Maximum Power Angle (MPA) Based Maximum Power Point Tracking (MPPT) Technique for Efficiency Optimization of Solar PV System

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Received: 21.08.2014 Accepted: 07.09.2014

Abstract- A novel maximum power angle (MPA) based maximum power point tracking (MPPT) technique is reported. In this technique, a graphical and mathematical approach based maximum power angle determination mechanism is adopted. On the I-V characteristic curve, the angle made from the intersection point of open circuit voltage (V_{OC}) and short circuit current (I_{SC}) with respect to the voltage (V) axis to the point of maximum power (MPP) is determined using the known parameters of the solar PV module. The proposed MPPT technique is able to minimize the dependency on various voltage and current sensor requirements, thereby the reduced requirement of hardware components. Due to this fact, the implementation cost of this technique is expected low and maintenance needs of such technique based MPPT system would be also minimized.

Keywords MPPT, Solar PV System, Efficiency, Maximum Power Angle, Optimizaton.

1. INTRODUCTION

Maximum power extraction from solar PV system is one of the most important aspects of utilization of these systems. Many Maximum Power Point Tracking (MPPT) techniques, methods and algorithms have been suggested by the various researchers [1-6]. MPPT techniques like Fuzzy logic based MPPT [1], Neural network based MPPT [2] and Constant voltage based MPPT [3], Incremental conductance based MPPT [3],[4] and Perturb and observe (P&O) method based MPPT [6] etc. have been explained. The most common MPPT technique is Perturb and Observe (P&O) method. The greatest advantage of this method is that it is simple to implement and easier to be modified to an improved version of P&O method. However it has limitation that it generates oscillations around the MPP which consequently causes the power wastage. Some modified versions of P&O methods have also been evolved by the workers which have improved the performance of the P&O method. Unfortunately no MPPT provide s an optimized efficiency of solar PV system at any instant of time. We discuss some existing MPPT techniques in the following section.

2. EXISTING MPPT TECHNIQUES

2.1 Perturb and Observe (P&O) based MPPT

This is the mostly used and a primary algorithm based technique which is quite simple to implement. In this method, the voltage is perturbed (changed) and output power is measured for various perturbation stages. Subsequently output is compared with the previous values and the voltage is perturbed accordingly to ensure the point of maximum power. Perturb and Observe method has been used by most of the researchers to develop its new variants like voltage based P&O [5] and Duty cycle based P&O [5]. Perturb and observe based MPPT [5],[7],[8] does not depend on PV array, its tracking efficiency is good but with unstable operating points, implementation is simple and the sensing parameters are voltage and current. The voltage based P&O technique can be represented by the following figure.

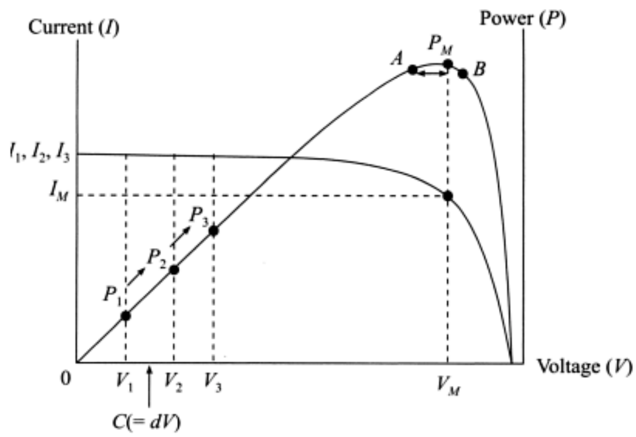

Fig. 1. Perturb and Observe (P&O) Technique for MPPT

2.2 Incremental Conductance based MPPT

The incremental conductance method [3],[5],[7],[9] is based upon the fact that the power would be maximum with the condition that its differential with respect to voltage equals to zero. On the P-V characteristic curve, the differential of power with respect to voltage is zero, positive or negative on the peak of the curve (i.e. at MPP), on the left to MPP and on the right to MPP respectively. The following description of this method gives the mechanism of operation. The maximum power point yields the following situation

At MPP, **dP/dV = 0**

Solving the above equation, the following situation persist for MPP and other two point,

dI/dV = -I/V at MPP

dI/dV > -I/V on LHS

dI/dV < -I/V on RHS

The operation of Incremental conductance method can be represented as in the following figure

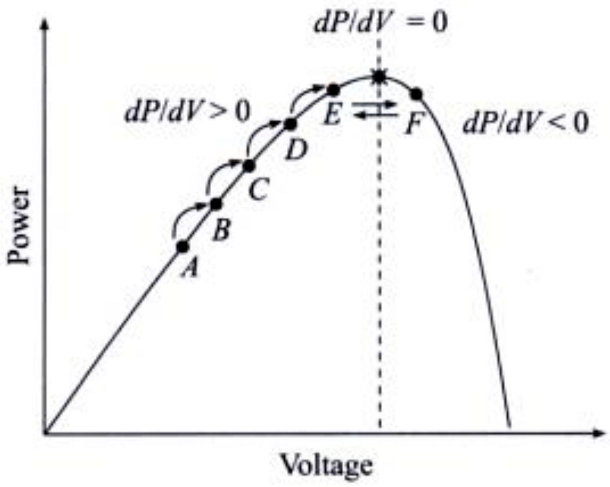

Fig. 2. Incremental conductance method for MPPT

Incremental conductance method provides the reduced number oscillations around the MPP and stable operation. The disadvantage of this method is its higher complexity in comparison to the Perturb and Observe (P&O) method.

2.3 Constant Voltage Ratio based MPPT

Constant Voltage Ratio based method [3,][6],[8],[9] is one of the cheapest methods for MPPT implementation. It does not require any sensor to sense the voltage or current. It works on the principle that for a given characteristic curve, the ratio of maximum power voltage to the open circuit voltage is constant and that will be less than 1. The greater value of this constant indicates the greater efficiency of the PV system at a given instant of time. After calculating the values of maximum power voltage (Vmp) and open circuit voltage (Voc), the operating point is forced to be at the calculated value of this constant. The precise value of the constant is the primary requirement of this MPPT technique. The biggest advantage of this technique is that it does not require any voltage or current sensor.

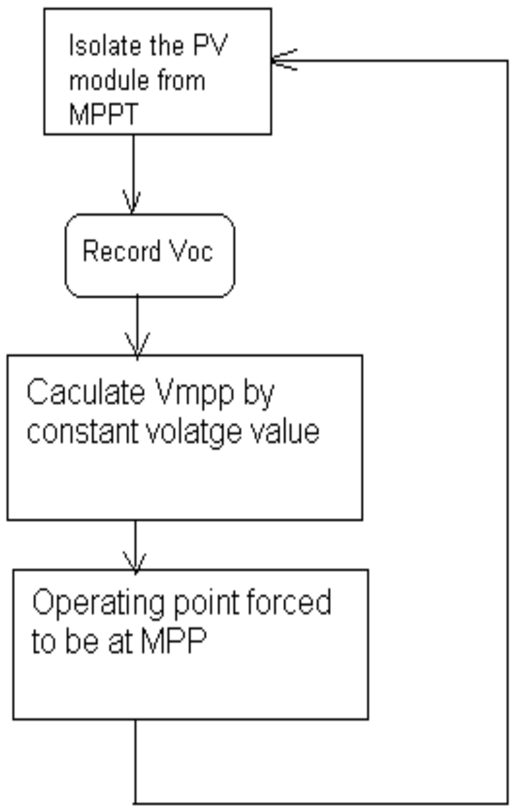

Fig. 3. Structure of Constant Voltage method

3. Characteristic Curves of Solar PV Module

I-V and P-V characteristics of solar PV module are the basic requirement for tracking of MPP using any of the MPPT technique or algorithm. Therefore the following characteristic curves are simulated in the MATLAB environment. The maximum power point (MPP) is also indicated on both of the curves.

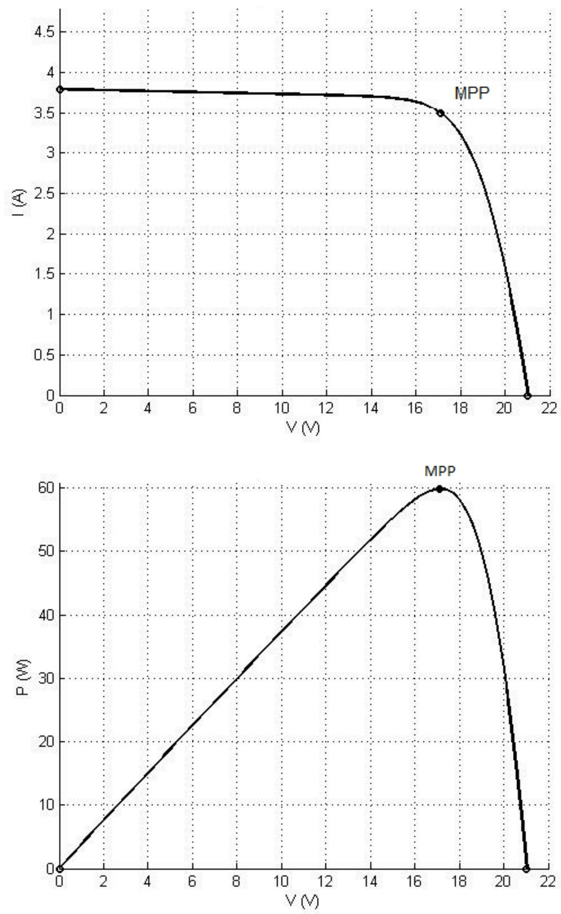

Fig. 4. Simulated I-V and P-V Characteristic Curves

4. Proposed Maximum Power Angle based Maximum Power Point Tracking (MPPT)

In the proposed MPPT method, the maximum power point (MPP) is tracked using the geometrical and mathematical analysis of the I-V characteristic curve of the solar PV module. In this method, the angle made from the intersection point of open circuit voltage (V_{OC}) and short circuit current (I_{SC}) with respect to the voltage (V) axis to the point of maximum power (MPP) is determined using the known parameters of the solar PV module. The MPP angle determination for the following characteristic curves is analyzed as follows.

The point of theoretical power (P_{TH}) is the intersection point of V_{OC} and I_{SC}. Therefore a hypotenuse is drawn from the point P_{TH} to the point of origin. Then the angle made by this hypotenuse and the voltage (V) axis is 45^0 (as evident from the figure). It also reflects that the angle made by this hypotenuse and current (I) axis is also 45^0. Now it is needed to determine the angle made by the line (joining P_{TH} and I_{SC}) and the line (joining P_{TH} and MPP).

The following calculation steps are used for determining the MPP angle for the given characteristic curves.

The corresponding value of voltage at MPP

(V_{MP}) = 17 volts

The corresponding value of current at MPP

(I_{MP}) = 3.5 A

The corresponding value of voltage at V_{OC} = 21 volts

The corresponding value of current at I_{SC} = 3.8 A

It is also clear (from the figure 6) that

AB = I_{SC} - I_{MP}= 3.8 - 3.5= 0.30 Amp. & BC = I_{MP} - I_{MP}' = 3.5-3.05= 0.45 Amp.

Therefore AB<BC

Where, AB = distance between MPP and I_{SC} – P_{TH} line and

BC = distance between MPP and hypotenuse (line joining P_{TH} to origin)

Therefore the maximum power angle (MPA) will be

$$0^0 < \theta_{MPP}\text{(MPA)} < 22.5^0$$

In right-angled triangle Δ AB BP_{TH} (as shown in figure 6),

$$BP_{TH}^{\ 2} = AB^2 + BP_{TH}^{\ 2}$$

$$\text{or } BP_{TH} = \sqrt{AB^2 + AP_{TH}^2}$$

where, AB = 0.30

$$AP_{TH} = 21\text{-}17 = 4$$

$$\text{Therefore, } BP_{TH} = \sqrt{0.30^2 + 4^2} = \sqrt{16.09} = 4.011234$$

Now the θ_{MPP} (MPA) can be easily determined as the following formula

$$Cos(\theta_{MPP}) = AP_{TH} / BP_{TH}$$

$$\text{or } \theta_{MPP} = Cos^{-1}(AP_{TH} / BP_{TH}) = Cos^{-1}(4/4.011234) = Cos^{-1}(0.9972) = 4.2886^0$$

$$\theta_{MPP} = 4.2886^0$$

This is the approximate value of MPP angle for the given characteristic curve.

The generalized formula for determining the MPP angle has been derived as

$$\theta_{MPP} = Cos^{-1}(AP_{TH} / BP_{TH})$$

In this method, the operating point is forced to reach to MPP using proposed MPP angle determination methodology.

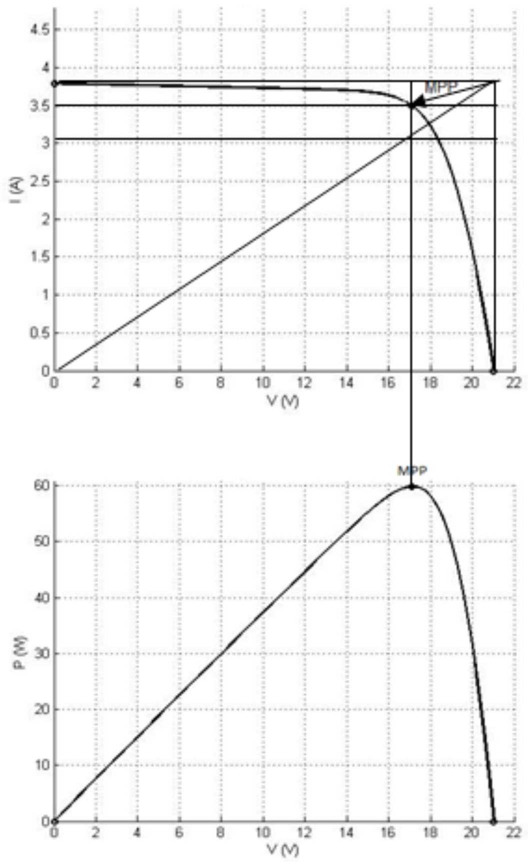

Fig. 5. Mechanism of maximum power point (MPP) angle method for MPPT

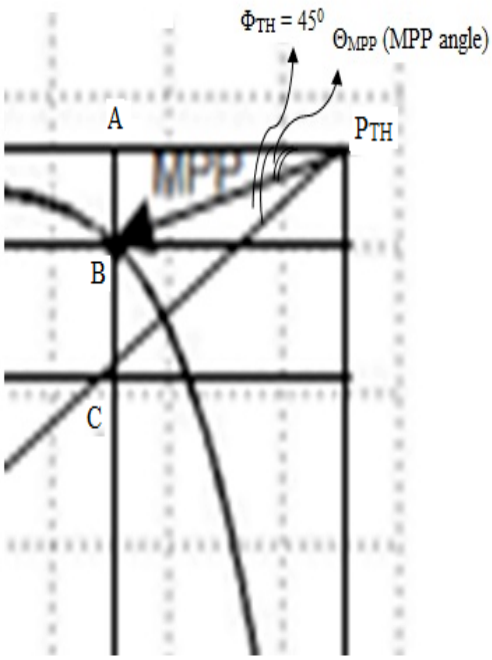

Fig. 6. Parameters of MPA method for MPPT

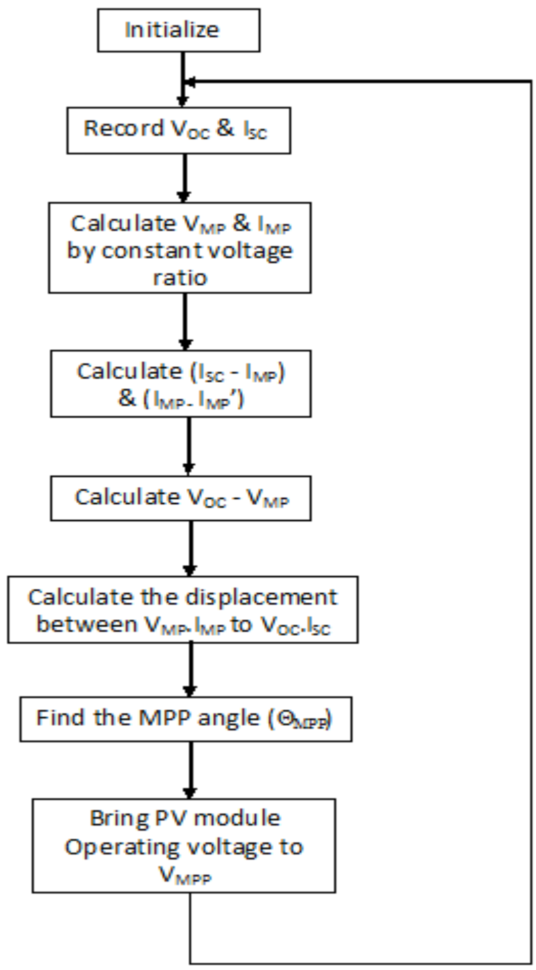

Fig. 7 Maximum Power Angle (MPA) algorithm

The following illustrations show the mechanism for the proposed MPPT control method based on MPP angle determination.

The above mechanism is an effective approach for determination of the maximum power angle (Θ_{MPP}). After finding out this angle, the operating point is forced to reach at MPP by using Θ_{MPP}. By using the proposed method, the requirement of sensors is reduced. Mathematical approach of the method gives a room of modifications easily as needed. Thereby the different versions of the method are possible to introduce for various applications.

5. Results and Discussion

The proposed technique is a data based approach in which the different parameters of solar PV module are analyzed and then these parameters are used to find the MPA. This angle MPA is further able to find and track the MPP throughout the day. The results have been obtained for a solar PV module in which the performance parameters (V_{MP}, I_{MP}) differ.

Table 1. Maximum power angle (MPA) determination of solar PV module in varying insolation

S.No.	Insolation	V_{OC}	I_{SC}	V_{MPP}	I_{MPP}	$(V_{OC} - V_{MPP})$	$(I_{SC} - I_{MPP})$	MPA
1	100 W/m^2	0.4	0.005	0.33	0.005	0.07	0	0
2	200 W/m^2	0.42	0.01	0.35	0.009	0.07	0.001	0.818455
3	300 W/m^2	0.43	0.015	0.36	0.014	0.07	0.001	0.818455
4	400 W/m^2	0.43	0.02	0.36	0.019	0.07	0.001	0.818455
5	500 W/m^2	0.44	0.025	0.37	0.023	0.07	0.002	1.636577
6	600 W/m^2	0.44	0.03	0.37	0.028	0.07	0.002	1.636577
7	700 W/m^2	0.45	0.035	0.38	0.033	0.07	0.002	1.636577
8	800 W/m^2	0.45	0.04	0.38	0.038	0.07	0.002	1.636577

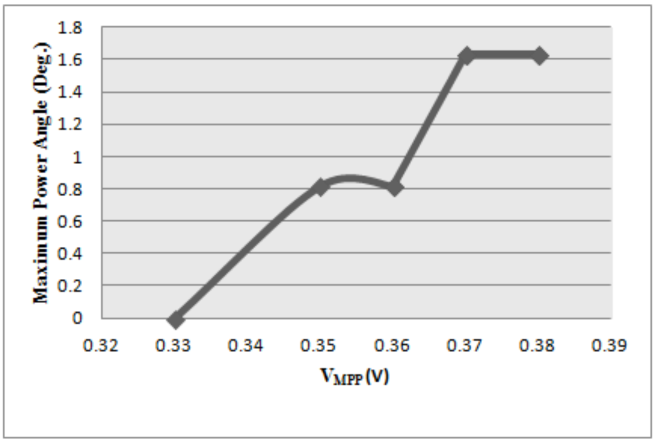

Fig. 8 Variation of maximum power angle with V_{MPP}

The results are taken to find the MPA (θ_{MPP}) by using the different given parameters of solar PV module at various solar insolation levels in different instant of the day. The results show that the MPA varies proportionally in most of the portion of the graph. At some places the MPA is unaffected from the increase in V_{MPP}. It is also clear from the schematic of mechanism of the proposed technique that MPP can be tracked by determining the MPA which is periodically proportional to V_{MPP} (as shown in the graph of V_{MPP} versus MPA).

The present MPA method for MPPT is improved and beneficial in comparision to the existing MPPT techniques which can be summarised as follows.

- Reduced oscillations around MPP due to determination of exact MPA (and hence MPP) in varying solar insolations.
- The hardware circuitry and sensor requirements are minimized.
- Implementation complexity is reduced.
- Cost of overall MPPT system cuts down.
- Greater scope of modification due to its data based approach

6. Conclusion

The design of a MPPT is very crucial part of efficient utilization of solar PV system. In most MPPT designs require voltage and current sensors and subsequently the cost and maintenance increases accordingly. In the proposed MPPT design, the sensor requirement is eliminated thereby this MPPT would be cost-effective. The important part of the proposed MPPT strategy is that it needs the prior information about the various parameters of the solar PV module and accordingly it adjusts the MPP during different insolation level throughout the day. The result show that MPA varies proportionally with V_{MPP}. Therefore, the MPP can be tracked by determining the MPA at specific instant of time of the day in varying solar insolation conditions. It is observed that the proposed method would be able to sufficiently improve the efficiency of solar PV system with a cost effective approach.

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