A Research and Improvement on a Maximum Power Point Tracking Method for PV System under Partially Shaded Conditions

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Abstract

The output characteristic of Photovoltaic cells is nonlinear. When PV module is under partially shaded conditions, the output power-voltage curve contains multi-local maximum points. This paper presents a new complex algorithm to track the maximum power point (MPP) in complex conditions. This algorithm is used in photovoltaic energy system simulation model what established in PROTEUS simulation platform, and proved that it can track maximum power point of PV module more quickly and accurately than other algorithms.

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1. Introduction

As the deepening of energy crisis, many governments have introduced incentive policy to develop green energy. More and more families begin to use solar energy, and install photovoltaic system on the roof and walls. When the clouds, buildings or other objects cast shadow on the PV module, it will cause the system to "mismatch" problem, and lead to electricity generation decline.

Maximum power point tracking (MPPT) is usually a major component of photovoltaic power generation system. Although researchers have developed a variety of MPPT algorithm, but these conventional popular methods (such as: P&O, InCond, RCC, dual-mode, etc.) are effective just when PV module under uniform solar irradiance. However, because of the multi-local maxima point which can be existed on P-V characteristic curve under partially shaded conditions, these MPPT methods can fail to...
track the real MPP. Actually, it’s found that the power loss of commercial power conditioning system (PCS) can be as high as 70% under partially shaded conditions [1]-[4].

In this paper, a new MPPT algorithm that is capable of tracking the real MPP under partially shaded conditions is proposed. This algorithm improves the original conventional composite MPPT algorithm [5], adds new calculation parameters, and uses a more streamlined and flexible algorithm program tracking the real MPP. The performance of proposed MPPT algorithm is analysed according to the position of real MPP and is verified by simulation and experimental results. In the non-uniform sunlight or rapid change of sunlight conditions, it can quickly and accurately track the maximum power point.

2. Characteristic analysis of PV modules in series under partially shaded conditions

PV module is composed of a number of photovoltaic cells in series, to obtain the required voltage. For protect the module from the damage of hot spot, we parallel a bypass diode on each PV modules. When all PV modules are under the same solar radiation conditions, there is only one MPP on the P-V curve of PV modules. However, under partially shaded conditions, there will be more than one local MPP in the P-V curve of PV modules.

The PV module we designed in this paper is based on MSX-83 PV panels. It consists of 18 single polycrystalline silicon photovoltaic cells in series. Its short-circuit current is 4.3A, open circuit voltage is 10.5V, maximum power is 29.7Wp. In experiment, we divided PV module into three parts: SUN1, SUN2 and SUN3, it is shown in Fig.1. In this design, load is 12V battery, ambient temperature is 25℃. When three groups of photovoltaic cells are not affected by the shade, the P-V curve under the standard light intensity (1000W/m²) is shown in Fig.2 (a). As shown in Fig.2 (b), the P-V curve is under partially shaded conditions. SUN1 is not blocked, SUN2 is under 0.2 times standard light intensity, and SUN3 is under 0.6 times standard light intensity. In the curve, only one local maximum is the real MPP.

Fig.1 18 single photovoltaic cells composed PV module in series (10th, 16th and 18th single photovoltaic cells are blocked).

Fig.2 (a) The output P-V curve of PV module under uniform lighting conditions. (b) The output P-V curve of PV module under partially shaded conditions.
So, why does the conventional MPPT algorithm track failure under partially shaded conditions? We found answer in Fig.3. As shown in Fig.3, before the partially shaded conditions come, PV module works at point A. After partially shaded conditions come, the operating point moves to point B, and may gradually moves closer to point C.

Fig.3 Conventional MPPT algorithm tracks failure under partially shaded conditions.

In this case, the real MPP is point D. Nevertheless, because of the conventional methods changes the operating point due to predetermined voltage reference step, the operating point is oscillated on vicinity of point C. At the meantime, the power capacity between $P_C$ and $P_D$ is lost due to the MPPT failure. To prevent this power loss, MPPT control procedure has to move the operating point to point D. Although some researchers have worked on real MPPT algorithm under partially shaded conditions \[6\]-\[8\], but some of these methods are very complexity, and accuracy is not high enough.

3. MPPT algorithm under partially shaded conditions

The output P-V curve of the PV module has multiple local maxima values under partially shaded conditions. To address this situation, the design of MPPT algorithm generally can be divided into two kinds \[9\]. First, we parallel a power compensation unit on each photovoltaic module, so there is only one extreme point on the overall output characteristic curve in parallel. And then we implement MPPT by conventional algorithm. Second, under the output characteristic of multiple extreme points without changing conditions, we develop a new MPPT algorithm that what can identify the pseudo-maximum power point. Our algorithm uses the second thought. Firstly, we move the operating point of the PV system to the area of MPP. Then we conduct accurate MPP position by conventional algorithm.

Our algorithm is divided into two steps. In First step, we use 0.5V fixed step to move the operating voltage from the open circuit voltage $V_{OC}$ to the neighborhood place of real maximum power point voltage, to avoid tracking the local maximum power point. In this scanning process we record the local maximum power value. The second step is to use the perturbation and observation method, we start tracking the MPP voltage from the previous determined work point voltage. If the current of the maximum value is less than the record of maximum, then the record of maximum value is real maximum power value. We should move the operating point to the record point.

In the first step of the algorithm, we need to identify an approximation of the real maximum power point. In the case of uniform illumination, according to the output V-I curve of PV module, we can determine an equivalent resistance line whose slope is $R$ by (1) \[5\]. The intersection of the equivalent resistance line and the V-I curve is the MPP. $V_{OC}$ is the open circuit voltage of photovoltaic components, $I_{SC}$ is the short circuit current of photovoltaic components. $K_v$ and $K_i$ are depending on the type of
photovoltaic components. For a given type of photovoltaic components, $K_v$ and $K_i$ are constant. $K$ is an adjustment factor that depends on the number of single photovoltaic cells what are in series or in parallel.

$$R = K \frac{K_v V_{OC}}{K_i I_{SC}}$$

(1)

In the course of study, we established a simulation model of photovoltaic cell in the PROTEUS simulation platform. By this model, we can quickly and accurately get the MPP voltage $V_m$ and current $I_m$ of the PV module in standard light intensity. We are able to establish an equivalent electrical line on V-I curve, the slope of the $G_p$ determined by equation (2). The intersection of the equivalent electrical line and the V-I curve is the approximate of MPP. This is the starting point of the second step in this algorithm. Next, we use single peak MPPT algorithm - perturbation and observation method, making the system works at real maximum power point.

$$G_p = \frac{I_m}{KV_m}$$

(2)

In this design, the electrical parameters of PV module what works in the standard conditions (1000W/m², 25°C) list below: open circuit voltage $V_{OC}$=10.5V, short-circuit current $I_{SC}$=4.3A, MPP voltage $V_m$=7.41V, MPP current $I_m$=4.01A, maximum output power $P_m$=29.7WP.

In this paper, improved step by step MPPT algorithm process is shown in Fig.4 (a). As shown in Fig.4 (a), $G_r$ is a conductance, which calculated by current voltage and current values from the PV module operating point. Comparing it with the $G_p$, we can determine whether the current operating point is near the MPP. Because when the light intensity changes ($I_{SC}$ changes), the position of MPP has not changed. So the program doesn’t need returning to the first step to re-scan.

4. Simulation and experimental result

Fig.4 (b) is a simulation schematic of photovoltaic system model. The system program is written into the PIC16F873 microcontroller in simulation model. Then we can simulate and analyze the system model.
4.1. Overall track condition

When SUN1, SUN2 and SUN3 are all subject to standard light intensity, the track conditions are shown in Fig.5 (a) (b).

![Graphs showing track conditions](image)

When SUN1 is subject to standard light intensity, SUN2 is subject to 0.2 times standard light intensity, SUN3 is subject to 0.6 times standard light intensity, the track conditions are shown in Fig.5(c)(d).

In order to better understand the track conditions of the entire system, we changed the light intensity the three groups of photovoltaic cells subjected, observed the output power conditions of the entire system, analysed tracking performance. The result is shown in Table 1. SUN1, SUN2 and SUN3 respectively represent the three groups of PV module. P1 is the ideal output power of PV module. P2 is the actual output power of PV module. \( \Delta \) is the absolute error of tracking power. \( \Delta / P1 \) is the relative error of tracking power.

As shown in table 1, absolute error of the tracking power is less than 0.5W; relative error maintained below at 2%; our algorithm could well achieve the MPPT in any shadow conditions.
Table 1 Tracking performance analysis of photovoltaic system under different light intensity.

| SUN1 | SUN2 | SUN3 | P1/W | P2/W | △W | △/P1 |
|------|------|------|------|------|-----|-------|
| 1    | 1    | 1    | 29.7 | 29.3 | 0.4 | 1.3%  |
| 1    | 0.5  | 0.5  | 17.0 | 16.8 | 0.2 | 1.1%  |
| 0.9  | 0.8  | 0.7  | 23.4 | 23.2 | 0.2 | 0.8%  |
| 0.9  | 0.8  | 0.4  | 15.7 | 15.5 | 0.2 | 1.2%  |
| 0.8  | 0.7  | 0.6  | 20.4 | 20.2 | 0.2 | 0.9%  |
| 0.7  | 0.5  | 0.4  | 14.3 | 14.2 | 0.1 | 0.6%  |
| 0.6  | 0.6  | 0.6  | 19.0 | 18.9 | 0.1 | 0.5%  |
| 0.5  | 0.7  | 0.8  | 17.7 | 17.6 | 0.1 | 0.5%  |
| 0.3  | 0.2  | 0.1  | 4.39 | 4.38 | 0.01| 0.2%  |
| 0    | 0.8  | 0.5  | 10.7 | 10.5 | 0.2 | 1.8%  |

4.2. Adjustment time

Fig. 6 is a part of the voltage curve in Fig. 5(c) enlargement, the first 200ms in Fig. 6 is tracking time. The tracking time is a little long relative to the single peak MPPT algorithm. This is because in this paper the MPPT algorithm adds a voltage scanning process. The cost of sacrificing the track speed is for improving track accuracy, and it improve overall system performance. In reality, the light intensity isn’t always dramatic change, so the track time 200ms is acceptable. In addition, track time is also related with the step size of duty cycle D. The larger the step, the shorter the adjustment period, and the larger the amplitude at maximum power point. In the programming process, to reduce the time of voltage scanning and the power vibration of disturbance track, we set the step of the scanning voltage is D+2, the step of disturbance track is D+1.

Fig. 6 Adjustment time of the PV module output voltage during the tracking process.
5. Conclusions

In partially shaded conditions, as there are several local maxima values on the P-V curve, conventional MPPT algorithm usually tends to follow less than the real MPP, and it cause great power loss.

To avoid this situation, an improved step by step MPPT algorithm is presented in this paper. In order to validate algorithm performance, we conducted a large number of simulation experiments. A PV system model has been established. It has a quick response and good performance. Even if some parts of the PV module are under partially shaded conditions or sunlight rapidly changing circumstances, PV system can quickly works at MPP. Our algorithm can replace those MPPT algorithms those widely used in various types of photovoltaic power conditioner. The design can be applied to the LED lighting of photovoltaic system very conveniently and efficiently, and it also contributes to the socio-economic and environmental protection.

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