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New Maximum Power Point Tracking Technique Based on P&O Method

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Abstract

In the most described maximum power point tracking (MPPT) methods in the literatures, the optimal operation point of the photovoltaic (PV) systems is estimated by linear approximations. However, these approximations can lead to less optimal operating conditions and significantly reduce the performances of the PV systems. This paper proposes a new approach to determine the maximum power point (MPP) in order to increasing the system efficiently as much as possible. The proposed algorithm is a combination of two loops, set point calculation and fine tuning loops. In first stage, the maximum power is approximated based on the nonlinear modeling of the PV panels by using the set point loop. In second stage, the exact amount of the maximum power will be tracked by the fine tuning loop, which is based on the Perturbation and Observation (P&O) method. The proposed method is simulated in MATLAB/SIMULINK software environment. The simulation results demonstrate that the approach clearly improves the tracking efficiency of the maximum power available at the output of the PV panels. The new method reduces the oscillations around the MPP as well as increases the average efficiency of the obtained MPPT. The new MPPT method will deliver more power to any generic load or energy storage media.

Keywords: Maximum Power Point Tracking, Photovoltaic, Perturbation and observation, hybrid method.
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1. Introduction

Renewable energy power conversion systems have been increasingly developed during the last decades. Among the renewable resources of energy, solar energy provides a suitable option for a variety of applications mainly due to the possibility of direct conversion to electricity by using PV systems. Nevertheless, utilizing the PV systems as an alternative source of energy requires a substantial amount of investment. In this regard, extraction of maximum power from the solar cells in an important factor at optimal designing and reducing the overall cost of PV systems.

In the maximum power point tracking (MPPT) methods, two important issues in the PV system are required to be considered; the first change is the irradiation intensity, which includes the ambient temperature and load impedance, and the second issues is the physical parameters, which are related to the solar cell materials. It is worth mentioning that the characteristics of the solar cell materials are changed with the passing the time and these materials are usually faced with aging phenomena [1, 2]. Most of the proposed MPPT in the previous researches are related to the first change. Therefore, the PV systems can continuously operate on the maximum power points irrespective of load variation, solar radiation and temperature changes. However, most of them require accurate knowledge about the physical parameters relating to the solar cell materials and manufacturing specification; while, this information are mainly unavailable for users. In additions, some physical parameters of the solar cell materials are changed with the passing the time and increasing lifetime. The maximum power point tracking, not only increases the delivered power from the PV module to the load, but also enhances the operating lifetime of the PV system [3].

In recent decays, many MPPT methods have been developed and implemented [4-6]. These methods can be categorized from different points of view such as the types of required sensors, convergence speed, cost, range of effectiveness, implementation of the required hardware and popularity [6].

In [6], different MPPT methods have been divided to three categories: offline methods, online methods and hybrid methods. The offline methods, which are dependent on solar cell model, have quick response .These methods such as neural network [7], Open Circuit Voltage [8] and Short Circuit Current [9] need to re- periodically regulation of the parameters during lifetime. The online methods, which do not specifically rely on modeling of the solar cell behavior, have accurate response. In these methods such as Perturbation and Observation (P&O) [10], Incremental Conductance (IncCond) [11] and Extremum Seeking Control method (ESC) [12], the parameters have been regulated once by user just at start-up. The hybrid methods are implemented based on the advantages of offline and online methods to improve the accuracy, speed and robustness of tracking. In these methods such as [13, 14, 15], the response speed will be decreased, and need to re-regulation of parameters that related to PV model.

In this paper, a hybrid approach is presented to track the maximum power point (MPP) which is robust against changing the physical parameters of solar cell during lifetime; it is shown that the proposed method is able to track the maximum power very effectively in spite of its simplicity. This method is able to tracking MPP over the lifetime with the accuracy and speed like the beginning time. Therefore, this method is recommended for some unhandy applications of PV systems such as satellite. This article is managed in following sections; an overview of photovoltaic systems and solar panel models is provided in section 2. The proposed method by this paper to track the maximum power is presented in section 3. In section 4, the simulation results are provided and finally some important aspects of the proposed method are discussed in section 5.

2. System Overview

Boost converters, buck converters and buck-boost converters. Choosing the type of DC–DC voltage converter depends on the level of voltage variations. Installing the battery allows the photovoltaic system to behave as a real source to In order to study MPPT for PV systems, one first needs to know how to model the PV device that is connected to the converter and load. Figure (1) shows the PV system that consists of solar panels, DC–DC voltage converters, controllers and batteries.

DC–DC voltage converters are used to match the characteristics of the load with solar panels. DC–DC voltage converters are classified into three categories as the feeder so that it may exhibits constant voltage level for different power (load) levels. The battery is also required to save power and temporary compensation of power variation. The mathematical model of PV panel is briefly presented in following.

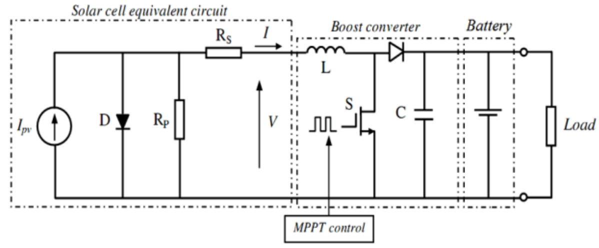

Fig. 1. Photovoltaic system

A solar panel is composed of several photovoltaic cells that have series, parallel or series-parallel external connections. Equation (1) shows V-I characteristic of a solar panel [16].

$$I = I_{PV} - I_O\left[\exp\left(\frac{V+R_S I}{aV_t}\right)-1\right]-\frac{V+R_S I}{R_P} \quad (1)$$

Where I_{PV} indicates the photovoltaic current, Io shows saturated reverse current, 'a' represents the ideal diode constant, $V_t = N_S K T q^{-1}$ shows the thermal voltage, NS indicates the number of series cells, q is the electron charge , K represents the Boltzmann constant, T is the temperature of p-n junction, R_S and R_P are series and parallel equivalent resistance of the solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is dependent to temperature variations. Values of I_{PV} and I_O are calculated according to the following equations:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \quad (2)$$

$$I_O = \frac{I_{SC,n} + K_I \Delta T}{\exp\left(V_{OC,n} + K_V \Delta T\right)/aV_t - 1} \quad (3)$$

where, $I_{PV,n}$, $I_{SC,n}$ and $V_{oc,n}$ are photovoltaic current, short circuit current and open circuit voltage in standard conditions (T_n = 25 C and G_n= 1000 Wm^{-2}) respectively. K_I is the coefficient of short-circuit current to temperature, $\Delta T = T - T_n$ is the temperature deviation from standard temperature, G is the light intensity and K_V is the ratio coefficient of open circuit voltage to temperature.

Open circuit voltage, short circuit current and voltage – current corresponding to the maximum power are three important points of I-V characteristic of Solar Panel. These points are changed by variations of atmospheric conditions. By using equations (4) and (5) which are derived from PV model, short circuit current and open circuit voltage can be calculated in different atmospheric conditions.

$$I_{SC} = \left(I_{SC,n} + K_I \Delta T\right)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = V_{OC,n} + K_V \Delta T \quad (5)$$

3. Maximum Power Point Tracking

In order to determine the optimal operating point which is correspond to the maximum power P, the system is modeled for various levels of solar radiation and temperature, and numerical methods can be used to show the linear relationship between the optimal current and the short circuit current [9,17]. The basic equation can be given as follows:

$$I_{MPP} = K_i I_{SC} \quad (6)$$

where K_i shows the current ratio constant. In this method, direct measurement of I_{SC} leads to decreasing the efficiency of method as well as there is no guarantee to accurate MPPT. In this respect, the main idea of the proposed method is to calculate the I_{SC} based on the governing model and fine-tuning of solar panel set point on MPP. A similar approach, based on the linear approximation of the optimal voltage relative to the open-circuit voltage has been presented in [14]. The presented method in [14] is a simple hybrid method and its algorithm comprises two stages; the first one is to estimate the voltage of maximum power point (V_{MPP}) and the second is to track the exact maximum power point.

In this section, an improved hybrid method for MPPT is proposed based on the relationships of PV model. In this method, instead of calculating V_{MPP}, the current of the maximum power point (I_{MPP}) is calculated. This procedure leads to better efficiency and higher accuracy [9].

The overall algorithm of the improved hybrid MPPT method is shown in Figure (2). The first part of the algorithm is Initialization. The initial values of the photovoltaic system parameters are divided into two categories. The first group concerns the solar panel data, which are provided by the manufacturer. The second group consists of the parameters which are used to track the maximum power point (MPPT) or modeling PV panel that must be evaluated by the operator.

In this method in addition toK_i, K_{sc}, V_{oc}, n,… in which are from the first group; a, $R_s$and R_p are initial values that must be determined by operator. These three values are determined by substituting three points of ($0,I_{SC}$, n), (V_{oc},n, 0) and (V_{MPP},n, I_{MPP},n) of standard panel conditions (G_n= *1000* W_{M-2}, T_n=*25*) in equation (1) and solving the set of equations (7).

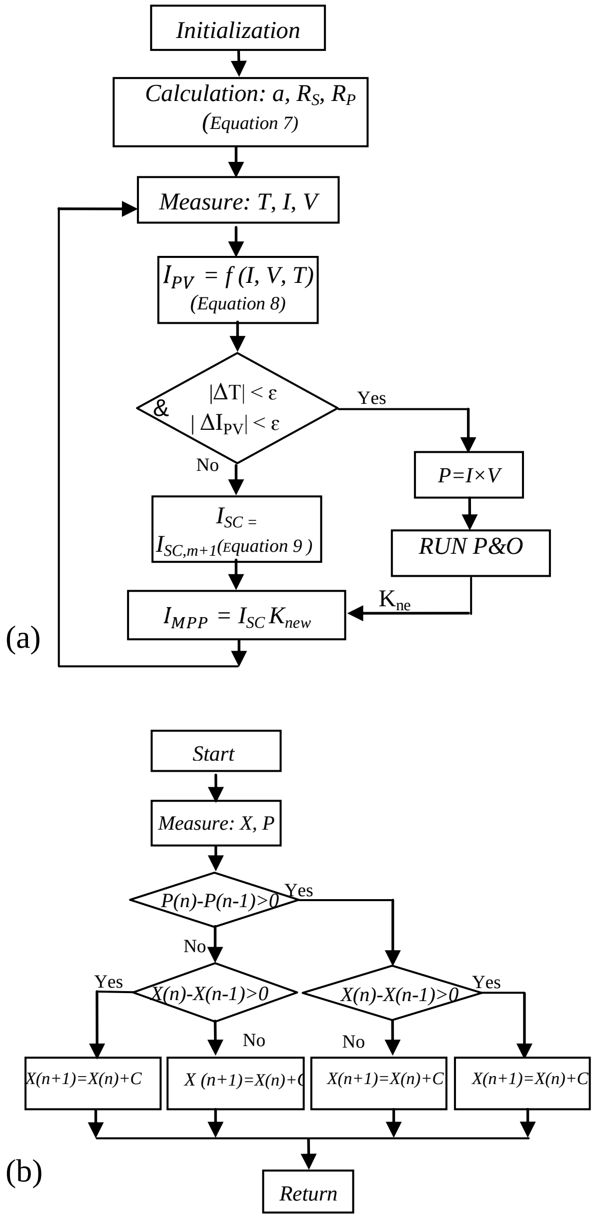

Fig. 2. a) Overall algorithm of the improved hybrid MPPT method, b) P&O method

$$\begin{cases} I_{SC,n} = I_{PV,n} - I_{O,n}\left(\exp(\dfrac{I_{SC,n}R_S}{aV_{T,n}}) - 1\right) - \dfrac{I_{SC,n}R_S}{R_P} \\ 0 = I_{PV,n} - I_{O,n}\left(\exp(\dfrac{V_{OC,n}}{aV_{T,n}}) - 1\right) - \dfrac{V_{OC,n}}{R_P} \qquad \rightarrow a, R_S, 1 \\ I_{MPP,n} = I_{PV,n} - I_{O,n}\left(\exp(\dfrac{I_{MPP,n}R_S}{aV_{T,n}}) - 1\right) - \dfrac{I_{MPP,n}R_S}{R_P} \end{cases} \quad (7)$$

The instantaneous values of voltage, current and temperature of the solar panel are measured. All parameter and variable related to modeling PV panel that is presented in section two are determined except light intensity or I_{PV}. With initial and measurement values, I_{PV} which is the only variable dependent on light intensity will be calculated by using equation (8). In this equation, V_T and I_o which are temperature dependent are updated by using $V_t = N_S KTq^{-1}$ and equation (3).

$$I_{PV} = I + I_O\left(\exp(\frac{V+IR_S}{aV_T})-1\right)+\frac{V+IR_S}{R_P} \quad (8)$$

After calculating I_{PV} that is approximate value of ISC, exact value of this current can be calculated by using equation (9). I_{SC} of the previous iteration will be substituted (equation 9). After m iteration, I_{SC} does not change which indicates the convergence of the short circuit current. Parameter 'm' is a small integer because of I_{PV}, which is the first estimation of I_{SC}, is very close to it. In other words, in a few iterations I_{SC} will be found with an acceptable approximation.

$$I_{SC,1} = I_{PV}$$
$$I_{SC,m+1} = I_{PV} - I_O\left(\exp(\frac{I_{SC,m}R_S}{aV_T})-1\right)-\frac{I_{SC,m}R_S}{R_P} \quad (9)$$
$$m = 1,2,...m \quad , \quad I_{SC} = I_{SC,m+1}$$

In the proposed method, the fine tuning loop is used to correct the calculation of the I_{SC} in order to compensate the effect of the measurement error and possible model mismatch of solar panel. In this method, In the case of small variations of temperature and I_{PV}, the fine tuning loop regulates output power. Since I_{PV} varies with radiation intensity, it can be inferred that the fine tuning loop will be run when atmospheric conditions are approximately constant. Consequently, because in rapid changes of atmospheric conditions the fine tuning loop is not run, the amplitude of the perturbations of the P&O algorithm does not need to be great which leads to small variations of power in steady state conditions around the optimal value.

4. Simulation and Results

The photovoltaic system shown in Figure (1) consists of a 60 Watt solar panel and its specifications are given in Table 1, a boost voltage converter, a 36 V lead-acid battery with maximum current rating of 5 A. The system is simulated by using the MATLAB/SIMULINK software and the proposed method is implemented in the software environment as MPPT controller to study the dynamic and steady state performance of proposed method and comparison it with the last method [14]. In following, the simulation results are presented in two subsections as set point calculation and fine-tuning.

A) Set point calculation

It is clear that if set point calculation is done very best, tracking the MPP will be done in high level efficiency. In Figure (4), power and voltage of photovoltaic panel are shown when method of [14] and proposed method are used to track MPP. In this case, sunlight and temperature are changed as figure (3).

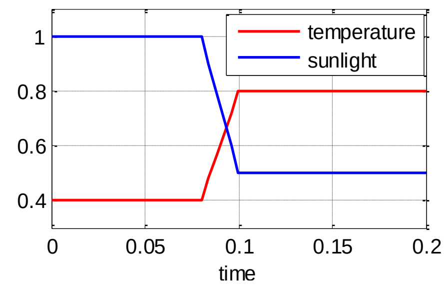

Fig. 3. Variations of sunlight and temperature

Set point calculation loop in method [14] comprises two approximately linear relationships, one of relationship that is use to calculate approximately amount of V_{oc}, is extracted from PV model relations, another one relationship that is used to estimate V_{MPP}, is between the open circuit voltage (V_{oc}) and the maximum power point voltage (V_{MPP}) ($V_{MPP} \approx KV_{oc}$). In this equation, K is a constant that must be determined by operator based on the trial and error method. This constant is not equal for two PV panels, also for a PV panel; there is not an optimal value for this constant that be able to cover all atmosphere condition. P-V characteristic curve can be divided in three terms as before MPP (V_{PV}<V_{MPP}), after MPP (V_{PV}>V_{MPP}) and MPP (V_{PV}=V_{MPP}). Initial estimation is placed at one of these partitions. The location of initial estimation is recognized based on the improvements of voltage in this figure. Figures 4a, 4b and 4c show results of the presented method by [14] under different values of K. Voltage curve of Figure 4a, show that initial estimation is placed after MPP. It should be noted that the slope of the P-V characteristic curve is greater for voltages than V_{MPP} in comparison with the smaller voltages meaning that a small change in voltage leads to a great change in power of the solar panel as shown in Figure 4a. In Figure 4b, constant K is determined such as the estimated MPP voltage is smaller than V_{MPP}. In Figure 4c, constant K is determined such as the estimated MPP voltage is approximate V_{MPP} of the solar panel, but in this case, when atmospheres conditions has changed, new estimated MPP is a few far from real MPP in comparison with two previous cases.

Figure 4d, shows result of the MPPT with the proposed method. According to this figure, estimated MPP is successfully carried out. Set point calculation loop in this method is performed based on the non-linear relationships that is extracted from PV model relationship to calculate I_{PV} and approximately linear relationship between short circuit current (I_{SC}) and the maximum power point current (I_{MPP}) ($I_{MPP} \approx KI_{SC}$) that is more accurate than $V_{MPP} \approx KV_{OC}$.

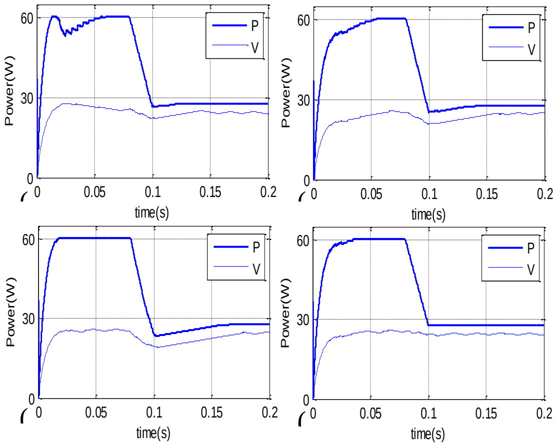

Fig. 4. Power and voltage of photovoltaic panel for (a, b, c) method of [14] and (d) proposed method

B) Fine tuning loop

Tracking the accurate value of maximum power will be achieved in this loop based on the online methods. In this regard, the responsibility classical method P&O is used in the presented method by [14] and the proposed method. Because of the initial amount of the V_{MPP} in method [14] and I_{MPP}, the propose method is estimated by set point calculation loop, convergence is fast and there is no need to use large disturbance in classical method P&O that generate disturbance in output power of PV panel in steady state. Figure (5) shows the effects of the variations amplitude disturbances on output power and voltage for the proposed method.

It is clear that the frequency of disturbance does not affect on the efficiency of the proposed method in steady state condition. In other words, the average voltage of maximum power and the area under the power curve are constant for different frequencies. However, reducing the disturbances amplitudes leads to reduce the voltage oscillations, increasing the area under the power curve and improving the efficiency of the system.

C) MPPT & PV lifetime

Some MPPT methods which have already been presented by researchers [7, 8, 9, 18] need to reregulate the parameters to guarantee the efficiency; while, the proposed method is simple and robust against changing in the parameters over the whole lifetime. In this method, in first the temperature and instantaneous voltage and current are measured under fixed atmospheric condition, then, a unique characteristic curve is considered for PV panel. This curve will be constant while the atmospheric conditions are constant. In fact, in this method, characteristic curve of PV panel for each atmospheric condition is modelled as well as classic P&O is incorporated to guarantee the accuracy of MPPT approach. In table 1, some of different methods are categorized based on the necessity of reregulation.

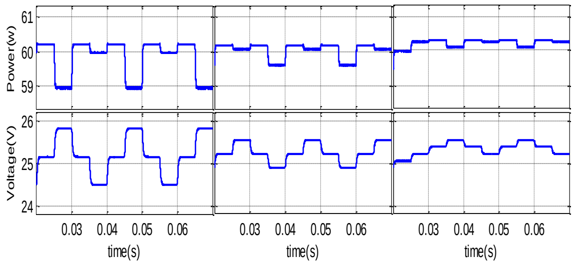

Fig. 5. Effects of the variations amplitude of disturbances on the output power and voltage

Table.1.
Categorized of the different methods

Methods	***Reregulation? yes/no***	***Reference***
Open circuit voltage	Yes	[8]
Short circuit current	Yes	[9]
Artificial neural networks	Yes	[7]
Fuzzy logic	Yes	[18]
P&O (fixed perturbation size)	No	[19]
P&O (variable perturbation size)	No	[10]
IncCond	No	[11]
ESC	No	[12]

5. Discussion

A) Robust and efficiency

MPPT method for photovoltaic systems must be robust. Since, in some of its applications such as power supply in satellite, photovoltaic systems are not available to reset the MPPT controller. Model-free methods are robust and provide self-tuning, but drifting of the operating point during changing atmospheric condition and trade-off between dynamic and steady state requirements are two drawbacks of these methods [20]. But, the proposed method based on PV modeling relationships guarantees the accurate estimation of MPP. This method is robust and provides high efficiency because of new parameters of PV panel that are used for MPPT, Some of the parameters will be extracted when the algorithm once fully implemented.

B) Dynamic response

The proposed method suitably approximates the MPP during start-up time and appropriately tracks the MPP following rapid changes in the atmospheric conditions. As mentioned in the first section, P&O method does not provide suitable response to the rapid changes, but fine tuning loop at the proposed method, which is based on the P&O method, is not run in rapid changes of the atmospheric condition.

C) Stability issue

The set point loop is run when the changes in temperature and sunlight (I_{PV}) are large, but the fine tuning loop is run under the following cases: (1) immediately following the set-point loop (2) when the temperature changes are small (3) when intensity changes are occurred. In the two latter cases, the operations of the two loops do not interfere with each other. If each of the two loops is stable, stability of the entire algorithm is guaranteed. On the other hand, in the presence of large temperature changes when the set point loop is running, there will be no discernible oscillations as the set-point loop converges quickly by positioning the search directly on the MPP. Furthermore, since our approach is based on the classical P&O method employing a small perturbation amplitude and low frequency, there will be minimal interference between the two loops and stability is not a major concern.

D) Simplicity and implementation

The proposed method is completely simple. In first, a linear relationship is used to estimate I_{MPP} as given by Equation (6) and the MPP can be easily estimated by using the known solar panel characteristics. Second, the simple classical P&O method is used to track MPP relatively accurately.

Easy implementation is an important factor to decide which MPPT technique should be used. However, this issue greatly depends on the end users' knowledge. Simplicity of method and the number of sensors required to implement MPPT also affects on the decision making process. By using the irradiance sensor, effects of random cloud move on the electrical variables of the MPPT exacerbate. Most of the time, it is easier and more reliable to measure the voltage than current.

6. Conclusion

A new MPPT method based on the nonlinear approach was developed to estimate the optimal operating point. Based on the proposed method, it is possible to adapt the load to the PV modules as well as following the MPP in coordination with changing the weather conditions. The proposed method was simulated in the MATLAB software. Simulation results of this new approach showed that the tracking efficiency of the MPP is better than last hybrid methods. The proposed method demonstrated acceptable efficiency and excellent performance during start-up time following rapid changes in the atmospheric conditions. Implementation of such a method in PV systems will increase the delivered power to any generic load or energy storage media.

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