Research on MPPT of photovoltaic system based on PSO with time-varying compression factor

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1. Introduction

The development of the world today is inseparable from energy, which provides the source of power for all work, but traditional fossil energy will eventually be exhausted, and fossil energy causes considerable pollution to the environment. Therefore, in order to realize the sustainable development of energy while protecting the environment on which we depend, we must vigorously develop clean energy. As a new energy source, solar energy is inexhaustible, which is of great significance for alleviating energy problems.

Nowadays, countries all over the world are vigorously researching photovoltaic power generation systems. In the research of photovoltaic systems, a core technology is the maximum power tracking technology of photovoltaic cells [1-7]. Mastering the maximum power tracking technology of photovoltaic cells under various conditions is of great help to the efficient operation of photovoltaic systems.

At present, the most commonly used maximum power tracking algorithms in the field are mainly the disturbance observation method, the conductance increment method and their improved algorithms, but these methods are no longer applicable in the case of partial shadows. The particle swarm optimization algorithm is one of the effective algorithms for solving the multi-peak problem. It has a certain effect on tracking the maximum power of the "multi-peak" photovoltaic array. However, the test results show that the standard particle swarm optimization algorithm is for some more complex data, there is a greater probability of falling into a local optimum or a slow convergence rate [8-10], which greatly affects the power generation efficiency of the photovoltaic system.

The improved particle swarm optimization algorithm proposed in this paper adds a time-varying compression factor to the velocity update formula, which is conducive to the proper conversion of the particle swarm between global search and local search. In the process of tracking the maximum power, the method proposed in this paper has a large compression factor in the initial stage, which is conducive to the global search ability of the particle swarm[11-15]. As the number of iterations increases, the compression factor will gradually decrease, which in turn enables the particle swarm to have better local search capabilities. Based on this time-varying compression factor, the particle swarm can cope well during the entire search stage, and ultimately can track the maximum power point faster and more accurately, which is of great significance to the research of photovoltaic systems.

Abstract When the photovoltaic system is put into use, some natural objects will cause partial shadows on the photovoltaic modules. And in this case, the output characteristics of the photovoltaic array will change from the original "single peak" to "multi-peak", and the power of the photovoltaic array will have multiple extreme values, which will increase the difficulty of tracking the maximum power of the photovoltaic array. The traditional maximum power point tracking (MPPT) algorithm is no longer applicable. Most of them fall into the local maximum power and cannot find the global maximum power. Although the particle swarm optimization algorithm (PSO) has a certain ability to solve the global optimization problem, the standard particle swarm optimization algorithm can’t be regarded as a complete global optimization algorithm. Since the power output curve of the photovoltaic array is severely non-linear in the shaded situation, the standard particle swarm optimization algorithm may also fall into a local optimum and fail to find the global optimum. Compared with the standard particle swarm optimization algorithm, the particle swarm optimization algorithm with time-varying compression factor proposed in this paper can better balance the relationship between global search and local search, and can effectively avoid falling into the local optimal value and not finding it. To the correct maximum power point, while also increasing the speed of convergence. Comparing the method proposed in this paper with the standard particle swarm algorithm through experiments, the results show that the method proposed in this paper is of great significance for improving the efficiency of photovoltaic systems under partial shadow conditions.

Keywords: Partial shade, photovoltaic system, PSO, time-varying compression factor, MPPT

Classification: Power devices and circuits

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2. Photovoltaic cell modeling and simulation under shadow conditions

2.1 Photovoltaic cell equivalent circuit model

A photovoltaic cell is a semiconductor electronic device that converts solar energy into electrical energy. In actual research, a photovoltaic cell can be equivalent to a constant current power supply, a series resistor, a parallel resistor, and a diode. Among them, the series resistance $R_s$ represents the loss resistance, and its resistance is generally small. The parallel resistance $R_{sh}$ is used as a bypass resistance, and its resistance is generally large. The actual photovoltaic cell generally has a leakage current due to production reasons, which is represented by $I_{sh}$, and $I_{ph}$ is the photogenerated current is proportional to the light intensity, $I$ is the output current, and $I_d$ is the diode saturation current [16]. The equivalent circuit of a photovoltaic cell is shown in Figure 1.

According to Kirchhoff’s current law:

$$I = I_{ph} - I_d - I_{sh}$$  \hspace{1cm} (1)

![Fig. 1 Equivalent model of photovoltaic.](image)

The expression of $I_d$ and $I_{sh}$ in formula (1) is (2)

$$I_d = I_0 \exp \left[ \frac{q(U + IR_S)}{AKT} \right] - 1 \quad I_{sh} = \frac{U + IR_S}{R_{sh}} \hspace{1cm} (2)$$

In the formula, $I_0$ is the saturated reverse current, $k$ is Boltzmann’s constant, and the value is $1.38 \times 10^{-23}$ J/K; $A$ is the ideal factor of the diode, and the value is usually between 1 and 2. This experiment takes the value is 1.3, and $q$ is the charge of the electron, which is $1.6 \times 10^{-19}$ C. Since $R_s$ in the equivalent circuit of the photovoltaic cell is much smaller than the forward conduction resistance of the diode, it can be approximately regarded as $I_{ph}=I_{sc}$, so the current expression of the photovoltaic cell can be simplified as:

$$I = I_{sc} - D_1I_{sc}\exp \left[ \frac{U}{U_{oc}D_2} \right] - 1$$  \hspace{1cm} (3)

In the formula, $D_1$ and $D_2$ respectively represent two intermediate constants, which are related to the short-circuit current $I_{sc}$, the open circuit voltage $U_{oc}$, the maximum power point current $I_m$ and the maximum power point voltage $U_m$ of the photovoltaic cell [17-20].

2.2 Photovoltaic cell simulink model

According to the mathematical model of the photovoltaic cell obtained in the previous section and the corresponding mathematical expression, the model is established in Matlab/Simulink, as shown in Figure 2. It can be seen from the model given in Figure 2 that there are four parameters $I_{sc}$, $U_{oc}$, $I_m$, $U_m$ in the model [21] that need to be entered manually, because the specifications of each photovoltaic cell are different when they leave the factory, resulting in different types of photovoltaic cells for these four parameters. Therefore, if you need to conduct a simulation study on a certain type of photovoltaic cell, you only need to know these four parameters to perform a simulation experiment on it.

![Fig. 2 Internal structure of photovoltaic cell model.](image)
2.3 Simulation of output characteristics of photovoltaic array under partial shadow conditions

Photovoltaic arrays will have partial shadows due to uneven illumination. In severe cases, there will be a "hot spot effect". In order to avoid this type of situation, a bypass diode is usually connected in parallel at both ends of the photovoltaic cell. Therefore, the simulink model of the photovoltaic array in the shaded situation is shown in Figure 3. For the photovoltaic array model in the partial shadow situation shown in Figure 3, under the premise of a certain temperature, change the shadow situation of the photovoltaic array according to Table 1 [22-25], and then simulate it according to the model shown in Figure 4, and get the output characteristic curves of photovoltaic cells under three different shades are shown in Figure 5. It can be seen from Figure 5 that the power output characteristic curve of the photovoltaic array will have multiple extreme values in the case of partial shadowing, and the extreme value of the photovoltaic array power will also be different under different shadow conditions, which will lead to the difficulty of tracking the maximum power point. Increasingly, the content studied in this article is specifically aimed at this situation, and has a certain effect on solving such problems.

3. Maximum power tracking of photovoltaic array

3.1 Standard particle swarm optimization

The particle swarm optimization algorithm is a random search algorithm based on group cooperation developed...
by simulating the foraging behavior of birds. It is generally considered to be a type of swarm intelligence (SI). It can be incorporated into the Multiagent Optimization System (MAOS). The particle swarm optimization algorithm was invented by Dr. Eberhart and Dr. Standard PSO power tracking results random particles (random solution), and then the optimal solution is found through iteration. In each iteration, the particles update themselves by tracking two "extremums". The first one is the optimal solution found by the particle itself. This solution is called the individual extreme value \( p_{Best} \), the other extreme value is the optimal solution found by the entire population. This extreme value is the global extreme value \( g_{Best} \), the particle swarm algorithm contains two important update formulas [26):

\[
V_{id}^{t+1} = wV_{id}^t + c_1r_1(p_{id}^t - X_{id}^t) + c_2r_2(g_{id}^t - X_{id}^t) \tag{4}
\]

\[
X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1} \tag{5}
\]

In the above formula, \( w \) is the weight of inertia, \( d \) is the \( d \) dimensional component, \( d = 1,2,...,D; \) \( i = 1,2,...,n; \) \( c_1, c_2 \) are learning factors, \( r_1, r_2 \) are \( 0~1 \) random number, \( t \) is the current iteration number, \( i \) represents the ordinal number of the particle. The standard particle swarm algorithm is used to track the maximum power of the photovoltaic array under the third shadow condition in Table 1, and the simulation results are shown in Figure 6. It can be seen from Figure 6 that when the standard particle swarm algorithm is faced with complex data, it may still fall into the local maximum, and cannot jump out of the local maximum, resulting in incorrect final results. If similar situations occur multiple times, the power generation efficiency of the photovoltaic system will be greatly reduced.

### 3.2 PSO with time-varying compression factor

The particle swarm optimization algorithm with time-varying compression factor proposed in this paper adds a time-varying compression factor \( m \) based on the standard particle swarm optimization algorithm. The value of \( m \) will change with the number of iterations. Since the two learning factors should not be too large, the function of the shrinking factor is to limit their size, and the shrinking factor should be dynamically matched according to the different learning factors. Therefore, the larger the value of \( C \), the smaller the value of the shrinkage factor. In the experiment, it is found that the value of \( C \) is more conducive to solving when the value is greater than 4. And the value of shrink factor must be less than 1. According to these rules, the expression of the contraction factor is deduced. At the beginning of the search, there is a larger compression factor, so that the particle swarm has a better global search ability. As the number of iterations increases, the value of \( m \) will become smaller and smaller, and the smaller the value of \( m \) conducive to local search. This can prevent the particle swarm from falling into the local optimum due to the imbalance of the search ability. At the same time, it can also prevent the search time from being too long due to too many iterations [27-29]. The update
The formula of the improved particle swarm optimization algorithm is:

\[ V_{id}^{t+1} = m(wV_{id}^t + c_1r_1(p_{id}^t - X_{id}^t) + c_2r_2(p_{gd}^t - X_{gd}^t)) \]  
\[ X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1} \]  
\[ m = \left(1 - \frac{t}{N}\right)^2 \left(1 - \sqrt{\frac{3}{\pi}} \right) \]  
\[ C = c_1 + c_2 \]

In the above formula, \(m\) is the time-varying compression factor, \(N\) is the total number of iterations, \(w\) is the weight of inertia, the value is 0.729, \(d\) is the \(d\) dimensional component, \(d = 1, 2, \ldots, D; i = 1, 2, \ldots, n; c_1, c_2\) are learning factors, both of which are 2.05, \(r_1, r_2\) are 0–1 random number, \(t\) is the current iteration number, \(i\) represents the ordinal number of the particle[30]. The flow chart of the particle swarm optimization algorithm with time-varying compression factor is shown in Figure 7.

Compared with the standard particle swarm optimization, the method proposed in this paper can effectively avoid falling into local optimum and increase the convergence speed. The particle swarm optimization algorithm with time-varying compression factor is used to track the maximum power of the photovoltaic array under the third shadow condition in Table 1. The simulation model is shown in Figure 8, and the simulation results are shown in Figure 9. It can be seen from the results that under the condition of partial shadows, the particle swarm optimization algorithm with time-varying compression factor can correctly track the maximum power point of the photovoltaic array, thereby avoiding the local maximum power, and the convergence speed is relatively fast.

### 4. Conclusion

Comparing the two particle swarm optimizations, the results in Table 2 can be obtained. The particle swarm optimization algorithm with time-varying compression factor proposed in this paper can accurately and quickly track the global maximum power of the photovoltaic array in the case of partial shadows, and the algorithm is in practical application. It also has strong adaptability and is less affected by the external environment. Compared with the traditional maximum power tracking algorithm, the improved particle swarm optimization algorithm performs well, and has certain research value for the development of photovoltaic systems.

|                  | Response time | Tracking results | Accuracy |
|------------------|---------------|------------------|----------|
| Standard PSO     | 0.2779 s      | local optimum    | error    |
| Improved PSO     | 0.5203 s      | global optimum   | correct  |

Fig. 8 Photovoltaic system simulation model of PSO with time-varying compression factor.

Fig. 9 PSO with time-varying compression factor power tracking results.
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