

Maximum Power Point Tracking Algorithms for Photovoltaic System: A Review

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Abstract

PV array has non-linear I-V characteristic and output power depends on environmental conditions such as solar irradiation and temperature. There is a point on I-V, P-V characteristic curve of PV array called as Maximum Power Point (MPP), where the PV system produces its maximum output power. Location of MPP changes with change in environmental condition. The purpose of MPPT is to adjust the solar operating voltage close to MPP under changing environmental conditions. In order to continuously gather the maximum power from the PV array, they have to operate at their MPPT despite of the inhomogeneous change in environmental conditions. The two most commonly algorithms for PV applications as they are easy to implement are Perturb and Observe (P & O) Incremental Conductance (Inc. Con.). A review of various MPPT algorithms is proposed with more focus on above two algorithms.

Keywords: MPPT Algorithms.

1. Introduction

Fossil fuels like gas and oil are not renewable, unclean and not eco-friendly energy source of energy. Solar energy is one of the most important renewable energy sources. PV system is divided into two categories: Stand-alone and Grid connected PV system. For places that are away from the utility grid, stand-alone PV systems are used at those places. In these systems, the performance of a PV system relies on the operating conditions. The maximum power extracted from the PV source depends strongly on three factors such as irradiation, load profile and temperature [Salas, 2006]. Places where utility grid is easily available, grid-connected PV system is used there.

The maximum power is generated by the solar module at a point of the I-V characteristic where the product of voltage and current is maximum. This point is known as the MPP. The role of the MPPT is to ensure the operation of the PV module at its MPP, extracting the maximum available power. If there is a good irradiance condition, the photovoltaic system can generate maximum power efficiently while an effective MPPT algorithm is used with the system. A lot of MPPT algorithms have been developed by Researchers all over the world such as Differential method, Perturb and Observe (P & O), Incremental Conductance (Inc. Con.), Curve fitting, Open-Circuit Voltage PV generator, Short circuit PV generator method. The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV module, efficiency of inverter (93-95%) and the efficiency of the Maximum Power Point Tracking (MPPT) algorithm.

2. Maximum Power Point Tracking Algorithms

MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. Among all the algorithms P & O and Inc Con algorithms are most common as they have the advantage of an easy implementation. In normal conditions the P-V curve has only one maximum point, so it is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves.

2.1 Curve Fitting method

The curve-fitting method is an offline method where PV module characteristics, all data and manufacturing details are required, mathematical model and equations describing the output characteristics are pre-decided. PV module characteristic is given by eq. (1), where a, b, c and d are coefficients determined by sampling m values of PV voltage V_{PV} , PV current I_{PV} and output power P_{PV} [Salas, 2006]. Once these coefficients are calculated, the voltage at which power becomes maximum is obtained by eq. (2).

$$P_{PV} = a V_{PV}^3 + b V_{PV}^2 + c V_{PV} + d \quad (1)$$

At maximum power point, $dP_{PV}/dV_{PV} = 0$.

$$V_{MPP} = \frac{-b \pm \sqrt{b^2 - 3ac}}{3a} \quad (2)$$

The advantage of this method is its simplicity. Disadvantage is that it requires prior and accurate knowledge of physical parameters. It requires large memory as number of calculation is more and Speed is less.

2.2 Differential Method

In this method, eq. (3) must be solved very fast in order to provide accurate operating point.

$$\frac{dP_{PV}}{dt} = V_{PV} \frac{dI_{PV}}{dt} + I_{PV} \frac{dV_{PV}}{dt} = 0 \quad (3)$$

Disadvantage of this method is that it requires more calculation time as after calculating eq. (3) parameters, sum $I_{PV}dV_{PV} + V_{PV}dI_{PV}$ is calculated and a comparison of this sum to an equal perturbation on the opposite side of the operating point or the operating point power. This is done till final sum becomes zero, if not than more calculations are required [Salas, 2006].

2.3 Open-Circuit Voltage method

In this method the ratio of PV array's maximum power voltage (V_{MPP}) to its open-circuit voltage (V_{OC}) is approximately constant as given by eq. (4).

$$V_{MPP}/V_{OC} \cong K_1 < 1 \quad (4)$$

The Open-Circuit method is implemented using the flowchart as shown in fig. 1. The PV array is temporarily isolated using from MPPT then V_{OC} is measured. After that V_{MPP} is calculated according to eq. (4), finally the operation voltage is set to the maximum voltage point. This process is repeated periodically.

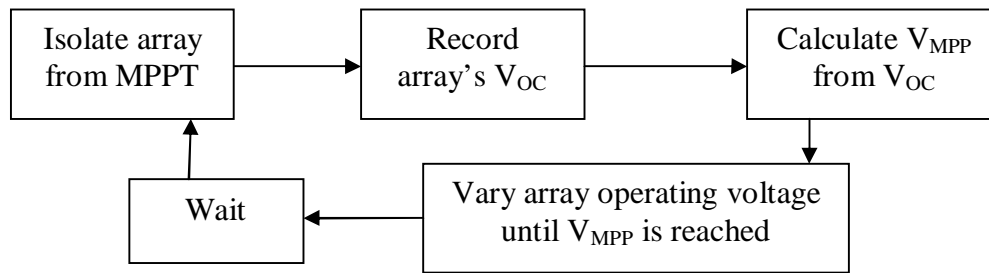


Fig. 1: Open-Circuit Voltage method flowchart [3].

Advantage of this method is that it is simple and cheap. Disadvantage is that it is difficult to choose an optimal value of constant K_1 . The literature [Salas, 2006 & Eltawil, 2013], reports K_1 values ranging from 0.73 to 0.80 for Polycrystalline PV modules.

2.4 Short-Circuit Method

This method is similar to Open-Circuit Voltage method, in this current in MPP (I_{MPP}) is linearly proportional to Short-Circuit current (I_{SC}) given by eq. (5). The value of K_2 is considered to be around 0.85 [Salas, 2006].

$$I_{MPP}/I_{SC} \cong K_2 < 1 \quad (5)$$

The way of determining K_2 is more complicated than any of fixed value. The flowchart, advantages and disadvantages are similar to that of Open-Circuit Voltage method.

2.5 Hill Climbing Techniques

P & O and Inc Con algorithms operate on Hill Climbing Principle, in which operating point of the PV module moves in the increasing direction of power [Morales, 2010].

2.5.1 Perturb and Observe (P&O) method

P&O is an iterative method. It senses the panel operating voltage periodically and compares the PV output power with that of the previous power; the resulting change in power (ΔP_{PV}) is measured. If ΔP_{PV} is positive, the perturbation of the operating voltage should be in the same direction of the increment. However, if it is negative, the system operating point obtained moves away from the MPPT and the operating voltage should be in the opposite direction of the increment [Salas, 2006], perturbation should be reversed to move back towards the MPP. This process continues till $dP_{PV}/dV_{PV}=0$ regardless of the irradiance and PV module's terminal voltage. Fig. 1 shows the P-V characteristics of PV module.

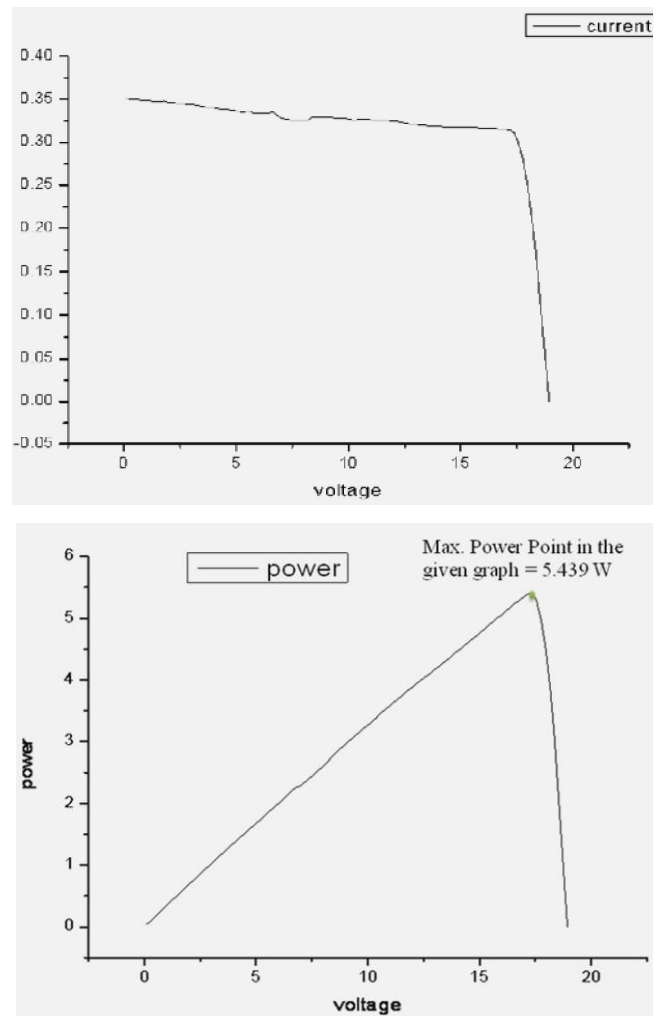


Fig. 1: I-V and P-V characteristics of PV module with MPP.

A scheme of the algorithm is shown in Fig. 2, according to which PV module output voltage V_{PV} and output current I_{PV} are sensed. Then power is calculated $P(n)$ and compared with the power measured at the previous sample $P(n-1)$ in order to calculate ΔP . Then according to the sign of ΔP and ΔV , MPP is tracked which is summarized in Table I, calculations are done according to I-V characteristics in Fig. 1.

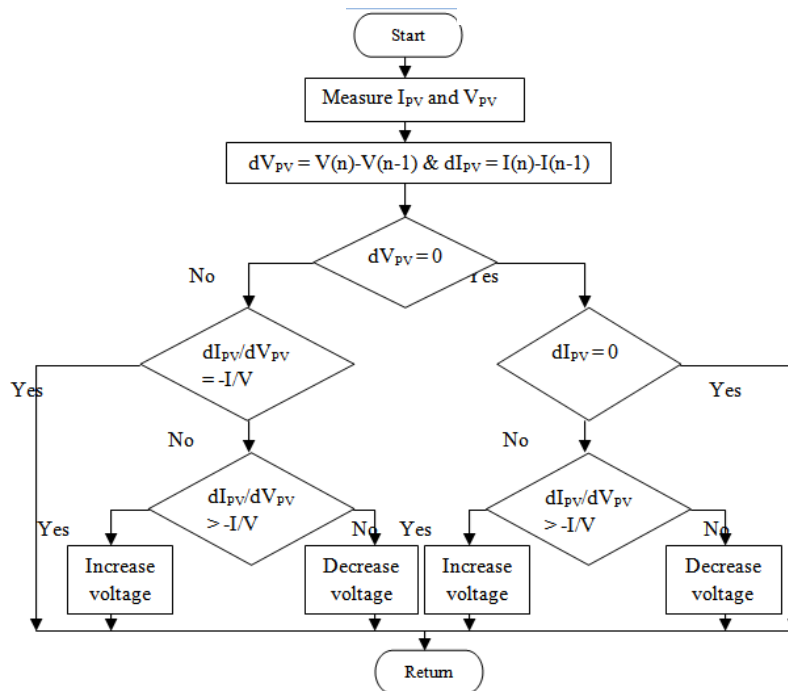


Fig. 2: Flowchart of P&O algorithm [Bhatnagar, 2013].

Table I: Calculation of P&O algorithm.

Current(A)	Voltage(V)	Power(P=A *V)	$\Delta P=P_n-P_{n-1}$	$\Delta V=V_n-V_{n-1}$	dP/dV
0.305	0.171	0.052	0.052	0.171	0.304094
0.344	2.492	0.857	0.805	2.321	0.346833
0.337	5.013	1.689	0.832	2.521	0.330028
0.327	7.534	2.463	0.774	2.521	0.307021
0.327	10.099	3.302	0.839	2.565	0.327096
0.322	12.521	4.031	0.729	2.422	0.300991
0.317	15.092	4.784	0.753	2.571	0.292882
0.313	17.263	5.403	0.619	2.171	0.285122
0	20.028	0	-5.403	2.765	-1.95407

From Table I. it is clear that, if $dP/dV > 0$ then operating point is moving towards MPP and if $dP/dV < 0$ then operating point is moving away from MPP.

The advantages of this algorithm, as stated before, are simplicity and ease of implementation. However, P&O has limitations that reduce its MPPT efficiency. One such limitation is that as the amount of sunlight decreases, the P–V curve flattens out. Another limitation of P&O is that it oscillates around the MPP, as this method becomes unstable with rapid change in atmospheric conditions such as irradiance and temperature. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT. A solution to this conflicting situation is to have a variable perturbation size that gets smaller towards the MPP [Esrām, 2007].

2.5.2 Incremental Conductance (Inc Con) Method. The disadvantage of P&O algorithm, of oscillating the operating point around MPP is removed by Inc Con method by comparing the instantaneous panel conductance (I_{PV}/V_{PV}) with the incremental panel conductance (dI_{PV}/dV_{PV}). The voltage of MPP is tracked to satisfy $dP_{PV}/dV_{PV}=0$, which is MPP [Bhatnagar, 2013].

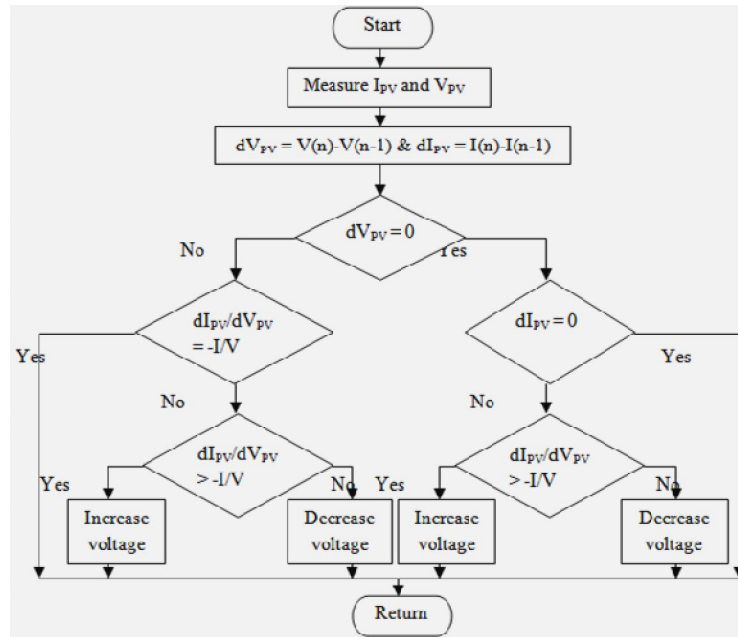


Fig. 3: Flowchart of Inc Con algorithm [Salas, 2006].

Output power of PV module P_{PV} is given by eq. (6).

$$P_{PV} = I_{PV} V_{PV} \quad (6)$$

Differentiating eq. (6) with respect to V_{PV} gives the basis of Inc Con algorithm

$$dP_{PV}/dV_{PV} = I_{PV} + V_{PV} dI_{PV}/dV_{PV} \quad (7)$$

The Inc Con method is based on the fact that $dP_{PV}/dV_{PV} = 0$ or $dP_{PV}/dV_{PV} = -I/V$ at the MPP, $dI_{PV}/dV_{PV} < -I/V$ or $dP_{PV}/dV_{PV} < 0$ if the operating point is on the right of the P–V curve and $dI_{PV}/dV_{PV} > -I/V$ or $dP_{PV}/dV_{PV} > 0$ if the operating point is on the

left of the P-V curve in Fig. 1 [Bhatnagar, 2013 & Hohm, 2003]. A scheme of Inc Con algorithm is shown in Fig. 3. In this algorithm, present and previous values of PV module voltage and current are sensed and are used to calculate the values of dI_{PV} and dV_{PV} . The calculation of Inc Con algorithm is given in Table II as per the I-V curve shown in Fig. 1.

Table II: Calculation of Inc Con algorithm.

Current (A)	Voltage (V)	Power (P=A*V)	$\Delta P = P_n - P_{n-1}$	$\Delta V = V_n - V_{n-1}$	dP/dV	$\Delta I = I_n - I_{n-1}$	dI/dV	I/V	$dI/dV + I/V$	$\Delta V/\Delta P$	$\Delta I/\Delta P$
0.305	0.171	0.052	0.052	0.171	0.304094	0.305	1.7836257	1.7836257	3.567251462	3.288462	5.865385
0.344	2.492	0.857	0.805	2.321	0.346833	0.039	0.0168031	0.1380417	0.154844836	2.88323	0.048447
0.337	5.013	1.689	0.832	2.521	0.330028	-0.007	-0.0027767	0.0672252	0.064448539	3.030048	-0.00841
0.327	7.534	2.463	0.774	2.521	0.307021	-0.01	-0.0039667	0.0434032	0.039436559	3.257106	-0.01292
0.327	10.099	3.302	0.839	2.565	0.327096	0	0	0.0323794	0.032379444	3.057211	0
0.322	12.521	4.031	0.729	2.422	0.300991	-0.005	-0.0020644	0.0257168	0.023652386	3.322359	-0.00686
0.317	15.092	4.784	0.753	2.571	0.292882	-0.005	-0.0019448	0.0210045	0.019059737	3.414343	-0.00664
0.313	17.263	5.403	0.619	2.171	0.285122	-0.004	-0.0018425	0.0181313	0.016288794	3.50727	-0.00646
0	20.028	0	-5.403	2.765	-1.954073	-0.313	-0.1132007	0	-0.11320072	-0.51175	0.057931

The advantage of the incremental conductance method, which is superior to those of the other MPPT algorithms, is that it can calculate and find the exact perturbation direction for the operating voltage of PV modules. Also it is easy to implement, has high tracking speed and highly efficient [Bhatnagar, 2013]. Disadvantage is that it requires complex control circuits [Salas, 2006].

3. Conclusion

In this paper, the various MPPT algorithms has been reviewed. As has been demonstrated, there are many ways of distinguishing and grouping the methods for tracking the MPP to the PV generator. Finally, it has been shown that other methods also exist by which MPP of PV module can be tracked.

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