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Maximum power point tracking of photovoltaic array based on improved Particle Swarm Optimization Algorithm

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Abstract—With the vigorous development of the photovoltaic industry, how to improve the efficiency of photovoltaic power generation has become an important issue, among which partial shadow occlusion is an important reason affecting the efficiency. The efficiency of photovoltaic power generation can be effectively improved by adopting the maximum power point tracking method (MPPT), but the traditional MPPT method is not ideal in the partial shadow occlusion of the photovoltaic array. To solve this problem, this paper proposes an improved particle swarm optimization method to effectively improve the tracking efficiency of MPPT when multiple peaks appear in the photovoltaic arrays power curve (P-V) under the partial shadow. The proposed method improves the learning factor of the traditional particle swarm optimization algorithm and designs the initial position of the particles according to the characteristics of the photovoltaic array. By adding the particle elimination mechanism, the number of particles changes dynamically, and the tracking speed of the algorithm for the maximum power of the photovoltaic array is improved. Through the result of the simulation, it is not difficult to get the conclusion that the improved particle swarm optimization algorithm can effectively improve the performance of the photovoltaic system under partial shadows.

1. Introduction

With the rapid development of the global economy, the energy demand is increasing gradually. At present, the fossil energy widely used has the problems of high pollution and over-exploitation, and renewable energy becomes the inevitable direction of energy development. Under the demand for environmental protection, industrial upgrading, and production safety, the solar photovoltaic power generation industry has attracted more and more attention[1]. In 2021, the newly connected photovoltaic power generation has accounted for 53.4% of the total capacity of the newly added grid[2].

With the wide application of photovoltaics, improving the efficiency of photovoltaic power generation has become the main issue of photovoltaic utilization. Maximum Power Point Tracking (MPPT)[3] is a commonly used method to improve photovoltaic utilization efficiency. This technology can stabilize the operating point of the photovoltaic array at the maximum power output point, thus greatly improving the efficiency of the photovoltaic system.

Traditional MPPT methods include perturbation and observation method (P&O)[4], incremental conductance method (INC)[5], constant voltage tracking (CVT)[6], etc. The principle of the P&O method is to apply a disturbance to the output current or voltage of the photovoltaic array. The disturbance of the next step will be changed by comparing the output power of this time with the output power of the last time. The advantages of this method are the low hardware cost and the simple algorithm, but it is easy to appear oscillation when the disturbance quantity is improperly selected. The INC method controls the signal by the conductance increment and instantaneous conductance, which has a fast response speed and strong adaptability. However, it requires high precision of sensor, and the algorithm implementation is complicated. The CVT method is simple to implement, but the tracking MPPT is a constant value, which has poor adaptability and large error with the actual MPPT. Due to the adoption of the fixed-step method in the traditional MPPT algorithm, tracking accuracy and tracking efficiency can not be achieved simultaneously. Therefore, some domestic and foreign scholars have proposed some improved MPPT methods, such as the MPPT control method based on variable step size[7], whose principle is that the step size decreases with the distance close to the point that the power reaches the maximum. For example, the fuzzy logic control method[8] is suitable for complex nonlinear models[9] that are difficult to be accurately described. For example, the neural network control method[10] gained strong learning ability and adaptability by combined with the artificial neural network.

Under the condition of uniform illumination, the output power curve is a single peak when the photovoltaic array receives the same irradiation intensity, and the maximum power point is relatively easy to find. Therefore, the aforementioned MPPT method is highly applicable. However, under the influence of the external environment, partial shadow occlusion will inevitably occur in large-scale photovoltaic arrays [11]. Since every photovoltaic module has a bypass diode in parallel[12], the output power curve of the photovoltaic array is multi-peak in the case of partial shadow occlusion, which leads to the local optimal value easily falling into the traditional MPPT method. Therefore, it is particularly important to study MPPT in the shadow state for the stable and efficient operation of photovoltaic power generation[13-15].

To solve the power tracking problem in the case of multiple peaks caused by shadows, many scholars applied heuristic intelligent algorithms to MPPT, such as Grey Wolf Optimization (GWO)[16], Particle Swarm Optimization (PSO)[17], Ant Colony Optimization (ACO)[18]. These algorithms can reduce the influence of local optimal values through information exchange in the global scope. Besides, these methods continuously update the position and speed through iteration, thus reducing the convergence time. Compared with the traditional method, the general advantages of these algorithms have fast response speed, high tracking accuracy and strong solving ability.

However, the appellate algorithm still has some problems such as poor convergence efficiency and easily falls into the local optimal solution. For example, particle swarm optimization[19] still has room for improvement in terms of convergence time and local optimal interference resistance. Therefore, this paper proposes an improved particle swarm optimization algorithm to improve the reliability and efficiency of MPPT.

When the temperature of the environment changes little and the irradiation intensity changes, the maximum power point voltage of a single component changes little. According to this characteristic, the proposed method optimizes the initial position of particles and places the initial position near the integer multiple voltages of the maximum power point of a single component, which greatly improves the convergence of the search. At the same time, the improved algorithm added the population elimination strategy and eliminated the particles with the lowest fitness after each iteration. The convergence time was reduced by the dynamic change of the number of particles, and it was not easy to fall into the local optimal solution. Compared with other algorithms, it can be seen that the improved particle swarm optimization algorithm has a better searching ability under the condition of partial shadow occlusion.

2. Photovoltaic system and mathematical modeling

The commonly used photovoltaic system topology is shown in Fig.1. The structure is composed of the BOOST circuit and DC/AC inverter circuit. Among them, photovoltaic modules with bypass diodes in parallel form photovoltaic arrays, and several photovoltaic arrays further form photovoltaic arrays. The BOOST circuit is directly connected to the photovoltaic array, and the voltage is regulated by the PID controller[20], which controls the duty cycle of the switch tube to achieve the tracking of the maximum power point of the photovoltaic array. The BOOST circuit connects to grid-connected inverters after passing through capacitive filtering and ultimately converts light energy into electricity for transmission to the grid.

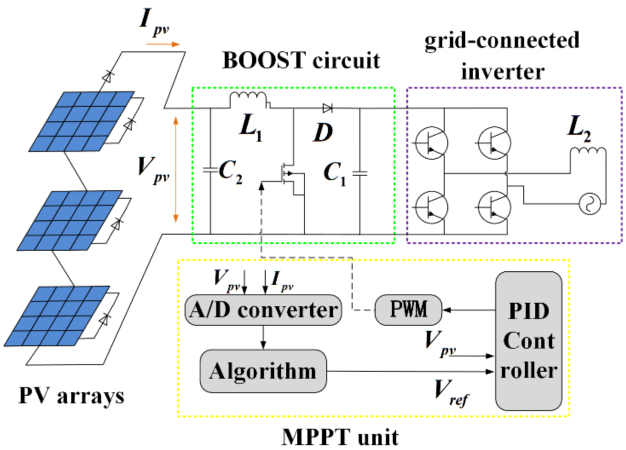


Fig.1 Photovoltaic system structure

2.1. Mathematical modeling of photovoltaic cells

The power generation principle of photovoltaic cells is that special semiconductor materials will generate electromotive force under light irradiation, and light energy can be converted into electric energy when connected to the load[21]. The photovoltaic cell model is usually composed of photogenerating current source, diodes, series resistances R_S and shunt resistance R_{sh}. The battery circuit model is shown in Fig.2.

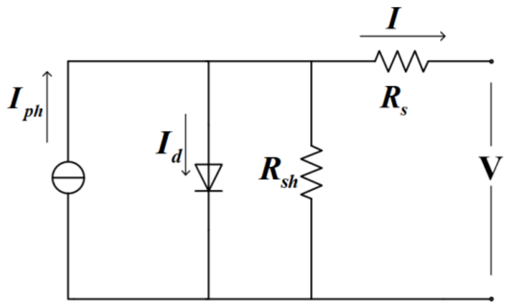


Fig.2 Photovoltaic cell circuit model

The output of photovoltaic cells satisfies equation (1).

$$I = I_{PH} - I_0[e^{\frac{q(V+IR_s)}{kTA}} - 1] - \frac{V+IR_s}{R_{sh}} \tag{1}$$

Where I_{PH} is the photo-generating current, which is proportional to irradiance, I_0 is the reverse saturation current of the diode, q is the unit charge, A is the diode quality factor, k is the Boltzmann constant and T represents the temperature of the photovoltaic array.

2.2. BOOST circuit

BOOST circuit（DC/DC Converter）is a DC voltage boost circuit that can transform the input DC into a higher voltage and adjustable DC by controlling the duty cycle of the switch tube[22]. It can be divided into two working processes. One is that the energy is stored in the inductor when the switching tube is closed. Another is that when the switch tube is disconnected, the inductor charges the capacitor while increasing the output voltage. By repeating the process, a voltage at the output higher than the voltage at the input is obtained.

The ratio of the closing time ton to a time cycle T of the switch tube is called the duty cycle. Input voltage u_{in}, output voltage u_{out} and duty cycle D in the BOOST circuit satisfy equation (2).

$$u_{out} = \frac{u_{in}}{(1-D)} \tag{2}$$

Duty cycle D satisfies equation (3).

$$D = {t_{on}}/{T} \tag{3}$$

The inductor in the BOOST circuit plays a role in storing electric energy and limiting current. Through formula (4), an appropriate inductor is obtained.

$$L > \frac{u_{out} D}{f_s \Delta i_{in}} \tag{4}$$

A suitable input capacitor can improve the stability of the input voltage, and the output capacitor is selected according to the input voltage. Input capacitor C_1 and output capacitor C_2 are determined by the formula (5) and (6).

$$C_1 > \frac{i_{in} D}{f_s \Delta u_{out}} \tag{5}$$

$$C_2 > \frac{\Delta i_{in}}{8 f_s u_{out} (1-D) \Delta u_{in}} \tag{6}$$

2.3. PID control in BOOST circuit

PID controller is widely used in industrial production, mainly composed of Proportion, Integration and Differentiation. It is the most widely used controller in the BOOST circuit at present. The PID controller model in the BOOST circuit calculates the control quantity through the error value *e(i)* of the first sampling and adjusts the duty cycle in the BOOST circuit, so as to achieve effective control of the output voltage. Its mathematical model is as equation (7).

$$u(i) = K_P e(i) + K_I \sum_{k=1}^{i} e(k) + K_D [e(i) - e(i-1)] \tag{7}$$

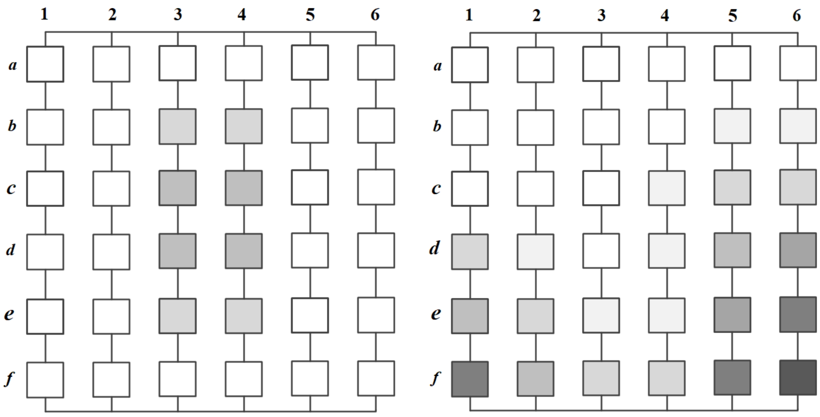
In equation (7), K_P is the proportional coefficient, K_I is the integral coefficient, K_D is the differential coefficient and $u(i)$ is the output value of the *ith* sampling.

PID control method has a simple principle, convenient construction, strong adaptability and superior stability performance. Through the PID-controlled BOOST circuit, the photovoltaic array can reach stable high output power.

2.4. Influence of shadow conditions on photovoltaic array output

In the actual working environment, the photovoltaic array is often affected by bad weather or the occlusion of trees and buildings, which will form partial shadow conditions with uneven irradiation. Therefore, a 6×6 photovoltaic array model consisting of 36 photovoltaic modules was built, and the temperature is set at 25℃. The irradiances of all PV modules were set to 1000W/㎡ in mode 0 (without shadow shielding). Shading conditions of mode 1 and mode 2 can be seen in Fig.3, Table.1

and Table.2 (the first row and column in the tables respectively represent the serial number of row and column of photovoltaic array, and the other data is irradiance which in the dimension of W/㎡).



(a)mode 1 (b)mode 2

Fig.3 Shadow occlusion of photovoltaic array

Table.1 PV module irradiance distribution in mode 1

	1	2	3	4	5	6
a	1000	1000	1000	1000	1000	1000
b	1000	1000	800	800	1000	1000
c	1000	1000	700	700	1000	1000
d	1000	1000	700	700	1000	1000
e	1000	1000	800	800	1000	1000
f	1000	1000	1000	1000	1000	1000

Table.2 PV module irradiance distribution in mode 2

	1	2	3	4	5	6
a	1000	1000	1000	1000	1000	1000
b	1000	1000	1000	1000	900	900
c	1000	1000	1000	950	800	850
d	850	900	1000	900	700	650
e	700	850	900	900	600	550
f	500	700	850	800	500	400

Compared with the PV module under constant irradiation, the characteristic curve of the PV module under the partial shadow is shown in Fig.4. Under constant irradiance, the *P-U* curve shows a single peak. But it will show multiple peaks under partial shadow conditions. If the traditional MPPT method is used under the condition of partial shadow, it is easy to fall into the partial optimal value. In this case, the maximum power point is difficult to reach. What's worse, it will affect the power generation efficiency and result in waste of resources. In some cases, this can cause photovoltaic modules to overheat and damage.

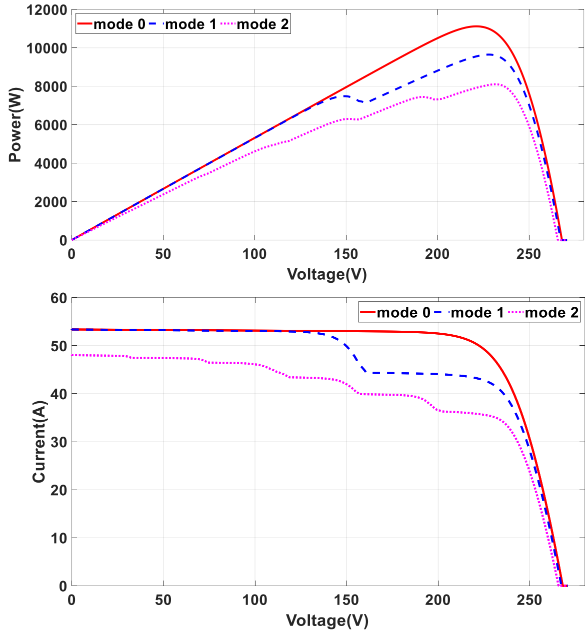


Fig.4. PV characteristic curves under three modes

3. Improvement strategy of PSO

3.1. PSO algorithm

PSO is an optimization algorithm based on swarm intelligence proposed by Kennedy and Eberhart [23]. Particle properties of the PSO algorithm are represented by velocity, position and fitness. The velocity represents the motion trend of the particle, the position represents the existence of the particle in the solution space, and the fitness value needs to be obtained through the appropriate fitness function. The evaluation of the particle can be obtained through the judgment of the fitness value. After an appropriate number of iterations, the purpose of optimization will be achieved.

The mathematical expression of the algorithm is as follows. Set a D-dimensional search space, input n particles to form a particle swarm, set the population $X=(X_1,X_2,\ldots,X_n)$, where the ith particle can be seen as a D-dimensional vector $\boldsymbol{X}_i=(x_{i1},x_{i2},\ldots,x_{iD})^T$, which is regarded as a potential solution of the optimal fitness and also represents the position occupied by the ith particle in the solution space. Taking the potential solution of each vector in $\boldsymbol{X}_i$ into the fitness function, the fitness value of each particle can be obtained. (8) and (9) are the formulas for updating particles' velocity and position.

$$V_{id}^{k+1}=\omega V_{id}^{k}+c_1r_1(P_{id}^{k}-X_{id}^{k})+c_2r_2(P_{id}^{k}-X_{id}^{k}) \tag{8}$$

$$X_{id}^{k+1}=X_{id}^{k}+V_{id}^{k+1} \tag{9}$$

In (8) and (9), ω represents inertia weight, $d=1,2,\ldots,D$, $i=1,2,\ldots,n$, V_{id} represents the velocity of the particles, k represents the current iteration number of the particles. c_1 and c_2 represent self-learning factors and global learning factors, which are usually non-negative constants. r_1 and r_2 are random numbers selected between 0 and 1.

3.2. Improvement strategy of particle swarm optimization algorithm

For the photovoltaic array with shadow occlusion, the traditional MPPT algorithms are prone to tracking failure and easy to fall into local optimal values. Besides, these traditional MPPT algorithms take a long time to converge, and the tracking efficiency of these methods is terrible. In this paper, the traditional particle swarm optimization algorithm is improved, the strategies include optimizing the initial position of the particles and using a particle elimination mechanism.

For the sake of optimizing the initial position of the particles, the initial positions of the particles were set at the integer multiple of V_{mp}. V_{mp} is a point where a single photovoltaic module can reach the maximum power. According to formula (2), the initial positions of particles can be set as 0.8619, 0.7239, 0.5858, 0.4477, 0.3097 and 0.1716 respectively.

As the algorithm is running, the fitness of some particles is terrible and they make little contribution to the maximum power tracking of the photovoltaic array. However, they carry a numerous of information that will greatly increase the time cost of the algorithm running. Therefore, eliminating these particles timely has little impact on the maximum power tracking effect, but this method can improve the efficiency of power tracks. After updating the velocity and position of each particle, some of the poorly behaved particles will be eliminated timely, and the remaining particles continue to iterate to realize the dynamic change of particle number and improve efficiency.

3.3. Algorithm process

(1) Set the fitness *loss* as infinite, the initial effective particle number n_0, and the initial position of the particle as p_0, set the number of particles eliminated after each iteration as n_1, the minimum number of retained particles as n_2, and the effective particle number after updating as n_3;

(2) Input the position of the effective particle into the photovoltaic system, measure the output power P_{out} of the photovoltaic system, and get the effective particle fitness;

(3) If the fitness of effective particles has been measured, proceed to the next step; otherwise, return to step (2);

(4) Update the velocities and positions of effective particles according to equations (8) and (9);

(5) Determine whether the number of effective particles n_3 is larger than the sum of n_1 and n_2; if the condition is true, proceed to the next step; otherwise, perform step (7) directly;

(6) Eliminate the poorly behaved particles to get new effective particles;

(7) Set the fitness to infinity;

(8) Determine whether irradiance changes; if it changes, return to step (1); otherwise, go to step (9);

(9) Judge whether the end condition is true; if it is true, terminate the iteration; otherwise, go to step 2.

The algorithm flow chart is shown in Fig.5, where the principle of determining whether irradiance changes are as follows: when the irradiance changes significantly, the output power of the photovoltaic system will also change. If the power at the previous time is *power(1)* and the power at the current time is *power(2)*, it is considered in this paper that the irradiance changes when formula (10) is satisfied; otherwise, the irradiance does not change.

$$\frac{\left|power(2)-power(1)\right|}{power(1)} > 8\% \tag{10}$$

4. The simulation and analysis

To verify the effect of the improved PSO on MPPT of photovoltaic array, this paper uses the photovoltaic system structure shown in Fig.1 to build a corresponding simulation model in Simulink. The main parameters of a single photovoltaic module are shown in Table.3.

The parameters of the main components of the BOOST circuit are output capacitor C_1, input capacitor C_2 and inductor L. See Table.4 for specific parameter settings

To verify the effectiveness of the algorithm, the GWO, PSO and the adaptive Particle Swarm Optimization (APSO)[24] were compared for simulation, and the sampling time was set as 0.018s. The experimental parameter settings were shown in Table.5, where *num* represents the number of particles or grey wolf, ω represents the inertia weight, c_1 and c_2 represent self-learning factors and global learning factors.

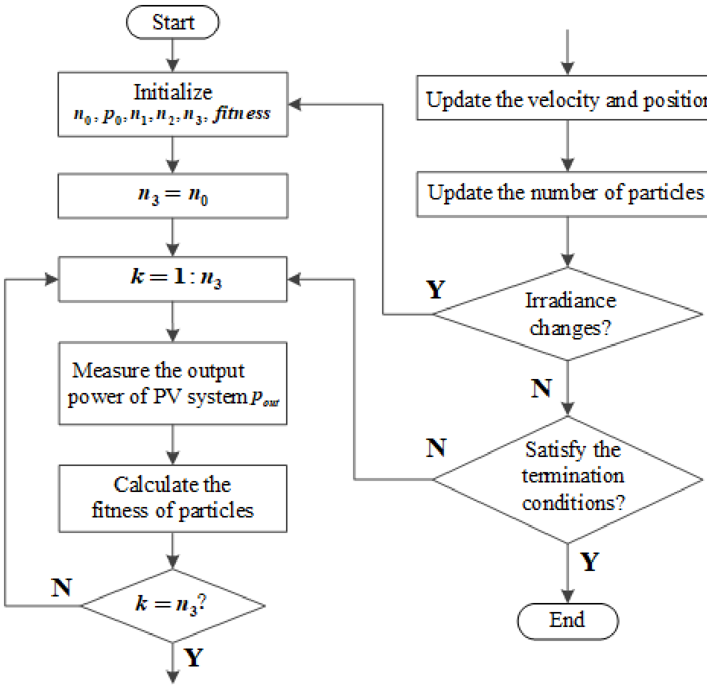


Fig.5 Flow chart of improved PSO

Table.3 Main parameters of a PV module

parameters	symbol	value
Maximum output power	P_m	310.43(W)
Open circuit voltage	V_{oc}	44.80(V)
Short circuit current	I_{sc}	8.87(A)
The voltage at the maximum power point	V_{mp}	37.00(V)
The current at the maximum power point	I_{mp}	8.39(A)

Table.4 Main component parameters of the BOOST circuit

parameters	C_1	C_2	L
value	900μF	800μF	2mH

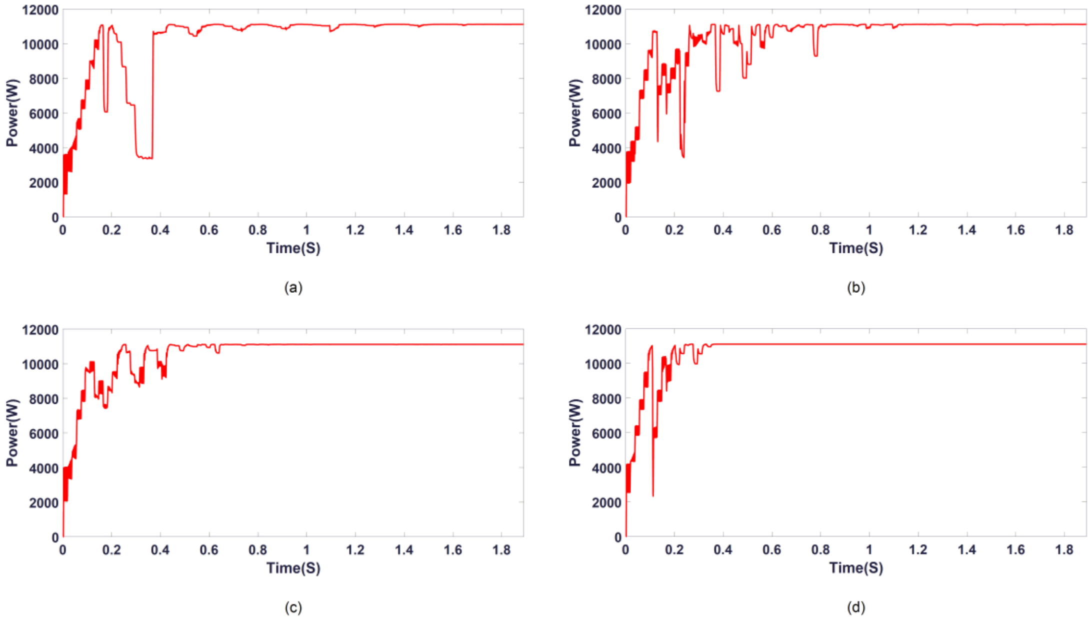
Table.5 Main parameters of the algorithms

parameters	GWO	PSO	APSO	Improved PSO
num	10	6	6	6
ω	-	0.4	0.15-0.25	0.4
c_1	-	0.8	0.8	0.8
c_2	-	1.2	1.2	1.2
x	1-0.1k	-	-	-

In GWO, the convergence factor x is set to start from 1 and gradually decrease with the increase of iteration times (see in Table.5), where k is the iteration times. Both the initial duty cycle of particles in PSO and APSO were set as 0.9, 0.8, 0.7, 0.5, 0.4 and 0.3. The initial duty cycle of the improved PSO algorithm proposed in this paper is set as 0.8619, 0.7239, 0.5858, 0.4477, 0.3097 and 0.1716. Eliminate one particle with the worst fitness in each iteration, and ensure that the minimum particle number is 1.

4.1 Shadowless mode

When there is no shading, the standard irradiance received by each component of the photovoltaic system is set to 1000W/㎡ and the temperature is 25℃. The *power-time* curve for tracking the output power using four different algorithms is shown in Fig.6.



(a) GWO, (b)PSO, (c) APSO, (d) The improved PSO proposed in this paper
Fig.6 Output power convergence in mode 0

4.2 Partial shadow occlusion mode

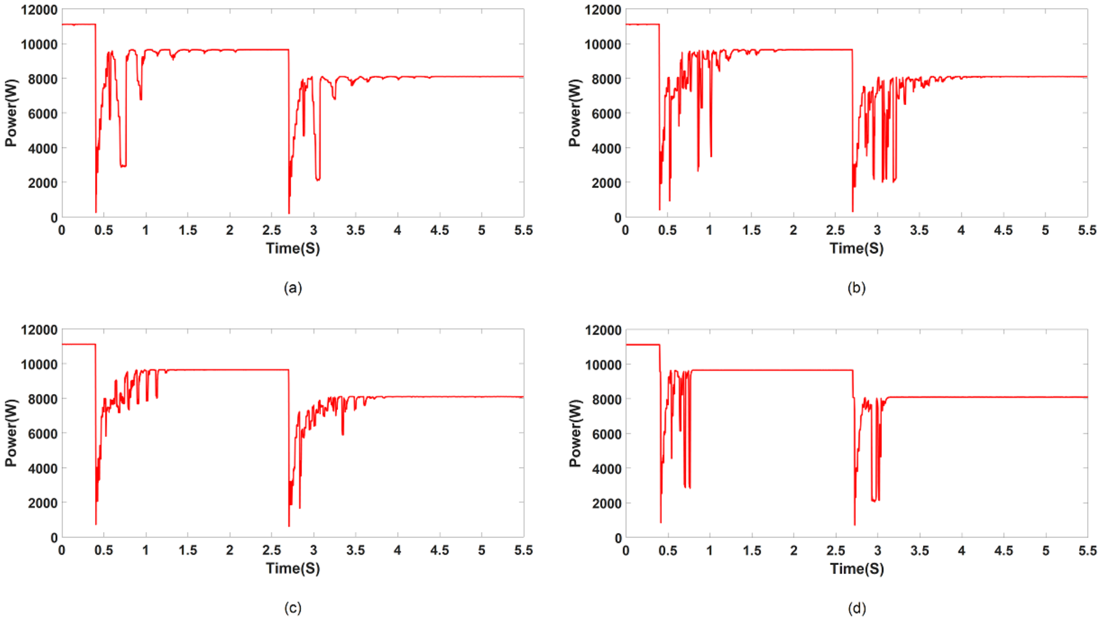
In the partial shadow occlusion, the irradiance received by each component of the photovoltaic system is shown in Fig.3, Table.1 and Table.2, and the temperature is 25℃.

Using GWO, PSO, APSO and the improved PSO proposed in this paper to track the maximum power point of the photovoltaic system. The output *power-time* variation curves of the four algorithms are shown in Fig.7. When t=0.4s, the photovoltaic array enters the partial shadow mode 1 occlusion condition, when t=2.7s, the photovoltaic array enters the partial shadow mode 2 occlusion condition.

4.3 Results analysis

As can be seen from the simulation results, the data statistics of maximum power tracking of the four algorithms for the photovoltaic system in three modes are shown in Table.6 and Table.7. The convergence times of the four algorithms are expressed by T_1, T_2, T_3 and T_4 respectively; the powers in the stable state are represented by P_1, P_2, P_3 and P_4 respectively. The actual maximum power in the corresponding mode is represented by P_m.

As can be seen in Table.6 and Table.7, in terms of the experimental results, the improved PSO proposed in this paper has achieved almost the same tracking effect as the other three algorithms while significantly shortening the tracking time. The improved PSO proposed in this paper achieves faster tracking of the maximum output power of the photovoltaic system by selecting appropriate initial positions and adding a particle elimination mechanism to the PSO to eliminate the particles with the lowest fitness in time.



(a) GWO, (b)PSO, (c) APSO, (d) The improved PSO proposed in this paper
Fig.7 Output power convergence in partial shadow occlusion mode

Table.6 convergent power in three modes

mode	P_1	P_2	P_3	P_4	P_m
mode 0	11092.7	11104.3	11105.5	11109.4	1118.3
mode 1	9639.1	9642.4	9632.8	9645.2	9647.8
mode 2	8091.1	8086.7	8091.5	8094.2	8101.9

Table.7 convergence time in three modes

mode	T_1	T_2	T_3	T_4
mode 0	1.482	1.121	0.655	0.359
mode 1	2.102	1.820	1.265	0.790
mode 2	4.407	4.049	3.861	3.152

5. Conclusion

In this paper, an improved PSO method is adopted to study the maximum power point tracking of the photovoltaic array. The main conclusions can be summarized as follows: (1) the initial positions of the particle swarm optimization algorithm were optimized; (2) the particle elimination mechanism is introduced in this paper; (3) the simulation shows that the improved PSO method shorten the convergence time obviously and ensures the accuracy of MPPT tracking. In terms of future work, the improved PSO algorithm will be applied in the actual photovoltaic system to improve the application significance of the algorithm in practical engineering.

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References

[1] Li J, Huang J. (2020) The expansion of China's solar energy: Challenges and policy options. Renewable and Sustainable Energy Reviews,132: 110002.
[2] National Energy Administration. (2022) Construction and operation of photovoltaic power generation in 2021.http://www.nea.gov.cn/2022-03/09/c_1310508114.htm.
[3] He, X., Ai, Q., Qiu, R.C.M., Huang, W.T., Piao, L.J., Liu, H.C. (2017) A big data architecture design for smart grids based on random matrix theory. IEEE Trans.
[4] Jung Y, So J, Yu G, et al. (2005) Improved perturbation and observation method (IP&O) of MPPT control for photovoltaic power systems[C]//Conference Record of the Thirty-first IEEE Photovoltaic Specialists Conference, 2005. IEEE, 2005: 1788-1791.
[5] Xuesong Z, Daichun S, Youjie M, et al. (2010) The simulation and design for MPPT of PV system based on incremental conductance method[C]//2010 WASE international conference on information engineering. IEEE,2: 314-317.
[6] Aganah K A, Leedy A W. (2011) A constant voltage maximum power point tracking method for solar powered systems[C]//2011 IEEE 43rd Southeastern Symposium on System Theory. IEEE, 2011: 125-130.
[7] Messalti S, Harrag A, Loukriz A. (2017) A new variable step size neural networks MPPT controller: Review, simulation and hardware implementation. Renewable and Sustainable Energy Reviews,68: 221-233.
[8] Yilmaz U, Turksoy O, Teke A. (2019) Improved MPPT method to increase accuracy and speed in photovoltaic systems under variable atmospheric conditions. International Journal of Electrical Power & Energy Systems,113: 634-651.
[9] Xie, L., Tao, D., & Wei, H. (2019). Early expression detection via online multi-instance learning with nonlinear extension. IEEE Transactions on Neural Networks and Learning Systems, 30(5), 1486-1496.
[10] Jiang L L, Nayanasiri D R, Maskell D L, et al. (2015) A hybrid maximum power point tracking for partially shaded photovoltaic systems in the tropics. Renewable energy,76: 53-65.
[11] Sun K, Yao W, Fang J, et al. (2019) Impedance modeling and stability analysis of grid-connected DFIG-based wind farm with a VSC-HVDC. IEEE Journal of Emerging and Selected Topics in Power Electronics,8(2): 1375-1390.
[12] Yang B, Yu T, Shu H, et al. (2018) Robust sliding-mode control of wind energy conversion systems for optimal power extraction via nonlinear perturbation observers. Applied Energy,210: 711-723.
[13] Xie, L., Luo, Y., Su, S. F., & Wei, H. (2021). Graph Regularized Structured Output SVM for Early Expression Detection With Online Extension. IEEE Transactions on Cybernetics, DOI: 10.1109/TCYB.2021.3108143.
[14] Ji Y H, Jung D Y, Kim J G, et al. (2010) A real maximum power point tracking method for mismatching compensation in PV array under partially shaded conditions. IEEE Transactions on power electronics, 2010, 26(4): 1001-1009.
[15] Xie, L., Guo, W., Wei, H., Tang, Y., & Tao, D. (2022). Efficient unsupervised dimension reduction for streaming multiview data. IEEE Transactions on Cybernetics, 52(3), 1772-1784.
[16] Cherukuri S K, Rayapudi S R. (2017) Enhanced grey wolf optimizer based MPPT algorithm of PV system under partial shaded condition. International Journal of Renewable Energy Development,6(3): 203.
[17] Guan T, Zhuo F. (2017) An improved SA-PSO global maximum power point tracking method of photovoltaic system under partial shading conditions//2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe). IEEE, 2017: 1-5.
[18] Li G, Jin Y, Akram M W, et al. (2018) Application of bio-inspired algorithms in maximum power point tracking for PV systems under partial shading conditions–A review. Renewable and Sustainable Energy Reviews, 81: 840-873.

[19] Li H, Yang D, Su W, et al. (2018) An overall distribution particle swarm optimization MPPT algorithm for photovoltaic system under partial shading. IEEE Transactions on Industrial Electronics, 66(1): 265-275.
[20] Dounis A I, Kofinas P, Alafodimos C, et al. (2013) Adaptive fuzzy gain scheduling PID controller for maximum power point tracking of photovoltaic system. Renewable energy, 60: 202-214.
[21] Chattopadhyay S, Dubey R, Bhaduri S, et al. (2018) Correlating infrared thermography with electrical degradation of PV modules inspected in all-India survey of photovoltaic module reliability 2016. IEEE Journal of Photovoltaics, 2018, 8(6): 1800-1808.
[22] Mahdizadeh S, Sharivar R S, Gholizadeh H, et al. (2021) A Transformer less Quadratic Boost DC-DC Converter with Continuous Input Current and a Few Number of Components, Based on Classical Boost and Cuk Converter Suitable for Renewable Applications[C]//2021 29th Iranian Conference on Electrical Engineering (ICEE). IEEE, 2021: 252-257.
[23] Ishaque K, Salam Z. (2012) A deterministic particle swarm optimization maximum power point tracker for photovoltaic system under partial shading condition. IEEE transactions on industrial electronics, 60(8): 3195-3206.
[24] Zhan Z H, Zhang J, Li Y, et al. (2009) Adaptive particle swarm optimization. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics),39(6): 1362-1381.