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Photovoltaic Maximum Tracking Power Point System: Review and Research Challenges

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Abstract : The power production of Photovoltaic (PV) systems depends mainly on solar radiation and temperature. There is one operating point, called maximum power point MPP, where the system extracts maximum power from PV using tracking methods. This is achieved by matching the MPP with its corresponding converter's operating voltage and current. There are many methods and algorithms that have been reported. In this paper different methods are reviewed and presented. Also, comparison between the most known techniques has been done. Moreover, challenges have been highlighted. This paper aims at presenting a review of MPP tracking methods to researchers; designers and engineers dealing with PV systems.

Key words : MPPT, PV systems..

INTRODUCTION

The energy source is one of the main problems in this era and the search for it was and still one of most important concerns of countries. The search for the renewable energy is more important with the passage of time and in post industrial societies became one of the faster growing trends to solve shortfall problem in energy source there is wide range of fields and research to find new solutions [1]-[2]. The solar energy and photovoltaic (PV) is one of the best solutions of these problems especially in terms of cost effectiveness and efficiency. Also, it can be applied in huge area around the world as the resource for it is the available solar radiation [3]. PV is a method to get electrical power from the solar radiation. It's made up of one or more PV panels and the output power is not enough to meet the requirement of buildings that way the modules are connecting to gather as arrays. The capital cost of PV modules is the main drawback in addition to its depending on solar radiation and area temperature [4]-[5].

Maximum power point tracking is technique to get maximum possible power from photovoltaic systems. The best output is not constant because of the complex factors that affect the system such as solar radiation, the temperature and total resistance [6]-[7]. The maximum power point is the optimum point that can be obtained from a device located between PV modules and the load. To track the MPP for PV systems there are many methods proposed to get accurate output [6]-[27]. This study reviews different MPP methods and highlights the research challenges. Finally, a comparison of the main methods has been presented.

MPPT SYSTEM DISCRIPTION

The typical PV system contains of PV modules, batteries, DC-AC inverter, and DC-DC controller. A brief description is given in this section:

PV Module

It can be used to design (Size) a PV array for a given application based on expected power and/or energy Production on an hourly, monthly or annual basis [1]. The solar cells gathering together to collect the sun light, the cells connecting in series and parallel to have the required current and voltage. We call this number of cells in same board PV panel and if different PV panels connected series and parallel then it will be PV array. The PV systems include one or more arrays. The PV panel may be covered by class for protection and usually it lasts for more than 25 years.

Batteries

The batteries are used with PV systems for storage purposes and are important for most of standalone PV systems. Batteries accumulate excess energy created by PV system and store it to be used at night or when required. Batteries can be discharge rapidly and yield more current than that produced by the charging source, so pumps or motors can be run intermittently.

DC-AC Inverter

PV systems generate DC power and since most appliances consume AC power than inverter used for conversion. Inverter circuit used to convert DC power into AC. It consist semiconductor devices used as switches in the conversion process. Inverters could be classified into single-phase and three-phase according to the load [8].

MAXIMUM POWER POINT TRACKING ALGORITHMS

The maximum power extracted from a PV array strongly depends on three parameters: insolation, load impedance and cell temperature. When a PV system is directly connected to a load, the system will operate at the intersection of the I-V curve and load line, which can be far from the MPP. The MPP production is therefore based on the load line adjustment under varying atmospheric conditions. The variation of the output I-V and PV characteristics of a commercial PV module as a function of temperature and

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irradiation shows that the temperature changes mainly affect the output voltage, while the irradiation changes affect the PV output current. Nevertheless, PV systems should be designed to operate at their maximum output power levels for any temperature and solar irradiation levels at all times. Another significant factor which affects the PV output power is the load impedance which is not constant. To match the load resistance to the PV module and extract maximum power from it, the duty cycle is set to its optimal value which corresponds to its optimal operating point (V_{op}, I_{op}), as shown in Fig 1.

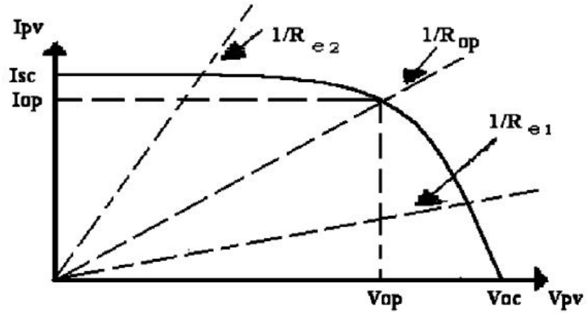

Fig 1: PV system operating points with varying loads

To determine the optimal operating point of voltage and current, a DC/DC converter is inserted between a PV array and a battery. A controller is also connected to the DC/DC converter to ensure the operation of the PV array at its MPP by means of implementing an MPPT algorithm. In the MPPT algorithm, when the solar radiation and temperature are varied, each of the MPP corresponds to only one value of the input resistance of the converter. Thus, as the solar radiation or temperature changes, the value of input resistance seen by the PV modules will also change so as to locate the new MPP. This can be achieved by varying the duty cycle which is then used to control the switching of the converter.

As shown in Figs 2 and 3, for any PV module, there is a unique point on the current-voltage (I-V) and a power-voltage (P-V) curve, called as the MPP, in which at this point the PV system is said to operate at its maximum efficiency and produces its maximum power output. The location of the MPP is not known but can be traced by using MPPT algorithms to maintain the PV array's operating point at its MPP. The MPPT algorithms can be classified as direct and indirect methods. The direct methods include those methods that use PV voltage and/or current measurements. These direct methods have the advantage of being independent from the prior knowledge of the PV generator characteristics. Thus, the operating point is independent of temperature or degradation levels. The direct methods include the techniques of differentiation, feedback voltage, perturbation and observation, incremental conductance, as well as fuzzy logic and neural network. The indirect methods are based on the use of a database of parameters that include data of typical P-V curves of PV systems for different irradiances and temperatures, or on the use of mathematical functions obtained from empirical data to estimate the MPP. In most cases, a prior evaluation of the PV generator based on the mathematical relationship obtained from empirical data is required.

The methods belong to this category include the use of curve fitting, look-up table, open circuit and short circuit PV voltages.

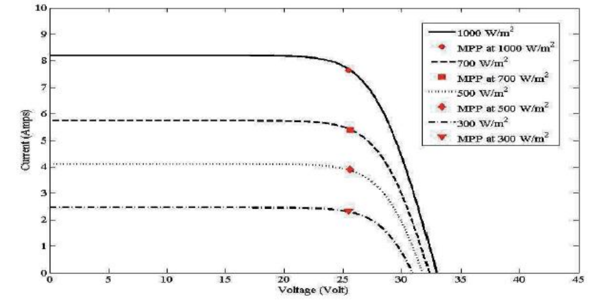

Fig 2:2 I-V Curve under different values of radiation

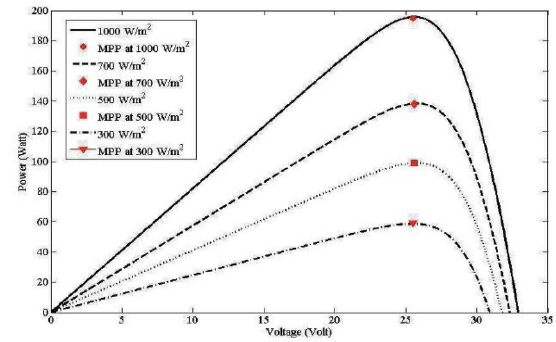

Fig 3:3 P-V curves under different values of radiation

MPPT METHODS

Curve Fitting (CF)

The curve-fitting techniques classified as an offline technique. Using two parameters: first one is the power gain G, and the second one is the environmental operation parameter X. The gain G becomes larger under the same environmental conditions, because of the increase of X [9]. This method is based on different models of PV panels and uses mathematical equations for these models. The voltage consistent to MPP is calculated and the operating point on the characteristics of the panel is moving [10]. One of such model, where PV panel characteristic determined using equation 1 and 2, where *α, β, γ*, and *δ* are coefficients determined by sampling *k* values of PV panel output voltage V_{PV}, PV current I_{PV} and output power P_{PV} [26]. When the factors are calculated the voltage at MPP can be calculated by using Eq:

$$p_{pv} = aV_{PV}{}^{3} + \beta V_{PV}{}^{2} + \gamma V_{PV} + \delta \qquad (1)$$

$$V_{MPP} = \frac{-\beta \pm \sqrt{\beta^2 - 3\alpha\gamma}}{3\alpha} \qquad (2)$$

The advantage of curve fitting method is its simplicity , because no differentiations are to be calculated. The disadvantage of this method is that it needs prior knowledge of the PV model, the mathematical equations of method and parameter dependence on cell material and specifications. Also, it requires large memory because of the number of calculations is large. Speed is less as large computation time is required to calculate α, β, *γ*, and *δ* for different environmental conditions.

Look up Table (LUT)

Look up table is classified as an offline method of MPP tracking. This tracking method is achieved by changing the duty cycle of step-down chopper and controlled by voltage controller. The controlled voltage of tracker obtained by measuring the open circuit voltage and searching in look –up table stored [15]. In look- up table method, the prior knowledge of PV panel material, like technical data, panel characteristics at different environmental conditions, is required. The PV panel output voltage V_{PV} and output current I_{PV} are sensed and the output power is calculated. The power is then compared with the stored values to track MPP and shifted the operating point to new maximum power point. The system needs to store large amount of data before actually tracking MPP. Therefore, the disadvantage of this method is its large memory requirement to store prior data. Also, the system becomes complex for changing atmospheric conditions [8], [25]. Moreover, the speed of this method is slow and it is not very accurate method of MPP tracking, and need more number of sensors.

Open Circuit Voltage (OCV)

This method is classified as an offline method. This method depends on the relation between MPP voltages V_{MPP} and open circuit voltage:

$$V_{MPP} \approx K_{MV} . V_{oc} \quad (3)$$

K_{MV} the voltage factor depends on PV panel. The MPPT momentarily sets the PV array current to zero by open circuit and measure V_{oc} then V_{MPP} is calculated according to above formula. The MPPT controller then, controls the duty cycle to obtain load voltage equals to V_{MPP}. This process is repeated periodically to get maximum power. The system requires a DC to DC converter which operates in buck or boost type. The driver circuit for this converter and also the shunt and the series switch are controlled by a microcontroller [27].

Short Circuit Current (SCC)

In this method maximum power is obtained during the entire operating the current based technique

$$I_{MPP} \approx K_{MI} . I_{sc} \quad (4)$$

I_{MPP} and I_{sc} are PV panel current during MPP and short circuit condition [16]. K_{MI} is a proportionality constant called current factor and its value varies from 0.7 to 0.9 depending on cell material and characteristic of panel used [25]. Where did not take in to account the temperature dependency in the above equation, since K_{MI} is not always constant, but varies with the surface conditions of the PV panel. Eq. 4 is plotted in Fig. 4. Hardware consists of a shunt switch (power electronic) for measurement of short-circuit current.

Short circuiting the panel [7], the I_{MPP} can be computed by using proportional controller after a hold circuit whose coefficient is K_{MI}. Short-circuit current of the panel(I_{sc}) is sampled periodically and from Eq 4 once K_{MI} is known, I_{MPP} can be calculated for different sampled values of I_{sc}. The duty cycle of DC/DC converter is increased or decreased so that output current to $I_{MPP,}$ at constant temperature and different insulations [8].

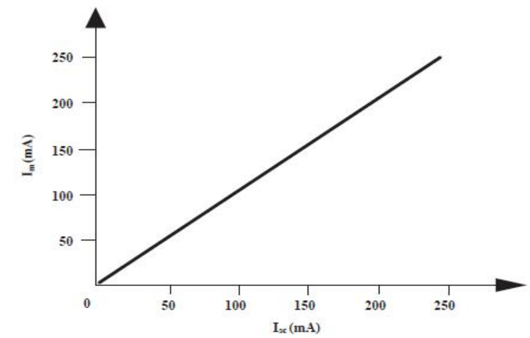

Fig 4:4 Plot pertaining to equation 4.

Differentiation Method (DM)

These methods generally depend on numerical differentiation which is a process of finding a numerical value of a derivative of a given function at a given point [17].

Perturbation and Observation (P&O)

The perturbation and observation (P&O) method is an iterative method for obtaining the MPP and it is a commonly used MPPT algorithm.

Incremental Conductance (IC)

Another widely used method for determining the MPP is the incremental conductance (IC) which is derived by differentiating the PV power with respect to voltage and setting the result to zero.

Since P&O and IC methods are the most two used methods then discussing and comparison them is essential in this study.

P&O METHOD

The perturbation and observation is an iterative method for obtaining the MPP and it is a commonly used MPPT algorithm. It is widely used in PV systems due to its simplicity and implementation [19]. It senses the panel operating voltage periodically than calculates and compares the PV output power with the previous power, and operating voltage by varying the duty ratio and change in the direction of power is observed to track MPP [18].

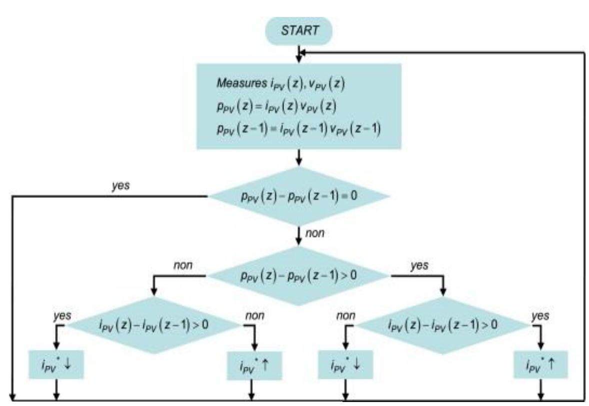

Fig 5: Flow chart of the P&O algorithm [20]

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The P&O algorithm has the benefit of being simple to be implemented in its basic form. It depends on the incremental step size for the change in current reference amplitude PV and the calculation step size as shown in the flowchart in Fig 5. The PV system has characteristic of the power P_{PV} and the current I_{PV} that is illustrated by the curves in Fig 6.

First from an operating point A, a perturbation Δi will carry the operating point to B. Because of the decrease in power and an increase in current between these two points, the perturbation will be reversed with the I_{PV} algorithm decrement [19]-[20].

When irradiance increases the power curve shift from p_{1PV} to p_{2PV} within one sampling period, the operating point will be C. This represents an increase in power because P_C _ P_B > P_A _ P_B, The perturbation is kept the same. As a result, the operating point diverges from the MPP and keeps diverging if the irradiance steadily increases. The algorithm will be able to converge toward MPP from the operating point, when an irradiance variation the condition P_C_P_B > P_A_P_B is fulfilled [20].

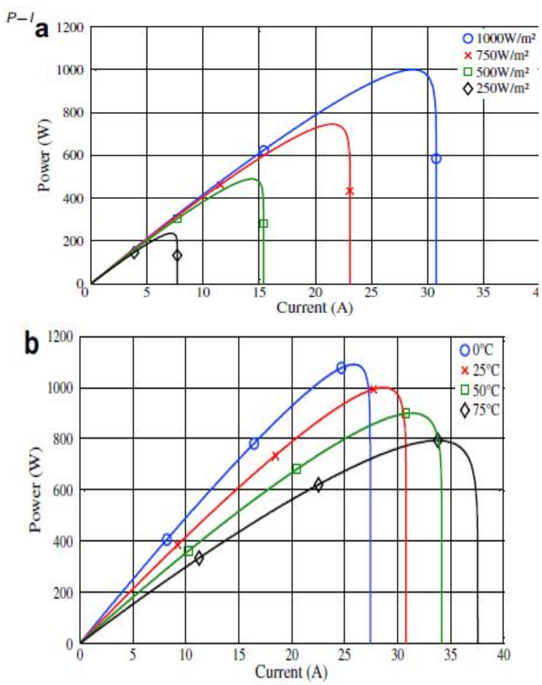

Fig 6: P-I characteristics of the PV system according to the irradiance (a) for T= ¼ T and to the cell temperature (b) for G = ¼ G [20].

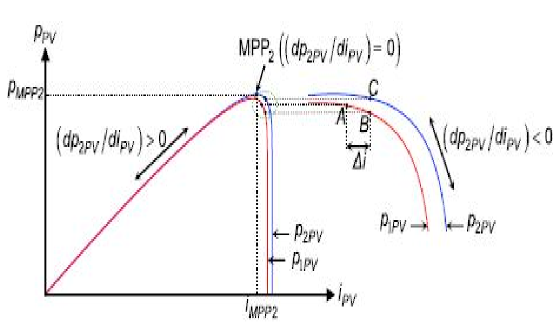

Fig 7: Divergence of P&O from MPP

IC METHOD

IC is one of the MPPT methods which are based on the fact that slope of the PV array power curve is zero at the MPP. The slope is decreasing on the right of the MPP and increasing on the left hand side of MPP

$$\frac{db}{dv}=0, \qquad \text{at MPP} \tag{5}$$

$$\frac{db}{dv}<0, \qquad \text{Right of MPP} \tag{6}$$

$$\frac{db}{dv}>0, \qquad \text{Left of MPP} \tag{7}$$

This method consists in using the slope of the derivative of the current with respect to the voltage in order to reach the maximum power point [22]. Fractional-order incremental changes of the PV array terminal to quickly track the maximum output power. For maximum power transfer from the PV array to the load terminal, by adjusting the duty cycle the DC/DC converter as a DC transformer can match the optimum load array [23]. In other terms the *dv/dp* must be equal to *-1/v* by applying a variation on the voltage toward bigger or smaller value influence appears on the power. If the power increases one continues varying the voltage in the same direction, if not, one continues in the inverse direction.

IC is derived by differentiating the PV power with respect to voltage and setting the result to zero,

$$\frac{dP_{pv}}{dV_{pv}}=I_{pv}\frac{dV_{pv}}{dV_{pv}}+V_{pv}\frac{dI_{pv}}{dV_{pv}}=I_{pv}+V_{pv}\frac{dI_{pv}}{dV_{pv}}=0 \tag{8}$$

$$\frac{-I_{pv}}{V_{pv}}=\frac{dI_{pv}}{dV_{pv}} \tag{9}$$

The left-hand side of (8) represents the opposite of the instantaneous conductance, $G=dI_{pv}/dV_{pv}$, whereas the right hand side of the (8) represents its incremental conductance. The incremental variations, dV_{pv} and I_{pv}, can be approximated by the increments of the parameters, ΔP_{pv} and ΔI_{pv}, with the aim of measuring the actual values of dV_{pv} and I_{pv}. The incremental variations dV_{pv} and I_{pv} are expressed as follows:

$$dV_{pv}(t_2)\approx \Delta V_{pv}(t_2)=V_{pv}(t_2)-V_{pv}(t_1) \tag{10}$$

$$dI_{pv}(t_2)\approx \Delta I_{pv}(t_2)=I_{pv}(t_2)-I_{pv}(t_1) \tag{11}$$

Figure 8 shows the basis of the IC method.

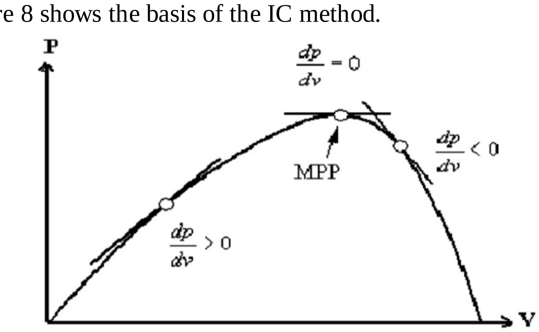

Fig 8: The basis of the IC method

Fig 9 shows the tracking algorithm of the IC method. The tracking starts with measuring the module's voltage and current at two time instants, t_1 and t_2. The difference between the measured values are represented by dV_{pv} and I_{pv} and then the voltage of the PV module increased by C until making the left and right sides of (8) equal.

The main advantage of the IC method is that it offers a good yield under rapidly changing atmospheric conditions. In addition, it has lower oscillation around the MPP as compared to the P&O method. The MPPT efficiencies of the IC and P&O methods are, essentially, the same. However, implementing the methods in hardware it requires complex control circuit which may result in high cost.

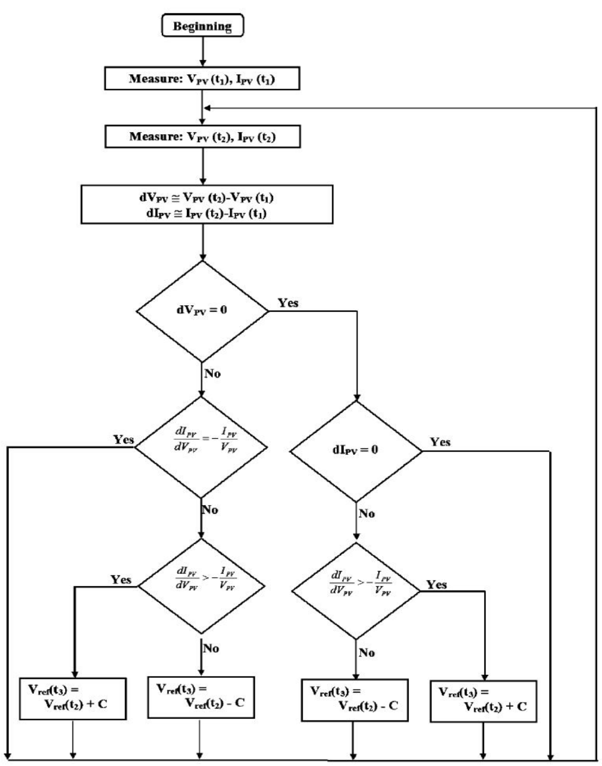

Fig 9: Incremental conductance method

COMPARISON AND DISCUSSION

P&O and IC methods have widespread in PV application. There are many studies and improvements that had been made on P&O and IC. For P&O, the strong point of this method is its simplicity and good accuracy of tracking. However, the speed of transient tracking is slow. The accuracy of tracking in IC method is high and speed of transient is fast. Both of P&O and IC methods have been developed to other new methods called modified P&O and modified IC to improve the speed and accuracy and comparison is shown in Table 1.

Table 1: Comparison between different MPP methods

Criteria	CF	LUT	OCV	SCC	P&O	IC
Tracking accuracy	Low	Low	Low	Low	Medium	High
Transient tracking speed	Slow	Slow	Slow	Slow	Medium	Fast
Sensors	voltage	Current and voltage	Current and voltage	Current	Current and voltage	Current and voltage
Classification of techniques	Offline control	Offline control	Offline control	Offline control	Online control	Online control
Cost	Not expensive	Not expensive	Not expensive	Not expensive	expensive	expensive
Complexity	simple	simple	simple	simple	simple	complex

Open circuit voltage and short circuit current methods are fast as no derivatives are required to be calculated, and are practical method for MPP estimation. The current based method is more complicated and expensive as compared to voltage based method, accuracy of current based technique is more compared to voltage based technique where as voltage based technique is more efficient and has fewer losses. IC method is advantageous as compared to P&O method in case of fast changing environment parameters. Also, the number of required sensors for IC is more and the cost is high.

CONCLUSIONS

In order to maximize the energy extracted from the PV array, a maximum power point tracking method is needed to find and maintain the peak power. This paper reviews different MPPT techniques reported in literatures, used in photovoltaic system. The working principle of these methods have been discussed and compared against each other in terms of some critical parameters such as accuracy, speed, complexity, cost, and tracking efficiency. The tabular comparison provided at the end of the paper, should be helpful in choosing appropriate MPPT method. Due to the number of different MPPT methods, it could be concluded that the MPPT is still a very active research area.

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