3)$$

We know that P=VI, applying chain rule in the power equation we get,

$$\left(\frac{dP}{dV}\right) = \left[\frac{d(IV)}{dV}\right] \quad (4)$$

$$\Rightarrow \quad \left(\frac{dP}{dV}\right) = I+V\frac{dI}{dV} \quad (5)$$

Since at MPP $\left(\frac{dp}{dv}\right)$=0, therefore the above equation can be written as:

$$\frac{dI}{dV} = -\frac{I}{V} \quad (6)$$

This method is much more complex and precise as compared to the P&O method. Slight variations in the PV curve can be tracked using this algorithm more accurately. Its complexity may be one of its drawback.

C. Fractional open circuit voltage method

This method defines that the voltage from the PV array (V_{mpp}) with respect to the maximum power is linearly dependent to the PV array open circuit voltage (V_{oc}) for various irradiation and temperature values [1] [9] i.e.

$$V_{mpp} = K1 \cdot V_{oc} \quad (7)$$

Where, K1 is a constant of proportionality which is dependent upon the characteristics of the PV array whose value varies between 0.71 - 0.79 [4] [23].

For operation of the PV array at the MPP, the array voltage and the reference voltage (from MPPT) are compared with each other. Consequently, an error signal is generated which is fed to the controller circuit which adjusts the duty cycle to make the array voltage equal to the reference voltagei.e. $V_{pv} = V_{ref}$.The PV array is disconnected from the load at regular intervals to measure the open circuit voltage (V_{oc}) samples corresponding to the MPP voltage (V_{mpp}) which is then taken as the reference voltage for the control system[1] [9].

It is also one of the simplest and cost effective methods. A disadvantage of this technique is that due to frequent disconnection of the PV array from the load for array voltage sampling, power losses are unavoidable.

D. Fractional short circuit current method

This method of tracking the MPP is quite similar to that of the Fractional open circuit voltage method. It states that the PV array MPP current (I_{mpp}) is linearly related with the PV array short circuit current (I_{sc}) under varying atmospheric conditions [2] i.e.

$I_{mpp} = K2 \cdot I_{sc}$ (8)

Where, K2 is a proportionality constant dependent upon the PV array characteristics and has a value ranging from 0.78 - 0.92.

The procedure for calculation of the MPP is the same as that of Fractional open circuit voltage method. An additional switch is implemented in the converter circuit to periodically short the PV array for measuring the short circuit current using a current sensor [2] [24].

The advantage of this method is that the implementation cost and complexity is moderate, where as the main drawback of this method is that the output power will not reach its maximum value as from equation (8) we can tell that it is an approximation.

E. Fuzzy Logic control method

Easy accessibility and low cost of microcontrollers have made the application and implementation of this method very popular over the time. This method is composed of threeimportant steps [5] namely, fuzzification, inference and defuzzification. In the first step i.e. fuzzification the numerical values fed to the system is converted into linguistic values or variables with respect to the membership functions which are predefined in the system. The second step i.e. inference is the most essential part of the fuzzy system where all the controlling happens. It uses a rule base lookup table for accurate and precise decision making. The second step is followed by defuzzification which is the final step in a fuzzy MPPT system. Here the conversion of linguistic variables into numeric variables takes place which provides analog signals for controlling the duty cycle of the power converter eventually obtaining the MPP of the system [2].

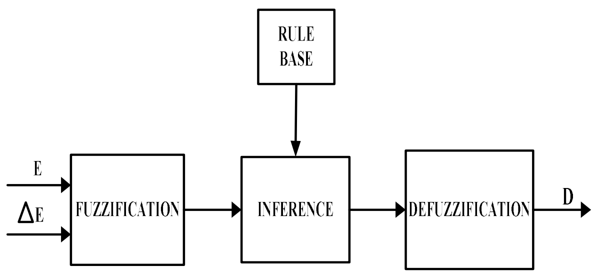

Fig.3 Block diagram of a fuzzy controller

In Fig.3, E represents error and ΔE represents change of error which can be formulated as [6]:

$$E(k) = \frac{P_{PV}(k) - P_{PV}(k-1)}{V_{PV}(k) - V_{PV}(k-1)} \quad (9)$$

$$\Delta E(k) = E(k) - E(k-1) \quad (10)$$

Where, P_{PV} and V_{PV} are the instantaneous power and output voltage of the PV array respectively.

In defuzzification, center of gravity method is implemented for the calculation of the duty cycle.

$$D = \frac{\sum_{j=1}^{n}(\mu(D_j) - D_j)}{\sum_{j=1}^{n}\mu(D_j)} \quad (11)$$

The advantage of fuzzy controlled MPPT is that it can work with inaccurate inputs, does not need an accurate calculating unit and is able to deal with nonlinearity [11]. The major drawback of fuzzy controlled MPPT systems is their high implementation cost and complexity.

F. Neural Network method

Another technique of implementing MPPT which are also well accustomed with microcontrollers is neural network method. This method comprises of three layers which are, input layer, hidden layer and output layer [25] [26]. Parameters such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), irradiance, temperature or a combined data of all these are fed at the input layer. The most significant role is played by the hidden layer which is responsible for tracking the MPP of the system at any given instance. The accuracy of this layer for identifying the MPP is developed by training the neural network. At the output layer, the system corresponds to one or more than one reference signals among which a particular signal will change or modify the duty cycle of the DC-DC converter to make the systemoperate at MPP [5].

This method is implemented for MPP tracking under non-uniform and partial shading conditions and can be seen as a merit of this technique. One of the disadvantages of this method is that it requires regular periodic training so as to overcome and adapt to the frequent modification of the system parameters. As this is an artificial intelligence based system it is not 100% predictable and reliable. Research works are being carried till date to improve its performance and reliability.

G. Look up table method

This is a method where the optimum conditions for obtaining the MPP for a system is already logged into the MPPT system at various insolation levels [3]. The tracking of the MPP of the system is done by selecting some particular pre-logged data under given atmospheric condition. Comparison of the look up table reference voltage and the actual PV module voltage is done eventually generating a gate pulse to adjust the duty cycle for load-source impedance matching [10]. This approach reduces the complexity of tracking the V_{mpp} as compared to other algorithms.

This method responds quicker to the changing atmospheric conditions and tracks the MPP faster than other methods as less amount of calculations are involved [3]. The efficiency of this method is higher as compared to other techniques at changing insolation conditions. The disadvantage of this method is that it requires real time data to get proper results as it is a tiresome and laborious job to do for very large PV systems.

H. Hybrid MPPT techniques

As the name suggests, this type of technique uses a combination of two or more MPPT algorithm to track the MPP of a system [10]. The concept of hybrid system is simple, different MPPT algorithms are combined and used together as a unit to cover up one's weak section by the other's stronger section and come up with a more efficient, accurate and adaptive system as possible. A hybrid system using P&O and incremental conductance algorithm is used to improve the tracking of MPP at varying insolation and weather conditions [10].Another hybrid method implemented for more efficient MPP tracking is a combination of incremental conductance, fractional open circuit voltage and fractional short circuit current [27].

The advantage of the method is that it makes the system more precise, efficient, accurate and adaptive in various given conditions. The only disadvantage of these systems would be their designing and implementing cost.

IV. CONCLUSION

This paper was designed to serve as a guide for our fellow researchers and engineers who want to know and learn about the most widely used and efficient power delivering system like MPPT. A brief review on the most used, popular and trending MPPT techniques along with their comparison, merits and demerits are highlighted to the best knowledge in this paper. The use of these techniques for efficient harvesting of renewable sources of energy is highly recommended because it is high time that we start thinking about our future generations and the impact that it is going to put on them if we keep on polluting and exploiting our earth and our resources at the present furious rate.

Table 1. COMPARISON OF DIFFERENT MPPT TECHNIQUES

MPPT Technique	Complexity Level	Cost	Converter Used (DC/DC or DC/AC)	Periodic Tuning	Applications	Control Variable
Perturb and Observe	Low	Inexpensive	DC/DC	No	Standalone	Voltage & Current
Incremental Conductance	Medium	Expensive	DC/DC	No	Standalone	Voltage & Current
Fractional open circuit voltage	Low	Inexpensive	DC/DC	Yes	Standalone	Voltage & Current
Fractional short circuit	Medium	Inexpensive	DC/DC	Yes	Standalone	Voltage & Current
Fuzzy logic control	High	Expensive	Both	Yes	Standalone & Grid	Voltage & Current
Neural Network	High	Expensive	Both	Yes	Standalone & Grid	Voltage & Current
Look up table	Low	Inexpensive	DC/DC	Yes	Standalone	Voltage & Current
Hybrid	Medium/High	Expensive	Both	Yes	Standalone & Grid	Voltage & Current

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