Improved voltage scanning method for maximum power point under partial shadow conditions

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Abstract. This paper proposes a novel maximum power point tracking (MPPT) algorithm with global search. The algorithm combines global voltage sweep and incremental conductance method, and introduces a Judging factor as a criterion for global voltage scanning. The Judging factor is compared with the threshold and the scan step size is selected based on the result. Take a large step when far from the peak. When approaches the peak, uses the incremental conductance method to find the local extrema and store it, then continues scanning. When the output power is close to zero, the scan is complete. Comparing all local extrema points then the global maximum power point will be found by this algorithm. Matlab simulation results show that the algorithm can find the global maximum and the search speed is fast.

1.Introduction

Solar energy has become a promising new energy source and is widely used in power generation. At present, solar photovoltaic power generation systems have the disadvantages of low solar photovoltaic conversion efficiency, high cost, and large initial investment [1]. In order to convert solar energy into electrical energy, it is necessary to find the maximum power point (MPP) of the photovoltaic array output. Maximum Power Point Tracking (MPPT) technology is key. The photovoltaic array has only one maximum power point under uniform illumination. However, in the actual environment, it is blocked by trees and buildings. The I-V curve of the PV array becomes a step shape, and the P-V curve exhibits multiple peaks. The traditional maximum power point tracking algorithm may be trapped at the local extremum point, so a global maximum power point tracking algorithm needs to be proposed. The literature [2,3] uses the regular design algorithm of the maximum power point voltage distribution obtained by observing the P-V curve. Although the global maximum power point can be found, the system parameters are highly dependent. The ideas of fuzzy logic control and artificial neural network control in the literature [4,5,6] are applied to the design of the algorithm. Although the algorithm performs well, it is costly. In this paper, by analyzing the mathematical formula of photovoltaic array under single peak condition and combining the output characteristic curve of PV array under multi-peak condition, a judgment factor $d^2P/dU^2$ can be found. It is used to compare with a threshold, combined with voltage scanning method. A large step is used to scan away from the local extreme point. When the extreme point is approached, the local extremum is found by the conductance increment method and recorded. These different local extreme points can be found by comparison to find the global maximum power point after the scan is completed.
2. PV array output characteristics

2.1 Photovoltaic battery mathematical model

When the light is constant, the $I_{ph}$ determined by the illumination does not change, so the equivalent circuit is regarded as a constant current source. The voltage at both ends of the load is $U$. The internal resistance of the battery board is equivalent to $R_s$. The value is generally small. Generally, it is only a few ohms. In order to prevent leakage current, the current flowing through the load is short-circuited. The resistor $R_{sh}$, whose value is generally greater than 1 KΩ. The voltage across the load and the voltage across the series resistors act on the P-N junction of the photovoltaic cell, producing a current $I_D$ that is opposite to the $I_{ph}$ direction, the magnitude of which is related to the voltage magnitude. Photovoltaic cell equivalent circuit diagram shown in Figure 1:

$$I_{ph} = I_0 \left(1 - \frac{q(U + IR_s)}{AKT} \right) - 1$$

$I_0$- Reverse saturation current (which is of a small order of magnitude, generally $10^{-4}$A); $q$-electronic charge ($1.6 \times 10^{-19}$); $K$-Boltzmann constant($1.38 \times 10^{-23}$J/K);
$T$-absolute temperature($T=t+273$K); $R_{sh}$-photovoltaic cell parallel resistance; $R_s$-photovoltaic cell series resistance.

$$I_{sh} = \frac{(U + IR_s)}{R_{sh}}$$

$$I = I_{ph} - I_0 \left(1 - \frac{q(U + IR_s)}{AKT} \right) - 1 - \frac{U + IR_s}{R_{sh}}$$

the rate of change $dP/dU$ of the power with voltage is introduced, and the load resistance is $R$ to convert the equation (4) into:

$$I = I_{ph} - I_0 \left(1 - \frac{q(U + IR_s)}{AKT} \right) - 1 - \frac{(1 + \frac{R_s}{R})U}{R_{ph}}$$

Assuming constant load resistance and no change in temperature, set two constant $C_1$ and $C_2$:

$$C_1 = \left(1 + \frac{R_s}{R_{ph}}\right)$$

Then the output power $P = I \times U$, namely:

$$P = U(I_{ph} - I_0(Ue^{C_1U} - U) - C_2 \times U^2$$

Then $dP/dU$ is:

$$\frac{dP}{dU} = I_{ph} - I_0(e^{C_1U} + UC_1e^{C_1U} - 1) - 2C_2U$$
For \( C_2 \), the general \( R_S \) is only a few ohms, the load resistance is not large, and the \( R_{Sh} \) is generally one thousand ohms, so the \( C_2 \) value is very small and can be ignored, then:

\[
dP / dU = I_{ph} - I_0(e^{\frac{U}{C_1}} + Ue^{\frac{1}{C_1}} - 1)
\]  

Deriving (9) again for \( U \) to obtain:

\[
d^2P / dU^2 = -I_0(2Ce^{\frac{U}{C_1}} + UC_1^2e^{\frac{U}{C_1}})
\]  

After derivation, you can see that there is no \( I_{ph} \) in equation (10), the size of \( d^2P/dU^2 \) has nothing to do with the \( I_{ph} \) value. Suppose the system performs a voltage sweep from zero to the maximum value. Since \( I_0 \) is very small, and the \( C_1 \) value can be regarded as a constant, the \( d^2P/dU^2-U \) curve can be considered as a unary composite function. The value is related to the size of the \( U \) value. Since the \( U \) value is not large enough at the beginning, when \( U \) is small, the value of \( d^2P/dU^2 \) is very small, and is close to 0. When \( U \) increases to a certain value, due to the rapid increase of the exponential function, the value of \( d^2P/dU^2 \) decreases rapidly.

### 2.2 \( dP/dU^2-U \) output characteristic curve under single peak condition

In order to obtain the output characteristic curve of the photovoltaic cell module, the photovoltaic cell module is selected for simulation. The short-circuit current \( I_{sc} \) of the photovoltaic cell component selected in the standard environment (\( T=25, S=1000 \)) is 3.74A, and the open circuit voltage \( U_{oc} \) is 21.06V, the current \( I_m \) at the maximum power point is 3.50 A, and the voltage \( U_m \) at the maximum power point is 17.01V. Three kinds of light intensities were selected for simulation. The simulation results are as follows:

![Figure 2. Photovoltaic cell I-V curve.](image)

![Figure 3. Photovoltaic cell dP/dU - U curve](image)

![Figure 4. Photovoltaic cell d^2P/dU^2 curve](image)

![Figure 5. Partition curve of photovoltaic cell P-U](image)

Analysisising Figure 5. The three curves have basically the same trend. In fact, the three curves should be coincident from formula (10), may because of the previous omission step leads to the translation relationship between the three lines on the X coordinate axis, take the Y coordinate value as -10, we can get three points: \( S=100W/m^2 \) (14.66, -9.94), \( S=500W/m^2 \) (14.35, -9.86), \( S=1000W/m^2 \) (13.75, -9.80), the two farthest points are on the \( S=100W/m^2 \) and \( S=1000W/m^2 \) curves, respectively, the voltage difference is only 14.66-13.75=0.91 (V). Thus, we can completely divide the P-U curve into three regions:
I : $\frac{dP}{dU} > 0$,  $0 > \frac{d^2P}{dU^2} > K$ ; II : $\frac{dP}{dU} > 0$,  $\frac{d^2P}{dU^2} < K$ ; III : $\frac{dP}{dU} < 0$,  $\frac{d^2P}{dU^2} < K$

Taking the P-U curve of $T=25$ and $S=100$ as an example, the partitioning method is divided into three areas, which can be scanned from left to right by voltage scanning method. When in the I area, the large voltage perturbation step can be used to quickly scan to the right. When reaching Zone II, use the conductance increment method to find the maximum power point with a smaller step size, as shown in the Figure 5.

2.3 $\frac{d^2P}{dU^2}$ characteristic curve in multi-peak case

Three photovoltaic cells are connected in series, and different illumination simulations are selected to obtain output characteristic maps corresponding to multiple peaks.

![Figure 6. I-U curve in the case of three peaks](image1)

![Figure 7. P-U curve in the case of three peaks](image2)

![Figure 8. $\frac{d^2P}{dU^2}$-U curve in the case of three peaks](image3)

It can be seen that for multi-peak, no matter what the illumination $\frac{d^2P}{dU^2}$-U characteristic curve is basically the same, take $\frac{d^2P}{dU^2}=-10$. Since the curve in the simulation is fitted with many points, find the point where $\frac{d^2P}{dU^2}$ is approximately equal to -10, and then compare the corresponding $U$. The coordinates of the first peak of the three illuminations corresponding to the Y axis are three approximate points (11.5, -29.27) (11.67, -29.35) (11.45, -29.74). The three approximate points of the second peak are (29.94, -29.45) (30.78, -29.57) (31.12, -29.7). The three approximate points of the third segment are (51.05, -30.19) (50.92, -30.24) (52.04, -29.73). It can be seen that when $\frac{d^2P}{dU^2}$ is the same as -10, the corresponding voltage is separated by a maximum of 1.12V.
3. A Novel Multimodal MPPT Algorithm Introducing $d^2P/dU^2$ Factor

![Figure 9. Algorithm flow chart](image)

A new multi-peak optimization method can be derived from the above formula and simulation analysis. In a complex lighting environment, the value of $d^2P/dU^2$ can be introduced into the discriminating condition. This paper combines the P-U and $d^2P/dU^2$-U in the PV output characteristic curve to select the threshold. The threshold is selected by the simulations of Figures 7 and Figures 8. In the illumination range $S=100$ to $S=1000$, the point of $d^2P/dU^2=-10$ is to the left of the local power maximum point, and the voltage difference between it and the maximum power point is larger than the large step voltage of the scanning voltage. When $P(K)>0$, $d^2P/dU^2(K)>-10$ and $\Delta P(K)>0$, $U$ is rapidly perturbed to the right due to the large-length scanning method on the left side $k$ far from the peak; $d^2P/dU^2(K)$ gradually decreases. When $d^2P/dU^2(K)\leq-10$, the distance peak is already very close. At this time, the conductance increment method is used to find the maximum power point of the peak and record the local maximum $P_{zmax}$; when the local maximum power point is found. The algorithm exits from the subroutine that performs the conductance delta method, and the scan voltage continues to move to the right in large steps. When the decision condition is triggered while the voltage continues to scan right: $P(K)>0$, $d^2P/dU^2(K)>-10$ and $\Delta P(K)>0$, the algorithm then enters the subroutine and runs the conductance increment method again, when the program finds the peak then records it as $P_{max}$. The peak values $P_{max}$ and $P_{zmax}$ are compared, if $P_{zmax}>P_{max}$, then $P_{zmax} = P_{max}$. This is repeated until $P(K)<0$, This marks the completion of the scanning process. After the scan is completed, the $P_{zmax}$ is the maximum power. Next, only the corresponding $U_{max}$ needs to be provided to the system, the system can perturb around the maximum power point by the conductance delta method. If the light intensity on the solar panel suddenly changes greatly, the conditions...
for rescanning will be triggered. The condition is also triggered if the program is in the conductance increment method subroutine for more than 20 minutes. The algorithm flow chart is shown in Figure 9.

4. Simulation analysis

4.1 Static Simulation

In order to verify the effectiveness of the algorithm, the experimental simulation of the system was carried out in the matlab/simulink environment. Three sets of photovoltaic cells are connected in series, and the short-circuit current $I_{sc}$ of each battery is 3.74A, the open circuit voltage $U_{oc}$ is 21.06V, the current $I_{mp}$ at the maximum power point is 3.50A, and the voltage $U_{mp}$ at the maximum power point is 17.01V. The illumination of the three groups of batteries is $S_1=500W/m^2$, $S_2=800W/m^2$, and $S_3=1000W/m^2$. The three peak points are 54.04W, 98.46W, and 99.85W, and the corresponding voltages are 15.52V, 34.13V, and 54.63V, respectively. Figure 10 is a plot of output power as a function of time. It can be seen from the graph that the maximum power point was successfully found by the algorithm. When it reached 0.2S, $P$ dropped to zero. After the scan is completed, the voltage corresponding to the maximum power point of 99.85W is given and stabilized directly at the global maximum power point.

4.2 Light mutation dynamic simulation

In order to analyze the implementation of the algorithm in the face of the illumination abrupt change factor, $S_1=500W/m^2$, $S_2=800W/m^2$, $S_3=1000W/m^2$ is mutated at 0.65S to $S_1=300W/m^2$, $S_2=600W/m^2$, $S_3=1000W/m^2$. It can be seen from the Figure 12 that when the light suddenly changes, the power drops to about 42W. At this time, the condition of the algorithm is triggered: $|dP|<K_P$, so the program automatically restarts the global scan and scans in the same way. After a period of time, it successfully finds a new one. Maximum power point of 75.49W

5. Conclusion

This paper presents an improved voltage scanning method. By simulation analysis find the judgment factor $d^2P/dU^2$ and define a threshold that is -10. When $d^2P/dU^2$ is greater than -10, the voltage is scanned to the right in larger steps. If $d^2P/dU^2$ is less than or equal to -10, the scanning process is paused, then the
algorithm uses the conductance increment method to find the local maximum in small steps. When the local maximum is found, the local maximum power point is recorded, and then the voltage continues to scan to the right in larger steps until all local maximum power points are found. When $P = 0$, the scan is stopped and the maximum power, corresponding voltage are directly supplied. Then use the conductance increment method near the maximum power point. The simulation results show that the proposed algorithm not only avoids falling into local optimum, but also has fast speed, and can jump out of local optimum for sudden changes in illumination, and can re-scan to find the maximum power point after the illumination changes.

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