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# A new maximum power point control algorithm of photovoltaic generation system

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## ABSTRACT

Due to the severe environmental changes, especially in the context of the greatly change of the sunlight, the output power of the solar power system will be unstable. In the case of partial obstruction, the equivalent characteristic curves of the photovoltaic panel show a multi-peak state, traditional maximum power control technology is prone to misjudgment and cannot find the maximum power point (MPP). In order to solve this problem, a Newton method based on particle swarm optimization (PSO) is proposed to control the multi-peak MPP. The algorithm will firstly optimize the inertia weight of the particle swarm algorithm, then it will use the optimized particle swarm algorithm to search for the multi-peak MPP. The Newton method will rapidly solve the maximum value to achieve multi-peak MPP tracking when curves approaching to the maximum value. Construction of the boost chopper circuit, which was compared with the particle swarm algorithm and Newton method, was simulated under different light intensities by the simulation softwares such as Simulink and Matlab. The results show that Newton method based on the PSO can quickly find the maximum power with characteristics of good convergence speed and accuracy.

## ARTICLE HISTORY

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## KEYWORDS

Solar power generation; multi-peak; particle swarm algorithm; Newton method

## 1. Introduction

Currently, environmental pollution and energy shortages are increasingly serious. For this reason, people have begun to pay attention to the research and utilization of renewable energy such as solar energy. With the development of materials science and semiconductor technology, the cost of photovoltaic (PV) power generation systems based on silicon materials has begun to decrease, and solar power generation has become an important component of the power industry.

The maximum power point (MPP) control technology has become a significant technology for improving PV power generation efficiency (Li, Chu, & Chen, 2012). Due to the rapid changes of the environment, especially when the light changes greatly, the output power of the solar power system may be unstable. Especially in the presence of cloud cover or other shelters, the external characteristics of the power voltage of the PV panel will exhibit multi-peak shape (Chen, Feng, & Du, 2011). The traditional tracking method is easy to track to the local extremum rather than the maximum, which can cause the misjudgment of the PV power generation system, and lose some of the electrical energy. For this problem many scholars have studied this difficult problem (Li et al., 2012) proposed a particle swarm optimization (PSO) algorithm in

the case of multiple peaks. The algorithm can accurately determine the maximum value problem, but its parameter selection is not easy. If its parameter settings are not reasonable, it will affect the control accuracy. The Newton interpolation method is proposed by Qiu, Ge, and Bi (2011), but the Newton method has certain requirements for the selection of interpolation nodes. If the interpolation node is not properly selected, misjudgment will occur. Feng (2012) used a dynamic configuration optimization under local shadow conditions is proposed to find the MPP, but its hardware implementation is more complicated as well as the tracking speed is slower. Zhou and Chen (2015) proposed a variable-step conductance increment method is proposed to find the MPP of a PV panel. However, in the case of partial occlusion, the algorithm, tending to cause mistakes, has a poor effect of tracking the MPP and it is easy to track to the local extreme value. In summary, to control the PV panel MPP in the partial blocking state mainly has the following disadvantages: its control speed is slow, and it is easy to trace to the local extreme value rather than the MPP.

For the multi-peak PV array tracking problem, this paper uses a Newton method for PSO. This method first uses the particle swarm algorithm to find the peak power under local shading illumination. Then, use this point as

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the initial point of the Newton method to iteratively find the maximum point. In this way, it can not only overcome the instability and speed problems of the particle swarm algorithm, but also the limitations of the Newton method which can only find the local optimum. Moreover, it can also quickly and accurately track the MPP in the case of multiple peaks.

## 2. MPP control principle

### 2.1. PV panel MPP control principle

The MPP control of solar power generation system mainly consists of PV cell components and boost circuit. The principle of the PV generation system is shown in Figure 1.

If the resistance in the chopper circuit is negligible and the chopper circuit has no loss, the solar panel and chopper circuit in Figure 1(a) can be equivalent to the series connection between the voltage source and resistor  $R_L$  in Figure 1(b). By the maximum power transfer theorem, when the load resistor  $R_1 = R_L$ , the system can track the maximum power (Feng, 2012; Guo, Man, Sun, & Bian, 2016). Therefore, the load impedance in the solar power generation system after the conversion of the chopper circuit can be expressed as

$$R_1 = R_L = (1 - D)^2 R. \quad (1)$$

In formula (1),  $D$  is the duty cycle of the booster circuit,  $R$  is the PV system load. Therefore, the MPP control principle of PV cells can be described as the PV power generation system can output the maximum power when the equivalent internal impedance of the PV power generation system matches the load impedance (Feng, 2012). Due to the influence of environmental changes such as illumination and temperature, the internal impedance of the PV power generation system will change as respond. Therefore, it is necessary to adopt a control strategy to track the equivalent internal impedance of the PV power generation system in real time for outputting the maximum power.

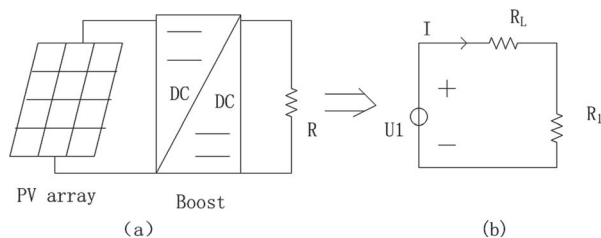


Figure 1. The principle of the PV generation system.

## 2.2. PV array model and electrical characteristics

### 2.2.1. PV panel model

The mathematical model of PV panel engineering is listed as follows:

$$I = I_{sc} \left( 1 - C_1 \left( e^{\frac{U}{C_2 U_{oc}}} - 1 \right) \right), \quad (2)$$

$$C_1 = \left( 1 - \frac{I_m}{I_{sc}} \right) e^{\frac{-U_m}{C_2 U_{oc}}}, \quad (3)$$

$$C_2 = \left( \frac{U_m}{U_{oc}} - 1 \right) \left[ \ln \left( 1 - \frac{I_m}{I_{sc}} \right) \right]^{-1}. \quad (4)$$

$I_{sc}$ ,  $I_m$ ,  $U_{oc}$ ,  $U_m$  are the short circuit current, MPP current, open circuit voltage, and MPP voltage of the panel, respectively, under a certain temperature and light environment.  $C_1$ ,  $C_2$  are constant. When the temperature and light conditions change,  $I_{sc}$ ,  $I_m$ ,  $U_{oc}$ ,  $U_m$ ,  $C_1$ ,  $C_2$  require corrections. Refer to the literature for detailed correction formulas (Ghoddami & Yazdani, 2011).

### 2.2.2. PV array and cell model

Under the partial shadows, the output characteristics of the PV array are not a simple addition between voltage and current (Ramdan, Koad, & Faheem, 2017). In the case of the partial shadow, the occluded battery element will not only generate none electricity, but also consume the heat generated by other panels (Yan, Fang, & Wang, 2016; Zhao, Zheng, & Tao, 2017). This is also called the hot spot effect. Therefore, solar panels should in parallel with diodes to prevent consuming energy from other battery components during the panel heating. The circuit connection diagram is shown in Figure 2.

Simulated by the simulation software Matlab, the output power curve under local shadow conditions is shown in Figure 3.

Figure 3 simulates three kinds of light conditions. In no shadows, the PV array curve has an inverted U-shape with only one peak. The PV array output under the environments of partial shadows 1 and 2 have characteristics of multiple peaks, and the maximum value is not necessarily at the first extreme value. In the case of multi-peaks, the traditional tracking algorithms are often misjudged, and lead to a local optimum and cannot find the MPP. This

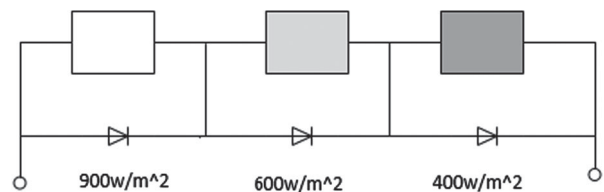
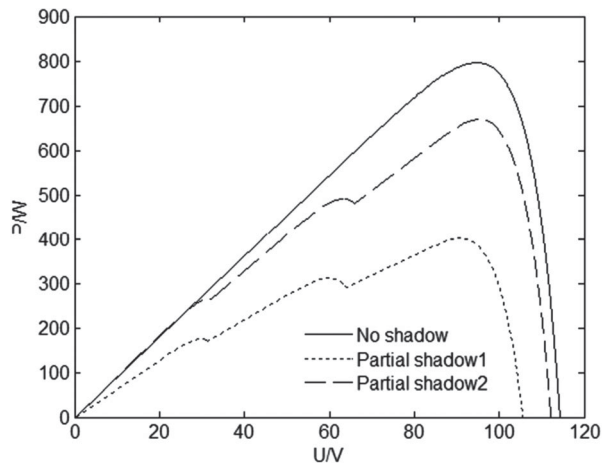


Figure 2. Series model of PV array.



**Figure 3.** P-V curves under different light conditions.

situation poses a challenge to the tracking of the solar power system MPP.

### 3. The Newton method based on PSO

#### 3.1. Particle swarm optimization (PSO)

The PSO algorithm finds the global maximum by continuously comparing and sharing information among particles (James & Russell, 1995). Particle updates depend on individual extremes  $p_{best}$  and global extremes  $g_{best}$ , and the particle velocity and position update formulas are shown as follows (Bai, Li, & Zheng, 2013; Hou & Zhao, 2013):

$$v_i(t+1) = wv_i(t) + k_1c_1(P_i - x_i(t)) + k_2c_2(P_g - x_i(t)), \quad (5)$$

$$x_i(t+1) = x_i(t) + v_i(t+1). \quad (6)$$

$k_1$  and  $k_2$  are random numbers between 0 and 1,  $c_1$  and  $c_2$  are learning factors,  $w$  for the inertia weight.  $P_i$  is the optimal position of the  $i$ th particle,  $t$  is the number of iterations,  $v_i$  the particle velocity, and  $x_i$  is the particle position. The linear differential derivative method is adopted to select  $w$ , and the formula is:

$$w = 0.9 - 2 \times 10^{-4} \times t^2. \quad (7)$$

By choosing the weight of linear differential decrement can make  $w$  reduce slowly in the initial stage of the algorithm, which can help to find the global optimum, while the decrease speed is accelerated in the later stage, which is beneficial to quickly find the optimal value.

The particle extremum update condition formulas are as follows:

$$P_i(t+1) = \begin{cases} P_i(t), & f(x_i(t+1)) \leq P_i(t) \\ f(x_i(t+1)), & f(x_i(t+1)) \geq P_i(t) \end{cases}, \quad (8)$$

$$f(x_i) = P = UI, \quad (9)$$

$f(x_i)$  is the fitness function to represent the PV panel power. When the PSO algorithm is used to solve the multi-peak PV panel MPP, the voltage is defined as each particle. Through the continuous updating the position, velocity and the calculation of the comparative fitness function value of the particles, the global optimum was found to find the MPP.

The end condition of the improved PSO algorithm is: if it reaches 50 iterations or the maximum distance between population particle voltages is less than  $5\%U_{array}$ , this point is returned as the initial point of the Newton method.

#### 3.2. Newton method

Newton method can achieve local second-order convergence and local extreme points, which depends on the selection of initial points. The Newton method iterative form is:

$$x_{k+1} = x_k - \frac{1}{g''(x_k)} g'(x_k). \quad (10)$$

In PV power generation systems,  $U$  is an independent variable,  $U$  and  $P$  can obtain by Equations (11) and (12):

$$U_{k+1} = U_k - \frac{dP_k/dU_k}{d^2P_k/dU_k^2}, \quad (11)$$

$$P = UI. \quad (12)$$

Substituting Equation (2) into (11), the derivation is:

$$dP_k/dU_k = I_{sc}(1 + C_1) - I_{sc}C_1 \left(1 + \frac{U}{C_2U_{oc}}\right) e^{-\frac{U}{C_2U_{oc}}}, \quad (13)$$

$$d^2P_k/dU_k^2 = -e^{-\frac{U}{C_2U_{oc}}} \frac{I_{sc}C_1}{C_2^2U_{oc}^2} (2C_2U_{oc} + U). \quad (14)$$

The initial point  $(U_k, P_k)$  which under certain environmental conditions is substituted into the formulas (10) and (11) to calculate the first derivative and the second derivative, update  $(U_{k+1}, P_{k+1})$ , and get the best value through the continuous iteration. The iteration end condition is: when  $|U_{k+1} - U_k| \leq \Delta U_{min}$ ,  $|P_{k+1} - P_k| \leq \Delta P_{min}$ , the algorithm stops, which should meet the control error requirements  $\Delta U_{min} \leq 0.5\%U_{array}$ .

The Newton method can be used to seek the MPP of the PV array, and the solution speed is fast, but the selection of the initial point is very important. If the initial point is not properly selected, the multi-peak MPP cannot be tracked. And the Newton method is used to solve the local optimum. When there have multi-peaks, the initial point should be solved firstly by the particle swarm algorithm, so that the MPP obtained by the Newton method is the global optimal value.

### 3.3. Newton method MPP control based on PSO

Based on PSO, the Newton method uses the global optimization capability of the PSO method to solve the voltage value near the MPP, which can be used as the initial point of the Newton method. Then, we can use Newton method to handle the local iteration. At this time, the initial value is already processed by the particle swarm algorithm, and the initial value is selected properly. This algorithm not only retains the global optimization ability of the PSO algorithm, but also has the local optimal feature of the Newton method, which can be used to solve the multi-peak MPP.

The PSO Newton algorithm steps in the MPP control application are as follows.

Set the particles  $N = 50$ , and the initial values of  $w$ ,  $t$ ,  $c_1$ ,  $c_2$ ,  $k_1$ ,  $k_2$ . Initialize the position and velocity of the particles. According to Figure 3, the voltage corresponding to MPP is approximately 0.8 times of the PV open circuit voltage. In order to make particles distribute as close as possible to the MPP, an initialization is performed in the interval  $[0.8U_{\text{module}}, 0.8U_{\text{array}}]$ , where  $U_{\text{module}}$  and  $U_{\text{array}}$  are the open circuit voltages of the solar panels and arrays.

Algorithm flow chart is shown in Figure 4.

- (1) Calculate the fitness value of each particle. The fitness can choose as  $P$ .
- (2) Update  $p_{\text{best}}$  and  $g_{\text{best}}$ , compare the size of function fitness, and get  $p_{\text{best}}$  and  $g_{\text{best}}$  according to Equations (7) and (8).
- (3) Update the speed and position of the particles.
- (4) The end condition is reached. If it reaches 50 iterations or the distance between the population particles is less than  $5\%U_{\text{array}}$ , then the current  $g_{\text{best}}$  is returned and output  $(U_k, P_k)$ , and proceed to the next step, otherwise, step 1 is performed.
- (5) Newton method. The iterative process is as described in Section 3.2.
- (6) End conditions. If the maximum number of iterations reaches 10 or the error requirement is reached  $\Delta U_{\text{min}} \leq 0.5\%U_{\text{array}}$ , output the voltage  $U_m$ .

## 4. Simulation and experiment

Based on PSO, Newton method uses Simulink to simulate the multi-peak PV array and design the chopper circuit. The simulation circuit diagram is shown in Figure 5.

The circuit output the MPP voltage through the MPPT module to control the gate-level voltage of the duty-cycle output MOSFET. The MPPT module consists of an S function constructed by the PSO Newton method. Input  $U$  and  $I$  is output duty cycle. The

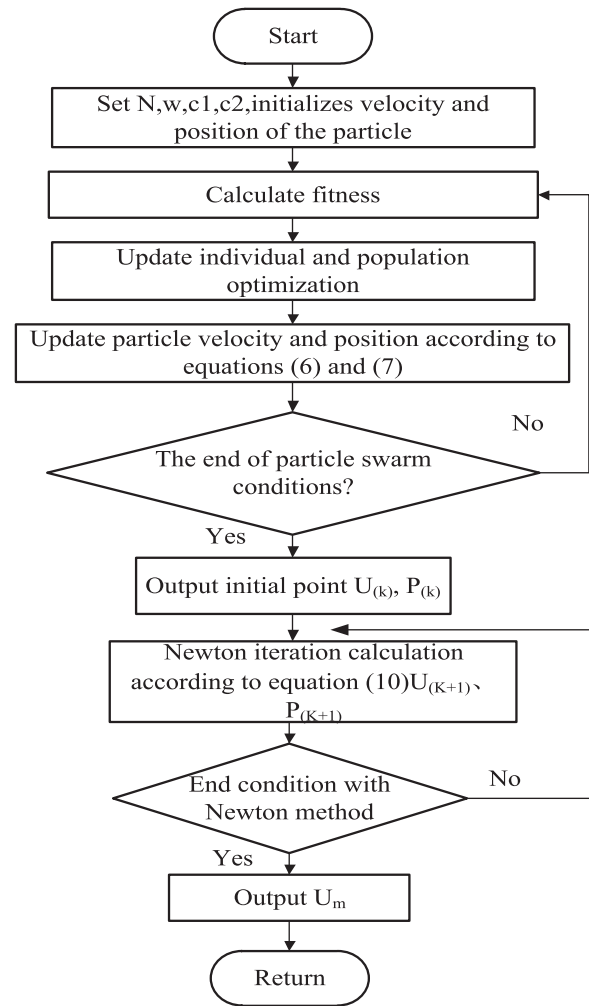


Figure 4. Workflow chart of Newton method of PSO.

simulation temperature is  $25^{\circ}\text{C}$ , using PV-HX0803 type of PV cell under the standard parameters of  $U_m = 31\text{ V}$ ,  $U_{\text{oc}} = 38.1\text{ V}$ ,  $I_{\text{sc}} = 9.08\text{ A}$ ,  $I_m = 8.45\text{ A}$ , The first stage light intensity of the panel in the simulated shadow state is  $700, 600\text{ W/m}^2$ , and the second stage light intensity is  $900, 600, 400\text{ W/m}^2$  respectively.

The iterative process of PSO and the improved PSO with optimized parameters in the second stage light intensity are shown in the Figures 6 and 7.

From Figures 6 and 7, we can see that the particle swarm algorithm obtains the MPP with 24th iteration, while the improved ones only use 17th iteration. Which shows that the improved particle swarm algorithm finds MPP is faster.

The comparison results of the output power waveforms of different algorithms through the Simulink simulation circuit are shown as Figure 8.

Figure 8 shows that the first stage of light intensity is  $1000, 700, 600\text{ W/m}^2$ . The maximum power theoretical value of  $494\text{ W}$  during this period has been marked

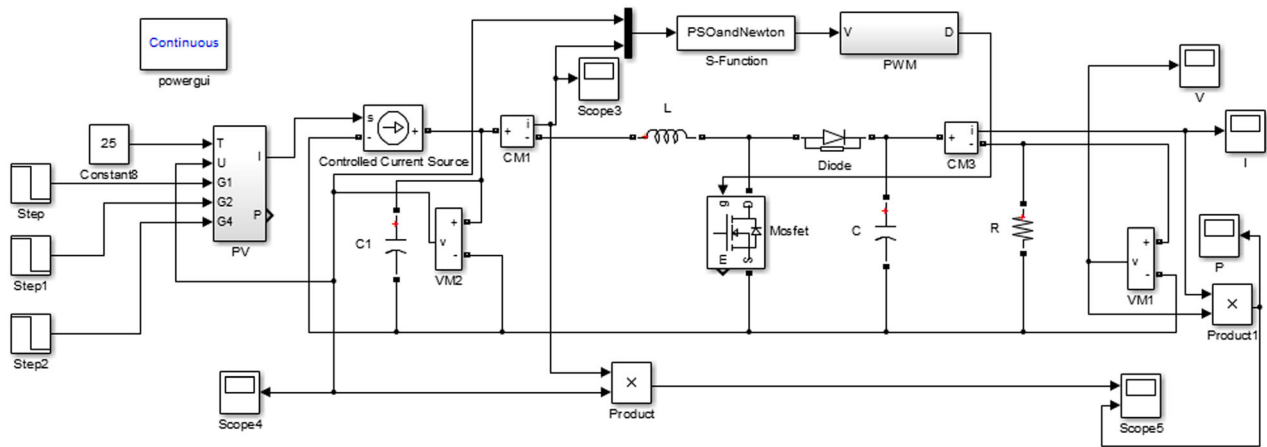


Figure 5. Simulink experimental circuit diagram.

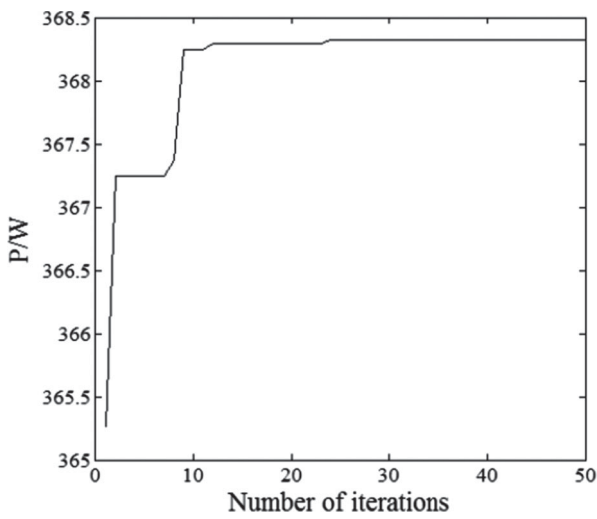


Figure 6. PSO iterative.

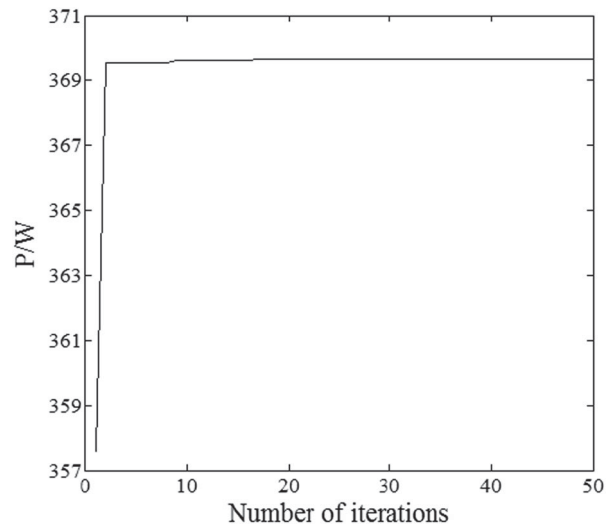


Figure 7. Improved PSO iterative.

in Figure 8. At 0.15 s, the Newton method with PSO and the PSO algorithm reach the stable value firstly, and the Newton method reaches the steady state at 0.2 s.

The maximum tracking power value is shown in Table 1. The second stage light intensity is 900, 600, 400 W/m<sup>2</sup>, respectively. The theoretical MPP voltage is

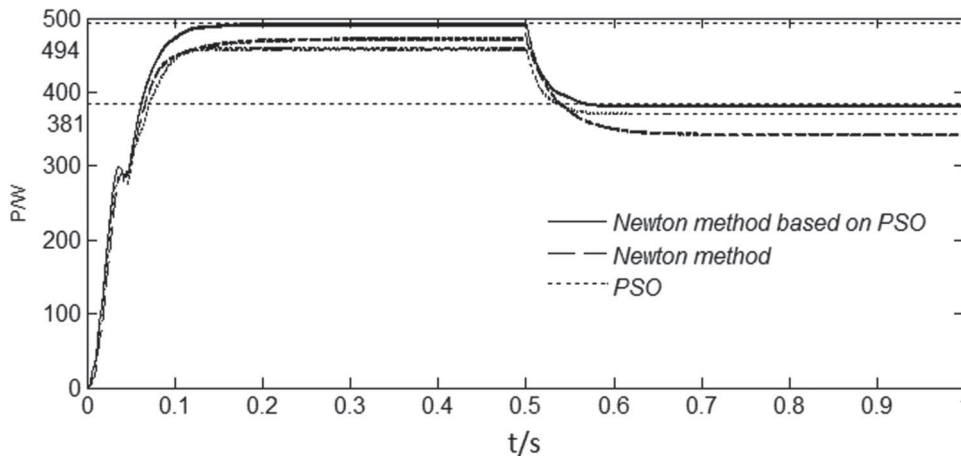


Figure 8. Comparison graph of light mutation algorithm.

**Table 1.** Simulation results analysis table.

Algorithm	Theoretical value	Experimental value	Accuracy (%)
The first stage light intensity is 1000, 700, 600 W/m <sup>2</sup>			
PSO	494 W	456 W	92.3
Newton method	494 W	472 W	95.5
Newton method based on PSO	494 W	491 W	99.3
The second stage light intensity is 900, 600, 400 W/m <sup>2</sup>			
PSO	381 W	368 W	96.5
Newton method	381 W	342 W	89.5
Newton method based on PSO	381 W	380 W	99.5

381 W. The Newton method for PSO firstly finds the maximum power at 0.6 s and it is closest to the theoretical value. The particle swarm algorithm also finds the maximum power at 0.6 s, but the accuracy is poor. The Newton algorithm is stable at 0.7 s, but the tracking accuracy was only 89.5% at this light intensity and no MPP was found. From above, it can be seen that the Newton method of PSO can track the MPP more accurately than the Newton method and the particle swarm method, as well as its algorithm has the fastest control speed.

## 5. Conclusion

In this paper, a Newton method based on PSO is proposed. The principle of MPP tracking for PV power generation was introduced, and a PV array Matlab model under the partial shadow was established. The Newton method based on PSO is proposed to solve the problem of multi-peak MPP tracking. The algorithm first uses PSO to select the initial point, and then uses Newton method to track the MPP. Experiments were performed with Simulink and compared with the particle swarm method and Newton method. Experiments show that the Newton method of the PSO can quickly and accurately track the multi-peak MPP.

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## Disclosure statement

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