Three-state Variable Step Perturbation Observation MPPT Algorithm Based on Power Prediction

Maoxin Du

Key Laboratory of Electronic Information of State Ethnic Affairs Commission, College of Electrical Engineering, Southwest Minzu University, Chengdu 610041, China

Abstract: In view of the application and research status of maximum power point tracking technology in photovoltaic power generation system, an improved disturbance observation MPPT method with variable step size and no oscillation at steady state is proposed in this paper. The method combines power prediction disturbance method and constant voltage method. Firstly, two reasons for power loss caused by traditional disturbance observation method are analyzed, which are disturbance misjudgment and steady state oscillation respectively. In order to reduce power loss caused by disturbance misjudgment and steady state oscillation, the three-point function sampling model based on Newton interpolation method is used to reduce disturbance misjudgment respectively, and a new variable step size factor is proposed to realize fast tracking of maximum power point through variable step size. And when the steady state is reached, the disturbance step size is immediately reduced to achieve a small shock output, so as to improve the efficiency of the whole system. Finally, the photovoltaic system model and experimental platform are built to track and simulate the maximum power point. The results show that the improved disturbance observation method can not only improve the disturbance misjudgment, but also achieve stable tracking of the maximum power point.

Keywords: Photovoltaic power generation, Maximum power tracking, Power prediction, Disturbance observation method, There is no oscillation in the steady state.

1. Introduction

As a clean and pollution-free renewable energy source, solar energy has received extensive attention in the field of power generation in recent years. Solar energy is directly converted into electricity through solar photovoltaic (PV) modules, and the maximum power point (MPP) of PV modules corresponds to the surrounding solar irradiation, PV module temperature, cell area and load conditions [1]. In order to make the photovoltaic module provide its maximum power and improve the power generation efficiency of the photovoltaic cell, this paper introduces the maximum power point tracking technology (MPPT), so that the photovoltaic cell can obtain the maximum power output.

There are many kinds of MPPT algorithms, and the commonly used power tracking algorithms include: (1) constant voltage tracking method (CVT). Under the condition that the temperature remains unchanged and only the light intensity is changed, the maximum power point voltage Um of photovoltaic cells is approximately proportional to the open circuit voltage. The advantage of this method is that it can reduce the design difficulty of MPPT controller [3-4]. Although this method is simple to control, easy to implement and has good stability, it ignores the influence of temperature change on open circuit voltage. Once the temperature changes, the voltage Um at the maximum power point will be offset [5]. Shao Cui et al. added a low-power photovoltaic cell with the same characteristics as the photovoltaic array to the system, and obtained the real-time maximum power point voltage Um of the photovoltaic array by detecting the open-circuit voltage of the low-power cell. Although this solved the voltage offset problem, the additional low-power photovoltaic cell increased the cost. (2) Incremental conductance method (INC) and disturbance observation method (P&O) are essentially the same, because their algorithm is simple and easy to implement, and can better achieve tracking effect, so they are one of the most widely used methods at present. Aiming at the problems of power oscillation and misjudgment of actual working point in this method, Zhang Guo-liang et al. [8] proposed an adaptive step disturbance method, which sets the step length quickly close to the maximum power point and adjusts it to a small step length in steady state. Although this method solves the phenomenon of power oscillation, the misjudgment problem still exists. Wang Wei et al. [2] applied the power prediction algorithm of three-point sampling model to predict the power of the next cycle and judge the disturbance direction based on it. Meanwhile, the variable step size disturbance method was adopted to solve the problem of misjudgment of the actual working point by the system.

In this paper, an improved disturbance observation MPPT algorithm is proposed, which has the following advantages over traditional P&O and CVT: 1) fast MPP tracking is achieved by variable step size, and small oscillations are achieved at steady state; 2) There is no need to add additional sensors, only through the voltage, changes to sense the sudden change of external conditions; 3) It can quickly respond to the maximum power point tracking when the external environment changes, and solve the disturbance misjudgment.

2. Model of Photovoltaic Power Generation System and Maximum Power Control

2.1. Mathematical model of photovoltaic cell

Build an equivalent model of photovoltaic cells. As shown in Figure 1, R_s and R_{sh} represent the loss of the PV cell, and R_L represents the external load of the cell connection. I_p represents photogenerated current, and Ipv and U_{pv} are the output current and output voltage of photovoltaic cells respectively. I_0 is the reverse saturation current of the diode, Rs and R_{sh} are the series resistance and parallel resistance of the PV cell respectively, q is the charge constant, A is the ideal coefficient of the diode, K is the Boltzmann constant, and T is the ambient temperature of the PV panel. According to this model, Kirchhoff's law can be obtained:

$$I_{pv} = I_{ph} - I_0\{\exp[\frac{(I_{pv} \times R_s + U_{pv})}{AKT}] - 1\} - \frac{U_{pv} + I_{pv} \times R_s}{R_{sh}} \qquad (1)$$

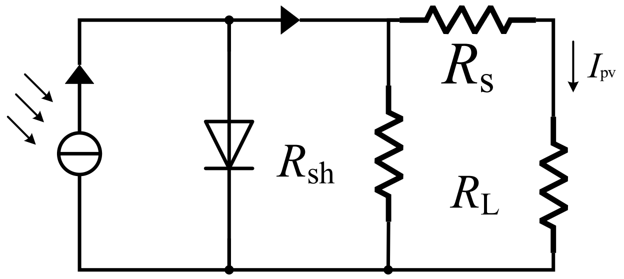
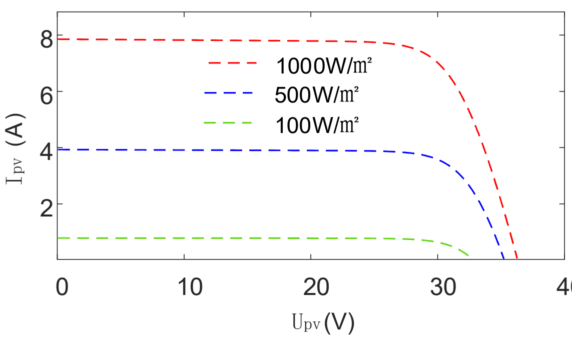


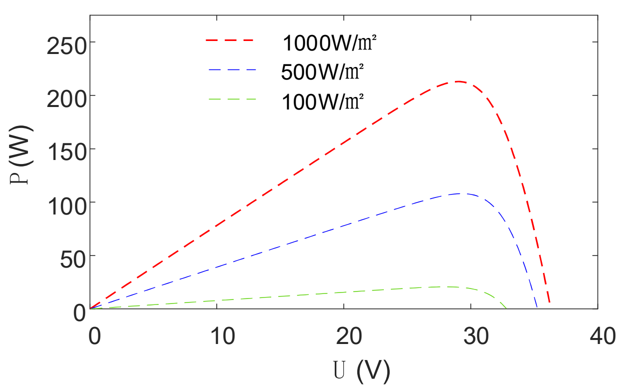
Figure 1. Equivalent mathematical model of photovoltaic cells

2.2. Output characteristics of photovoltaic cells

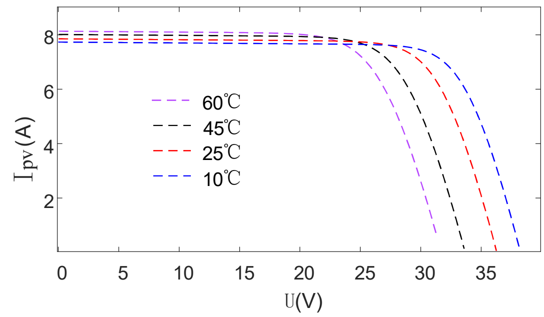
Figure 2 shows the voltage-current and voltage-power output characteristic curves of the photovoltaic cell under different temperatures and illumination. It can be seen that when the illumination intensity is constant, the photovoltaic cell outputs the maximum power Pm under a specific voltage Um, and the maximum power Pm of the photovoltaic cell will increase with the increase of the illumination intensity. When the light intensity is constant, with the increase of temperature, the overall output power of photovoltaic cells will decrease. Therefore, with the change of the external environment, the maximum power point of photovoltaic cells will also change, and compared with the influence of light intensity, the offset of the maximum power point is more obviously affected by temperature.



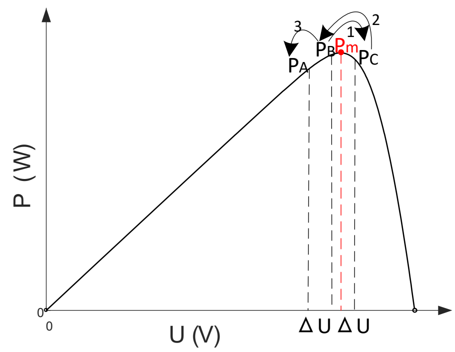
(a) I-U curves under different illumination at 25°C



(b) P-U curves under different illumination at 25°C



(c) 1I-U curves at different temperatures under light intensity of 000W/m2



(d) P-U curves at different temperatures under light intensity of 1000W/m2

Figure 2. P-U,I-U characteristic curves of PV cells

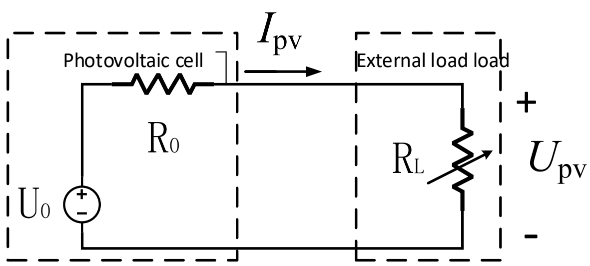


Figure 3. Equivalent circuit diagram of PV cell power output

The maximum power tracking of photovoltaic cells can be explained by the impedance matching principle. When the illumination and temperature are constant, the output power of photovoltaic cells changes with the change of the external load R_L. When R_L is less than R_0, the output power of the battery is less than the maximum power point, corresponding to the left half of the P-U curve. When RL is greater than R0, it corresponds to the right half of the P-U curve; When RL is equal to R0, the PV cell works with the maximum power point. The so-called maximum power tracking technology, in essence, is to control the ratio of the on-off time and the off-off time of the DC chopper circuit by controlling the switching frequency of the field effect tube. By matching the internal resistance of the photovoltaic module with the load resistance value, adjust R_L equal to R_0, and then make the photovoltaic module output the maximum power. The implementation process of the MPPT control strategy is to adjust the switching frequency of the field effect tube in real time according to the change of the output characteristics of the photovoltaic module, so as to make the load resistance value match the internal resistance of the photovoltaic module.

3. MPPT Algorithm

3.1. Disturbance observation method

The algorithm flow of the traditional disturbance observation method is shown in Figure 4. The disturbance observation method has two shortcomings in the process of power tracking. One is that when the external environment changes violently, such as the moment of sudden illumination, the algorithm logic of the disturbance observation method cannot determine whether the change of system power is caused by the change of illumination intensity or by its own disturbance. As a result, the wrong disturbance direction leads to power loss. As shown in FIG. 5, after the disturbance of ΔU is applied, the light intensity suddenly decreases, and the corresponding P-U curve changes, from the original curve L1 to curve L2, and the measured ΔP becomes ΔP*, which leads to the wrong judgment that the next disturbance is the disturbance in the opposite direction, resulting in power loss. Second, when it reaches the maximum power point, due to the existence of disturbance step, it will oscillate back and forth near the maximum power point, which will also cause power loss, as shown in Figure 6. Aiming at the problems of power oscillation and misjudgment of actual working point in this method, Wang Wei et al. [8] proposed an adaptive step size disturbance method, introducing variable step size factor as

$$d_{k+1} = \left|\frac{\Delta P_k \Delta I_{k-1}}{\Delta I_k \Delta P_{k-1}}\right| \tag{2}$$

The MPPT controller updates the disturbance step size in each sampling period, and the updated reference voltage is:

$$Uref(k+1) = Uref(k) \pm (dk+1)\Delta Uref \tag{3}$$

Although this method can improve the dynamic performance of the system and make the disturbance step adjust according to the position of the operating point, so that the system has a good dynamic response speed, it is difficult to control the size of the variable step factor, and has high requirements on the processor's ability to process data, so it is also difficult to solve the problem of misjudgment. In order to solve the problem of disturbance misjudgment and response speed in disturbance observation method, an improved disturbance observation method based on three states is proposed in this paper. The new variable step size factor is introduced as

$$d'_{k+1} = \frac{1}{I_k}\left|\frac{dP}{dU}\right| = \frac{1}{I_k}\left|\frac{d(UI)}{dU}\right| = \frac{1}{I_k}(I + U\left|\frac{dI}{dU}\right|) = 1 + \frac{U_k}{I_k}\left|\frac{dI}{dU}\right| \tag{4}$$

It can be seen from Figure 2-a that when the voltage is far less than the maximum power point voltage, the current is almost a straight line. In this interval, the dI/dU is approximately equal to 0, so the variable step factor is about equal to 1; Near the maximum power point, the value of dP/dU decreases gradually until it reaches the maximum power point, which is 0. Therefore, the purpose of 0 disturbance step can be realized near the maximum power point. When it is on the right of the maximum power point, in order to ensure the convergence of the algorithm, it is necessary to ensure that|d'_{k+1}|is less than 1, so when it is on the right of the maximum power point and |d'_{k+1}|>1, let|d'_{k+1}|=1. Through this design, the disturbance step size can be adjusted in the tracking process, and the disturbance can be reduced as much as possible in the steady state, and at the same time, the step size can not be too large, resulting in the non-convergence of the algorithm.

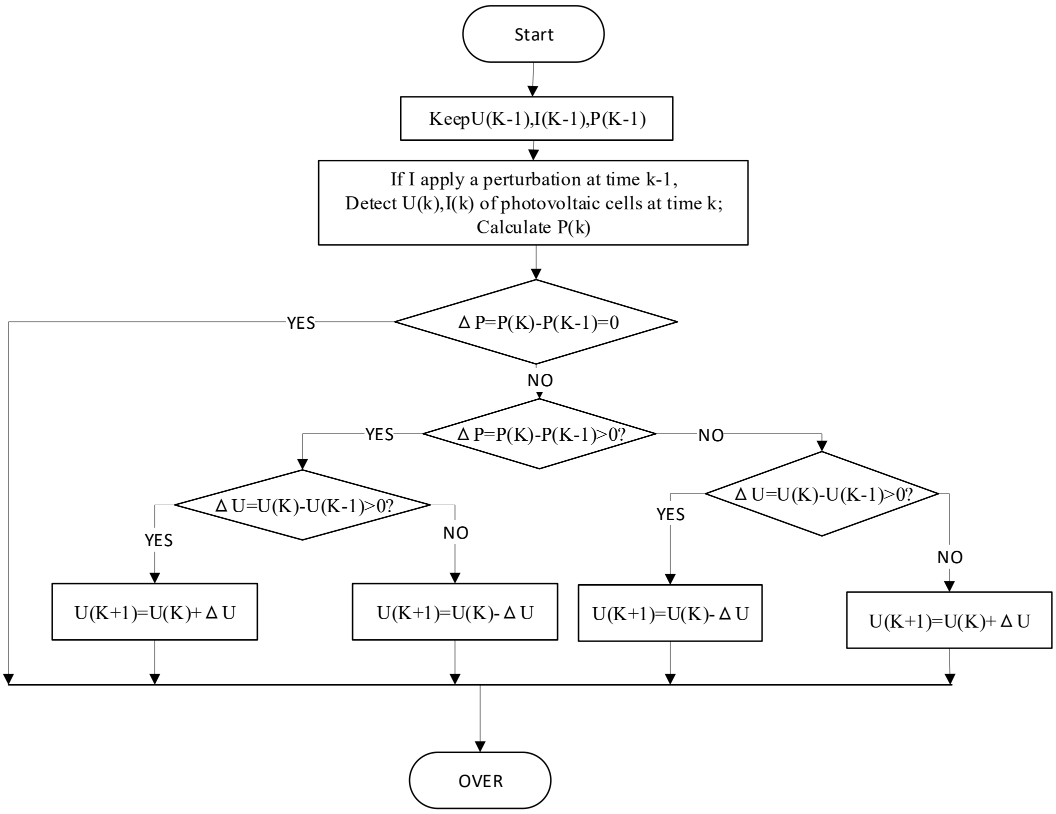


Figure 4. Flow chart of traditional disturbance observation method

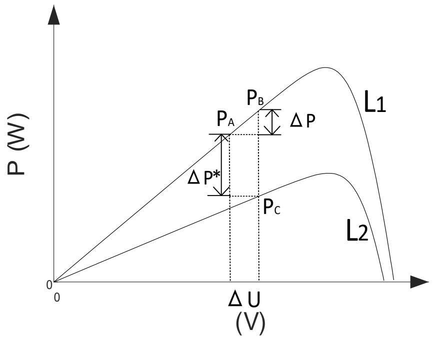


Figure 5. Analysis of misjudgment phenomenon

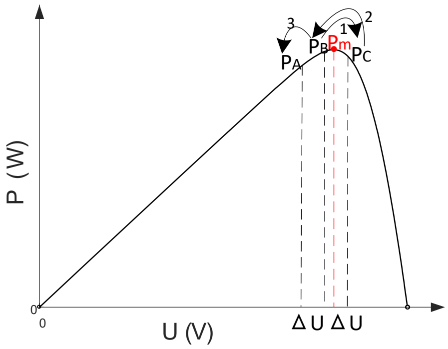


Figure 6. Analysis diagram of oscillation phenomenon

3.2. Three-state variable step perturbation observation method based on power prediction

The misjudgment of disturbance observation method in high-power photovoltaic system will cause the loss of system power oscillation. In terms of mathematical characteristics, the variance between the power curve obtained by the traditional disturbance observation method and the ideal power curve in the sampling period is large. In order to improve the problem of false judgment existing in the traditional disturbance observation method and two-point interpolation method, this paper uses Newton interpolation method to establish the power prediction model y=f(x) of three-point function sampling, as shown in Fig. 7. During the time of kT~(k+1)T, the external light intensity changes, and the corresponding P-U curve gradually changes from curve 1 to Curve 4. The voltage and current are sampled at kT, (k+1)T and (k+2/3)T respectively, and P(k), P(k+1/3) and P(k+2/3) are calculated. The predicted power value P*(k) at the time of (k+1)T is calculated by Newton interpolation method, and P*(k) is used to replace P(k) in the traditional disturbance observation method. The disturbance is applied immediately after the power acquisition of (k+2/3)T, so as to ensure that the P-U curve before and after the disturbance is applied is on the same curve. In this way, the original dynamic observation method can not distinguish whether the power change is caused by voltage or light.

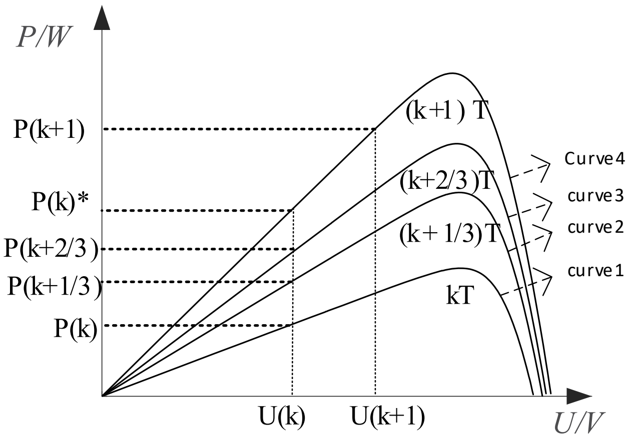


Figure 7. Power prediction method based on three-point sampling

The mean difference table is established according to the three-point sampling function model,as shown in Table 1

Table 1. Table of mean differences

x	*f*(*x*)	First order mean difference	Second order mean difference
k	*P*(*k*)		
k+1/3	*P*(*k*+1/3)	3[*P*(*k*+1/3)-*P*(*k*)]	
k+2/3	*P*(*k*+2/3)	3*P*(*k*+2/3)-*P*(*k*+1/3)]	4.5[*P*(*k*)+*P*(*k*+2/3)-2*P*(*k*+1/3)]

The functional expression of the three-point Newton interpolation method is calculated according to Table 1 :

$$y=f(x)=P(k)+3\left[P(k+1/3)-P(k)\right](x-k)+ \\ 4.5\left[P(k)+P(k+2/3)-2P(k+1/3)\right](x-k)(x-k-1/3) \quad (5)$$

By substituting it into Equation (2), we can obtain:

$$P^{*}(\mathrm{k})=P(k)-3P\left(k+1/3\right)+3P(k+2/3) \quad (6)$$

Equation (3) is the improved variable step size prediction power calculation formula, and then the positive and negative cases of P(k+1)-P*(k) and ΔU=U(k+1)-U(k) are integrated to judge the disturbance direction of the next cycle. Three-point interpolation further improves the accuracy of power prediction and reduces the problem of power misjudgment compared with the traditional interpolation prediction method. At the same time, in order to solve the contradiction between the dynamic response speed and the steady-state response accuracy of the photovoltaic system, this paper divides the tracking process into three stages for piecewise control.

1) In the initial start-up stage, the control method is set as constant voltage method, so that the voltage reaches a fixed value Ug=0.8Uoc. Before the fixed value is not reached, the reference voltage is kept U(k)=Ug unchanged for constant voltage control;

2) When the voltage reaches Ug, the variable step disturbance is started, and the improved power prediction disturbance method is used to track the variable step disturbance. When it is far from the MPP point, the disturbance is carried out with a large step size, and the direction of the disturbance is judged by the symbols of dP and dU;

3) When the voltage reaches the maximum power point, the step size of the disturbance will gradually decrease. When it reaches >1, the system will judge that it is at the maximum power point and automatically change the step size factor to reduce the steady-state oscillation. Its algorithm flow is shown in Figure 8.

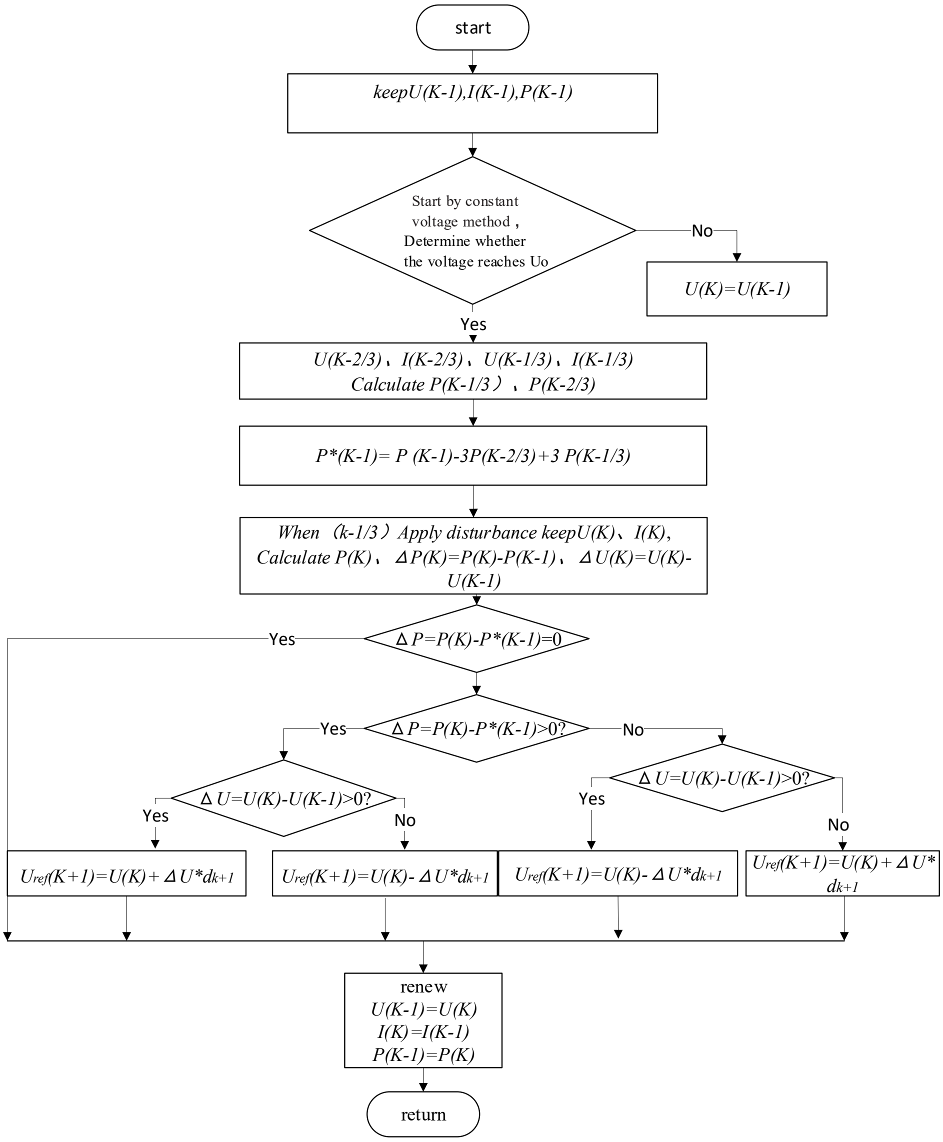


Figure 8. Flow chart of three-state variable step disturbance observation method based on power prediction

4. MPPT Algorithm Simulation

The solar cell adopts API-213 battery of Advance solar Company. The battery parameters are as follows: U_{oc} = 36.3V, I_{sc} = 7.84A, U_m = 29V, I_m = 7.35A. In this paper, 47 cells are connected in parallel and 10 cells are connected in series to simulate photovoltaic modules in engineering.

The simulation design is as follows:

1)In engineering, ladder signal is often used to verify the dynamic performance of control system, and sinusoidal signal is used to verify the tracking performance of control system. As shown in Figure 9, solar irradiance change curve 1 and irradiance change curve 2 are set. Curve 1 is the ladder signal. During 0-0.3 s, the irradiance is 1000 W/m2, and at 0.3 s, the solar irradiance S changes from 1000 W/m2 to 800 W/m2. It returns to 1000 W/m2 again at time 0.7 s and then holds. Curve 2 is a sinusoidal signal with solar irradiance S=600+200sin(t) during 0.3-2.5 S, solar irradiance s =600+500sin(3.5t) during 2.4-3.3 S, and s =1000 W/m2 after 3.3 s.

2）At a temperature of 25 ° C, the simulation results of the dynamic performance are shown in Figure 10. It can be seen from Figure 10 that the transient response of the improved three-state disturbance observation method in the start-up phase is faster. It can be seen in points 1-3 of Figure 10 that the three-state power prediction algorithm can reach the steady state faster in the start-up phase and the change of irradiancy, and the time to reach the steady state in the start-up phase is increased by 0.06s. The time for the irradiance mutation stage to reach the steady state is increased by 0.03s, and the steady state is more stable. In the study of dynamic performance, the comparative analysis of the data of the two algorithms using matlab can be obtained:

$$\int_0^{1.2} | P_1 | dt = 667W \tag{7}$$

P_1 is the power difference based on the three-state power prediction method and the traditional variable step disturbance method in Figure 10.

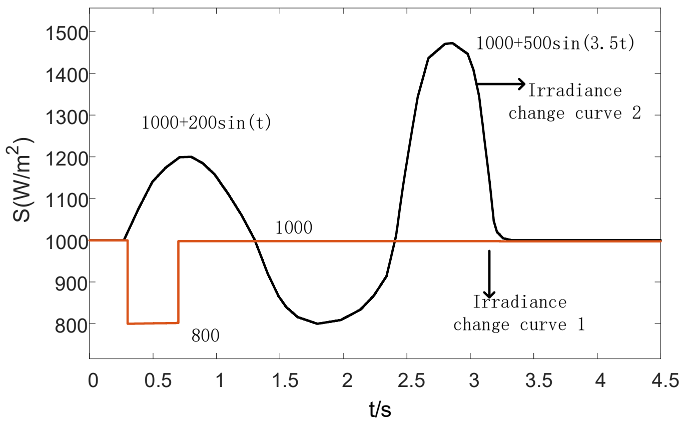


Figure 9. Solar irradiance change Settings

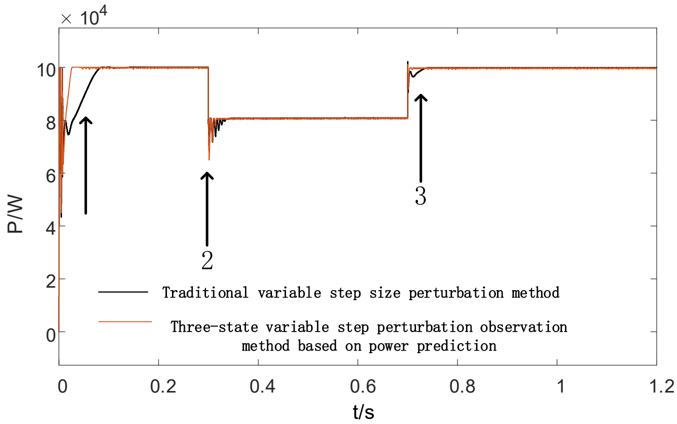


Figure 10. Simulation results of dynamic performance

3) At 25°C, the simulation results of tracking performance are shown in Figure 11. It can be seen from Figure 11 that the transient response of the three-state disturbance observation method based on power prediction is faster in the start-up stage. In the local magnification of Figure 11, it can be seen that the improved algorithm has less oscillation in the tracking process under the condition of non-uniform change of irradiation, so that the power loss is also more. It can be seen from points 1 and 3 of FIG. 11 that in the two stages of 2.2-2.3s and 3.2-3.3s, the traditional variable step size perturbation method will cause partial disturbance misjudgment when the illumination mutation is relatively severe. However, the improved algorithm can improve such misjudgment well and significantly improve the output power. In the study of tracking performance, matlab is used to make a comparative analysis of the data of the two algorithms:

$$\int_{2.2}^{3.2} |P_2|\, dt = 3687W \tag{8}$$

P_2 is the power difference between the three-state variable step perturbation observation method and the traditional variable step perturbation method based on power prediction in Figure 11.

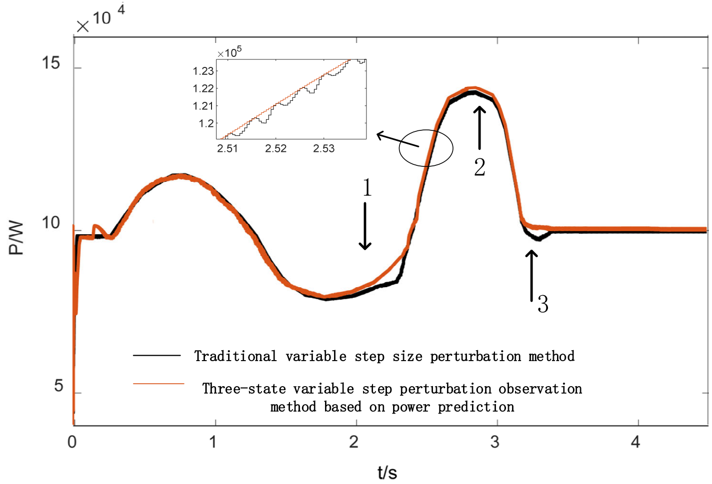


Figure 11. Optimization curve by disturbance observation method

When the photovoltaic system is at T = 25 ℃, the improved three-state variable step perturbation observation method based on power prediction is used to improve the dynamic performance and tracking performance compared with the traditional variable step perturbation observation method. Under the dynamic performance simulation experiment, the work of the improved three-state variable step perturbation observation method based on power prediction is increased by 687W in this example. In the tracking performance study experiment, the power was increased by 3687W.

5. Conclusion

Aiming at the problems of power misjudgment and inability to take into account both tracking speed and steady state oscillation in the traditional variable step disturbance observation method, a three-state variable step disturbance observation method based on power prediction is proposed in this paper. The constant voltage method is introduced in the initial stage to improve the tracking speed in the starting stage. The power prediction is improved by the method of three-point interpolation, and the problem of disturbance misjudgment is solved. At the same time, a new variable step size factor is introduced to improve the tracking speed and reduce the steady-state oscillation.

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