A Novel Control Algorithm for Maximum Power Point Tracking of Photovoltaic

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Abstract—**The output power of PV module varies with module temperature, solar insolation and loads. And in order to quickly and accurately track the sun, it is necessary to track the maximum power point (MPP) all the time. After studying various algorithms, a new algorithm was presented in this paper based on online short-circuit current,open-circuit voltage, and variable step of perturbation and observation method. This algorithm could track MPP change rapidly and accurately without the disturbance of photovoltaic system, and also can reduce the power oscillation around MPP and the light mutation of the false judgement phenomenon. A theoretical analysis and the designed principle of the proposed algorithm are described in detail. And some experiment and simulation results are made to demonstrate that the effectiveness of the proposed algorithm and also the proposed could reach MPP which is faster than traditional P&O method about 0.2s. The system has a good dynamic and steady-state performance.**

Index Terms—**MPPT, short-circuit current, open-circuit voltage, perturbation and observation method, variable step**

I. INTRODUCTION

Recently, with the development of economy and advancement of society, the need of energy will have an increasing. Photovoltaic power with the advantage of no pollution, no noise and easy maintaining is particularly predominant among other energy sources. It will convert solar energy directly to electrical energy. However, The output of photovoltaic(PV) has obvious characteristics of non-linear, which is effected by the external environment.In order to make the power output of PV maximize, the output of PV requires the maximum power point tracking(MPPT). There are many techniques that have been proposed for tracking the MPP of PV: open-circuit voltage method, short-circuit current method, perturbation and observation(P&O) method, incremental conductance (INC) method, and fuzzy control method[1]. Open-circuit voltage and short-circuit current method offer a simple and low-priced way to acquire the maximum power. Nevertheless, they have a larger steady-state error and low energy conversion efficiency. P&O method is widely applied in the MPPT controller due to its simplicity and easy implementation, but its accuracy is low in steady-state and the P&O method probably failed to track MPP when the insolation is changed rapidly. INC method has the advantage of fast tracking and dynamic stability, but the steps are difficult to determine. Fuzzy control method does not need to study the specific characteristics of PV, but the shape of membership functions needs more experienced designers[2].

According to the characteristics of PV and various control algorithms, a new MPPT control algorithm was proposed which short-circuit current method was applied at the left of the MPP, variable step of P&O method was used near the MPP, open-circuit voltage method was applied at the right of the MPP. The short circuit current was calculated by on-line in order to avoid interfering with the system caused by the traditional short-circuit current method, which can enable the left point of MPP back to the maximum power soon and thus improve the efficiency of photovoltaic power generation [3,4]. Gradual approximation was used to search step around MPP which can eliminate the slow convergence of traditional P&O method and the phenomenon of oscillation around the MPP. Open circuit voltage method can make the right point of MPP quickly back to the maximum power point.

II. THE MPP TRACKING PRINCIPLE OF PV

Maximum power point tracking is a self-optimizing process. The output maximum power could be intelligently controlled by the PV terminal voltage U, the battery under a variety of sunlight and temperature conditions. Output power of PV are greatly influenced by the external environment, ambient temperature, sunlight intensity, and output voltage. The relationship of PV output current and voltage [5] are:

$$I = I_s - I_0\left\{\exp(\frac{qU}{AkT}) - 1\right\} \tag{1}$$

$$P = I_s U - I_0 U\left[\exp(\frac{qU}{AkT}) - 1\right] \tag{2}$$

$$dP/dU = I_s - I_0 - I_0\exp[\frac{qU}{AKT}]\cdot[1+\frac{qU}{AKT}] \tag{3}$$

I,U is output current and voltage of PV cell respectively; I_s is short-current under the condition of 25℃ and 1000w/m^2; I_0 is reverse saturation current of

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PV; T is the temperature of PV; k is Boltzmann's constant ($k=1.38\times10^{23}$J/K); q is electronic charge($q=1.6\times10^{-19}$C); A is diode characteristic factors (T=300K，A is approximately equal to 2.8).

Fig.1 shows the output power characteristics of P-U curve[6]. P-U curve is a single convex curve. When the cell voltage is less than the maximum power point U_{max}, the output power increases with the increasing U; when the operating voltage is greater than the maximum power point voltage U_{max}, the output power decreases with the increaseing U.

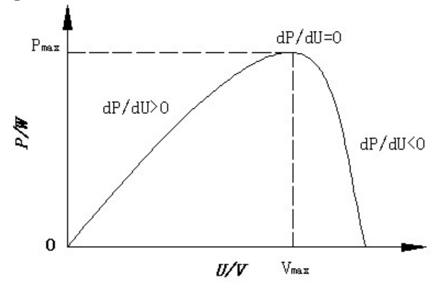


Figure 1. PV output power characteristics of P-U curve

III. Control Strategy of the Improved MPPT

Traditional P&O method is a commonly method in the MPP tracking.The thought of controlling algorithm is: measureing the current power output of photovoltaic cells P1, then at the initial output voltage U adding a small Δu, the output power will be changed to P_2, comparing P_2 with P_1. If the power increases, it will continue to use the initial disturbance.If the power reduces, it will change the direction of the initial disturbance.This method is simple and easy to be implemented, but there will be oscillation around MPP and resulted a energy loss. The tracking accuracy and speed of response could not be taken into account [7]. This paper was proposed an improved algorithm to solve above problems,.

A. The Basic Ideas of Improvement

If MPPT control strategy was applied the open-circuit voltage method and short-circuit current method, it could not be tracked the MPP accurately. Because the I_{mpp} and I_s, the U_{mpp} and U_{oc} of PV cells were approximately existed linear relationship [8], so the output power could not be reached the MPP under this control method, it can only work around the MPP. In order to enhance the efficiency of photovoltaic cells, after achieved the control objectives of system by short-circuit current method and open circuit voltage, P&O method could be used to detect disturbances around MPP in order to quickly and accurately track the maximum power point.

Fig.1 shows that dP/dU curve has the following characteristics.

$$\begin{aligned} &\frac{dP}{dU} > 0, \quad left \quad of \quad MPPT, \\ &\frac{dP}{dU} = 0, \quad at \quad MPPT, \\ &\frac{dP}{dU} < 0, \quad right \quad of \quad MPPT. \end{aligned} \tag{4}$$

Therefore, tracking algorithms could be divided into three sections. Short-circuit current method is used on the left of the MPP, variable step P&O method is used around MPP, and open-circuit voltage method is used on the right of the MPP. The test steps are followed as below:

(1) Detection of short-circuit current

Fig.2 shows the MPPT characteristic curve of dP/dU-u. It could be seen from the figure that dP/du decreases monotonically with the PV cells output voltage increasing. The curve of photovoltaic cells is in the short circuit condition at A point , the battery output current is zero, dP/du is equal to the battery's short circuit current. With the increase of output voltage, dP/du value is slowly declined which could be seen that the value is approximately equal to the short-circuit current in the AB Interval[9].

As the I_{mpp} and I_s have a approximate linear relationship, therefore, the output power of PV under the method can not reach the MPP and only work around the MPP. By this design, the algorithm could accelerate initial speed and rapidly approaching MPP.

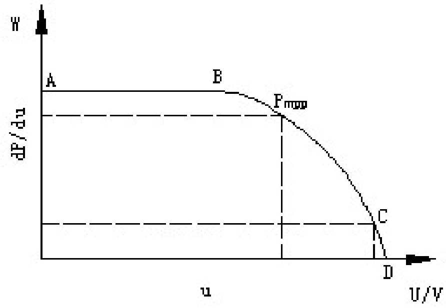


Figure 2. The MPPT characteristic curve of dP/dU-u

(2) variable step P&O method--gradual approximation search

The tracking algorithm could be realized by variable step P&O method around MPP which is carried out by the idea of gradual approximation step search[8]. The algorithm has a high precision and small fluctuations in a steady state. First, a larger step is used to search the region where the maximum power is and then go on to search by narrowing it to half step, at this moment, searching area will be reduced to the half and the precision will be doubled till to the MPP. The specific steps are: detecting the voltage U_{pv} and current I_{pv} around the MPP and calculating the power P. Assuming that the initial operating point at the left of MPP, the system will be searched with the initial step Δu , until $P_{k+1}<P_k$. At that time, the operating point is at the right of the MPP and should be changed the search direction, and reduce the step till Δu /2, then continue the search direction until the second time changed, at this time the precision is doubled. Search direction will be changed again so that step is further reduced to Δu /4, and the precision is doubled once again, and so on, until search to the MPP. The step will become Δu /(2i), i is search times, until searched $|P_{k-1}-P_k|<\varepsilon$. From the above search process, It can be seen that the accuracy of gradual approximation method is exponentially increased, and greatly enhanced the speed, combining the fixed step of rapid tracking speed and variable step of high tracking accuracy.

(3) Detection of open-circuit voltage

It could be seen from the Fig.3, dP/di increases monotonically with the PV output current increasing. The curve of PV is in a open state at D point, the battery output current is zero, dP/di is equal to the absolute value of the battery's open circuit voltage.With the battery output current increasing, dP/di value is slowly risen which the value is approximately equal to the open circuit voltage in the DC Interval.

Open-circuit voltage method could make the right of MPP rapidly return to the MPP. As it is an approximate point, so it can only work around MPP.

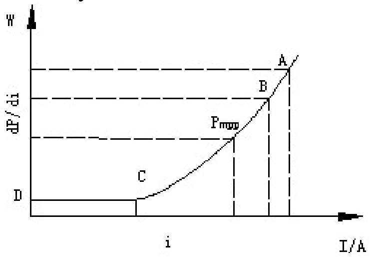


Figure 3. The MPPT characteristic curve of dP/dI-i

Based on the above analysis, the short-circuit current method could be used when the system is worked on the left of MPP(AB section), variable step P&O method could be used when worked around MPP(BC section)which the step is searched by the idea of gradual approximation, open-circuit voltage method could be used when worked on the right of MPP(CD section). The specific process is shown in Fig.4.

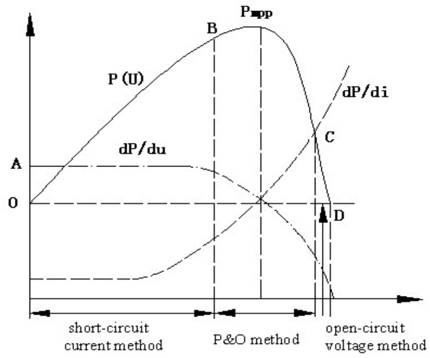


Figure 4. The whole process of the search improved algorithm

In the AB and CD section, dP/du and dP/di are respectively constant which are approximately equal to the short circuit current and open circuit voltage, only around MPP the two values will be significantly changed. If the change of power in any of the two intervals was known in the period, short-circuit current or open circuit voltage of PV cells can be obtained, then the system could be controlled by the short-circuit current method and open circuit voltage method. With the short circuit current and open circuit voltage, the far away point from the left and right could be made soon to return to the MPP. Thus the interfering with the system under the normal operation by the traditional short-circuit current method and open-circuit voltage method is avoided.

B. Algorithm Flow

Flow chart of the improved algorithm is shown in Figure.5

Specific process: (1) Calculate the output power of PV at time t and compare it to the time t-1, judging whether the system is working in the current source or voltage source mode; (2) If the system is working in current source mode, then it can be calculated that $I_t = dP_t / dU_t$ at time t and $I_{t-1} = dP_{t-1} / dU_{t-1}$ at time t-1 by output voltage and current, and compared to I_t and I_{t-1}. If the absolute difference between the two is less than ε (ε is a very small value), thus I_t could be realized that is equal to short circuit current; (3) If $U_t = dP_t / dI_t$ at time t and $U_{t-1} = dP_{t-1} / dI_{t-1}$ at time t-1 of the absolute difference value less than ε, thus U_t can be as a open circuit voltage; (4) If neither in the short-circuit current nor open circuit voltage state, it could be infered that the system works around MPP. MPPT controlling method is achieved by the variable step P&O method which is adopted the ideal of gradual approximation method. Assumed that the system operating point is at the left of MPP, step will be Δu to search.Where m and n are expressed dP/dU direction, m means the last direction, n means this direction,then compare the P_{t-1} and P_t, until up to $P_{t+1}<P_t$. At this time,the operating point is at the right of MPP,it should be changed the search direction, then reduced to $\Delta u/2$, the precision will be doubled, and continue to search until the search direction changed secondly.Then continue to reduce the step to $\Delta u/4$, the precision will be doubled again. And so on, until the MPP is searched. Using this variable step P&O method is the mainly control target of stability around MPP.The perturbation step size is selected by the requirements of MPP stability. As the step is much smaller than the traditional P&O method, therefore, the system can effectively eliminate oscillation at steady-state around MPP.

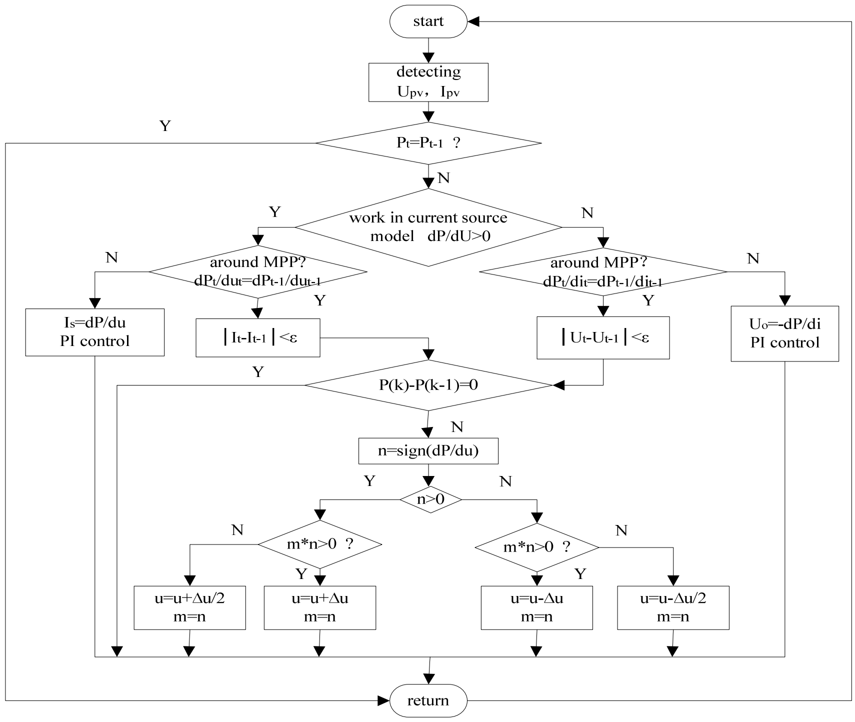


Figure 5. Improved Algorithm flow char

IV. EXPERIMENT AND SIMULATION

A block diagram of the main circuit system is shown in Fig.6. The controlling algorithm is achieved by the MCU. The system is consisted by photovoltaic modules, DC-DC converter and load.

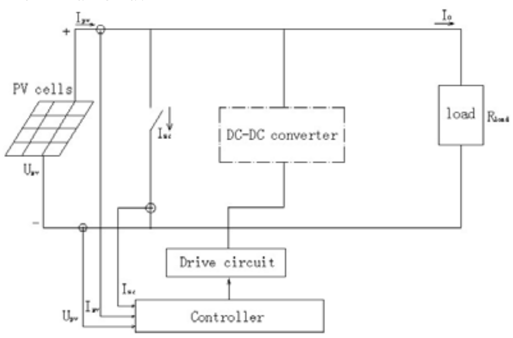
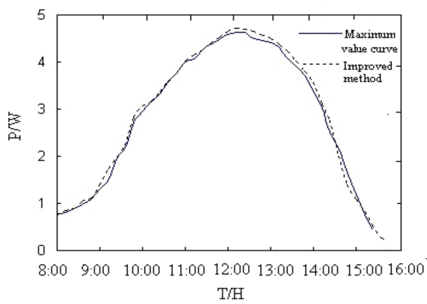
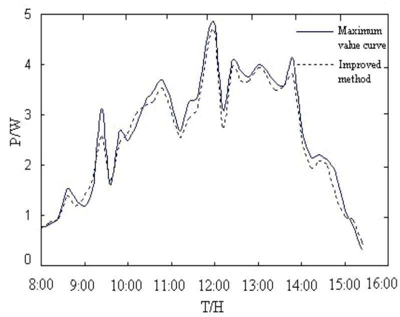


Figure 6. The main circuit diagram of the system

The experiment and simulation were conducted to verify the proposed control algorithm. Photovoltaic modules will adopt to solar panels, its parameters: open-circuit voltage U_{oc}=21.0V; short-circuit current I_s=0.33A; maximum power corresponding to the output voltage U_{mpp}=17.0V; maximum power corresponding to the output current I_{mpp}=0.29A; the maximum output power P_m=5.0W. Then according to the PV output voltage, temperature, illumination intensity, short-circuit current and open circuit voltage temperature coefficient calculate the output current. Compared to the experimental curves of the MPP, Fig.7 shows the MPP curve of the real experiment and simulation results in Jinhua which are tracked from the day and night in two different weather conditions.



(a) Sunny



(b) Cloudy

Figure 7. MPPT curve of expriment and new control algorithm

It can be seen from Fig.7 (a) that improved method can be better tracked to the real maximum power curve when the weather is sunny, and the algorithm had a good steady-state performance, fast searching and small fluctuation. Fig.7(b) shows that the comparison curve of expriement and simulation in the cloudy weather. It can be obtained more accurate value of the maximum power from the initial value, and avoided the phenomenon of wrong judgments. Therfore it can be accurately tracked the real maximum power curve and improved the efficiency of PV. However, the curve shows that the simulation existes a certain error compared with experimental of the MPP, because the system is hard to respond in time and has a certain lag when the light changed suddenly. The average of the tracking error is 0.53%, therefore, the errors are allowed within the range.

The traditional P&O method and improved method was simulated to verify the validity of the algorithm. The curves of obtaining the PV output power are shown in Fig.8 and Fig.9. Fig.8 shows the output power between traditional P&O method and improved method at 1000W/m^2 and 25℃. Fig.9 shows the comparison of output power about the two algorithms due to solar insolation change from 600 W/m^2 to 1000W/m^2.

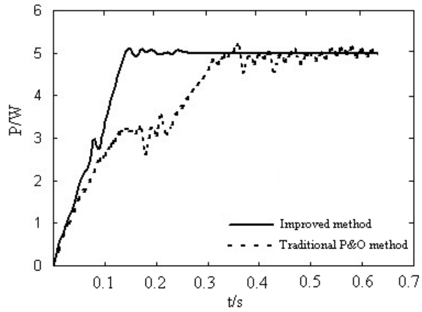


Figure 8. Comparison of two algorithmsfor output powe

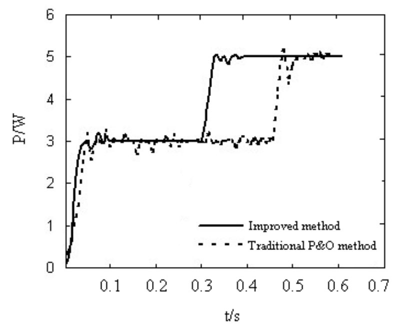


Figure 9. Light mutation of two algorithm for output power

As can be seen from Fig.8, traditional P&O method power oscillates at the beginning of the process. After a period of time, the waveform gradually stabilized and oscillated in a small area. It will reach maximum power about 0.35s and oscillate largely around the MPP, conversely, the power of improvement has a small oscillation at the outset and achieves MPP about 0.15s. It could be drawn that the improved algorithm has a quick tracking speed, high precision, small fluctuations around the MPP. Fig.9 shows that the power of illumination intensity mutates from 600 W/m^2 to 1000W/m^2 which the traditional P&O method has a poor tracking accuracy, larger fluctuations and a bad responsion when the light suddenly changes. Nevertheless, the improved algorithm has a rapid responsion to light mutated, and be quickly stabilized at MPP. It is proved that the improved algorithm has a better stability and high efficiency in different illumination conditions.

V. Conclusion

The paper analyses the characteristics of the PV power system and proposed a new MPPT control algorithm by combining with various control algorithms. The voltage and current can be calculated by the open-circuit voltage, short-circuit current online testing, thus the disturbance of PV system with traditional detection method. In order to reduce the power oscillation around MPP and the "false judgement" phenomenon, variable step P&O method is adopted by the idea of gradual approximation method to search step, so the MPP can be rapidly and accurately tracked. Through the experiment and simulation, it demonstrates that the improved algorithm can quickly track the change of external environment according to the curves of two algorithms and also avoid the power fluctuation. The results also confirm that the proposed can reach MPP which is faster than traditional P&O method about 0.2s and can be better tracked to the real maximum power curve which the average of the tracking error is 0.53%. It reveals that the designed control method has a adequate performance and good practical value.

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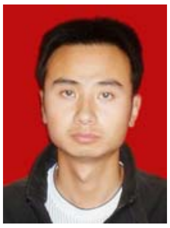

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