Maximum Power Tracking Algorithm for Photovoltaic System in Partial Shadow Based on Particle Swarm Optimization

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Abstract

Photovoltaic system is often encountered in partial shade in practical use, which makes the output power characteristic curve present many peaks. The traditional maximum power tracking algorithm falls into local optimum and can't effectively track the global maximum power point. According to global optimization characteristics of particle swarm optimization algorithm, we propose an improved particle swarm optimization algorithm based on adaptive inertia weight. We use the simulation software to study the optimization characteristics of the algorithm under the condition of partial shadow. Simulation results show that the proposed algorithm can effectively track the global maximum power point under the condition of partial shadow. At the same time, it has the advantage of fast tracking speed and high steady state accuracy.

Keywords

MPPT, local shadow, PV array, improved PSO algorithm

1. Introduction

The output characteristic of a single photovoltaic cell shows a strong nonlinearity which is more obvious when they are formed into arrays. In practical use, we control the output power of the photovoltaic array by adding a maximum-power-point-tracing controller between the array and the load. Owe to the constant changes of the weather, the constant movement of the clouds and the excrements of birds and so on, the array will be in a state of being overshadowed partly. Thus, the curve of the output appears the state with multiple peaks which possesses several local crest values and an overall crest value. The traditional MPPT is easily caught in the situation of local optimum when tracing the maximum power point without tracing the real one.

In allusion to the problem, the scholars at home and abroad put forward their solutions. The literature [1] shows the Chaotic Search method using the randomness and the ergodic property of chaotic searching to conquer the local optimum and improve the searching pace by combining the space dimension. The literature [2] raises a MPPT arithmetic based on fuzzy control and artificial immunity theory. This method has a good dynamic characteristic but a low accuracy. The literature [3] displays the differential evolution method to search the maximum power point in the overall situation but it only comes up with the method of thinking direction without emulation verification. The literature [4] uses the Fibonacci array to trace but it can't ideally search the whole peak when the photovoltaic array is partly overshadowed and it also has a high requirement of hardware.

This text excludes the disturbance of other parameters and adjust the inertia weight to control the arithmetic after analyzing the traditional particle swarm optimization. The improved arithmetic can separate the particle from the local peak point rapidly without being caught which increases the rate of converge. In conclusion, this text compares the conventional perturbation and observation method with the improved particle swarm optimization .After the emulation analysis ,we find that the improved particle swarm optimization can trace the maximum power point more rapidly and accurately in the situation of being partly overshadowed than the other one.

2. The model of pv array

2.1 Mathematical model of photovoltaic cell

Classic photovoltaic cell works as the Fig.(1) shows:

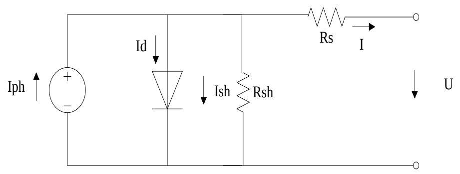


Fig. (1). PV equivalent model

The current source (I_{ph}) is on behalf of the photocurrent. Diodes simulates the P-N junction. R_{sh} is equivalent parallel resistance and R_s is series resistance. The output voltage is U. The output current is I. According to the equivalent circuit of the photovoltaic cell, we can represent the relationship between PV output voltage and current theoretical models based on (1)[5]:

$$I = I_{ph} - I_O\{[\exp(\frac{q(U+IR_S)}{nKT})]-1\} - \frac{U+IR_S}{R_{sh}} \tag{1}$$

When adequate lights, photocurrent is far greater than"$(U + IRs)/nKT$" . So we can ignore it in (2):

$$I = I_{ph} - I_O\{[\exp(\frac{q(U+IR_S)}{nKT})]-1\} \tag{2}$$

Where I_{ph} is photocurrent (A); I_o is reverse saturation current (A); q is electron charge (1.6×10^{19}C); U is Circuit voltage (V); K is Boltzmann's constant (1.38×10^{-23}J/K); T is absolute temperature(K); n is diode factor; R_s is series resistance(Ω); R_{sh} is parallel resistance(Ω).

2.2 The model of PV array under partial shade

Actually, the PV array is usually caused by a plurality of series-parallel battery pack assembled, due to changes in position of the sun, birds' droppings, moving clouds and other reasons, the PV array will sometimes be in partial shade. Partial shade will result in reduced power output of photovoltaic systems, which can cause severe burn hot spot that may affect the entire array.

When shading occurs, in order to prevent hot spot effecting the photovoltaic cells, the general approach is at both ends of the PV modules in parallel with a bypass diode to prevent the energy generated by the PV modules from gathering on the battery shaded. [6]When the photovoltaic cells is blocked, the bypass diode will make I-U and P-U output characteristics change. Fig. (2) simplifies the study of an equivalent circuit diagram, Fig.(3) shows the bypass diode in parallel tandem photovoltaic cell assembly branch.

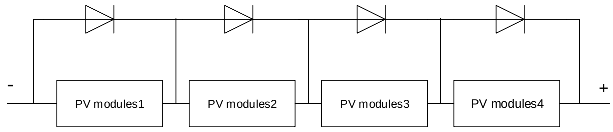


Fig. (2).Parallel bypass diode series arrangement of PV modules

If the photovoltaic cell 2 is blocked shadows, that at this time to accept a light intensity which is greater than the battery cell 2, the short-circuit current I_{ph1} of battery 1 is greater than the short-circuit current I_{ph2} of battery 2. When the external load is small, the circuit output high current I. When I> I_{ph2}, the bypass diode D4 of photovoltaic cell 2 is formed at both ends of the forward voltage, so that it is turned on. In this case only battery 1 provide electricity as a photovoltaic cells, not considering the voltage across the bypass diode , then the I-U of the equation of state PV module can be expressed as

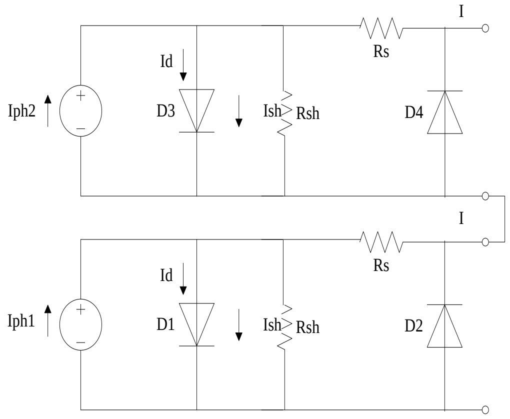


Fig. (3)PV series equivalent circuit diagram

$$I = I_{ph} - I_O \{[\exp(\frac{q(U+IR_S)}{nKT})] - 1\} \quad (3)$$

Equation (3) can be converted into

$$U = \ln(\frac{I_{ph1} - I}{I_o} + 1) \times \frac{nKT}{q} - IR_s, \quad I_{ph2} < I \le I_{ph1} \quad (4)$$

When the change of the load circuit output current I becomes smaller and smaller until I <= I_{ph2}, the bypass diode D4 are formed reverse voltage at both ends of the photovoltaic cell 2 that result in D4 off and the battery cell 1 and 2 together as a power source of foreign output power of PV modules in series IU equation becomes

$$U = U_1 + U_2 = \ln(\frac{I_{ph1} - I}{I_o} + 1) \times \frac{nKT}{q} + \ln(\frac{I_{ph2} - I}{I_o} + 1) \times \frac{nKT}{q} - 2IR_s \qquad 0 \le I \le I_{ph2} \quad (5)$$

3. Maximum power point tracking based on pso algorithm

In the D-dimensional search space, a random group named X=X_n, n is the number of particles, where in the i particle positions and velocities are represented by X_i= (X_{i1}, X_{i2} ….. X_{iD})^T and V_i=(V_{i1},V_{i2} ….. V_{iD})^T , the best personal number and global optimum is P_i=(P_{i1},P_{i2} ….. P_{iD})^T, P_g=(P_{g1},P_{g2} …..P_{gD})^T. The speed of particle and the formula of location update are (3-1) and (3-2) when iteration. To avoid searching the particle blindly and keeping away from searching space, we usually set X_{min}<X<X_{max}, V_{min}<V<V_{max}. The meaning of each parameter represent in the formula are as follows, w represents inertia weight, d represents searching space dimension, i represents particle number, c represents learning factor, r represents the independent number in (0,1), k represents iterations.

$$V_{id}^{k+1} = wV_{id}^{k} + c_1 r_1 (P_{id}^{k} - X_{id}^{k}) + c_2 r_2 (P_{gd}^{k} - X_{id}^{k}) \quad (6)$$

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \quad (7)$$

For the problems of maximum optimization in function, if the number of fitness function f(X_i) becomes larger, we will get the better number of fitness, so the definition of P_i and P_g are as follows:

$$P_i = \begin{cases} P_i & f(X_i) \le f(P_i) \\ X_i & f(X_i) > f(P_i) \end{cases} \quad (8)$$

$$P_g \in \{P_1, P_2, ..., P_n\} 且 f(P_g) = \max[\, f(P_i)] \ (1 \le i \le n) \quad (9)$$

By analyzing the meanings of particle swarm algorithm parameters, combining it with the rules of particle swarm algorithm of parameter settings, we find that inertia weight w is the most important study parameters in particle swarm optimization. In the initial stage of the algorithm, the bigger w can prevent the algorithm from tapping into the local optimum. In the later stage of the algorithm, the smaller one can improve convergence speed and make the constriction more steady. Experiments show that, when w is from0.8 to 1.2, the convergence speed of the particle swarm algorithm will speed up and the accuracy will be improved[7].

This passage uses the particle swarm optimization algorithm for optimization, the optimization of linear adjustment of inertia weight as shown in form (10), in this form, w means inertia weight, w_max means the biggest inertia weight, w_min means the minimum inertia weight, k means the current number of iterations, M means the largest number of iterations.

$$w = w\_max - (w\_max - w\_min) \times k/M \tag{10}$$

During the process of optimization, set the objective function as the total output power of photovoltaic array; record and save the maximum power point of the system that is calculated. The position of the particles represents the voltage value the array outputs.

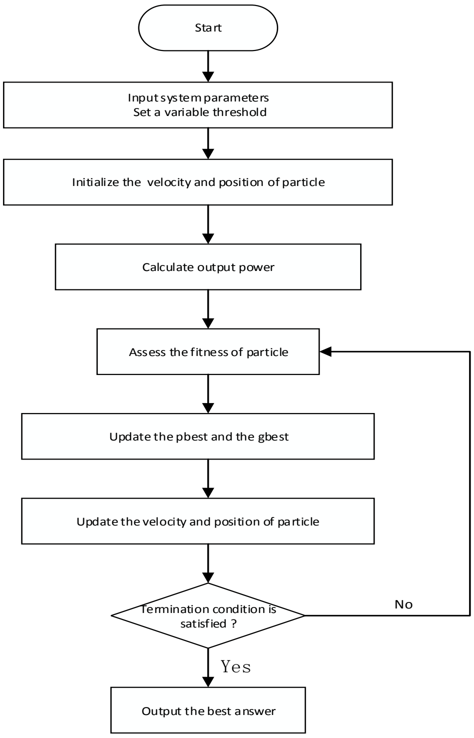


Fig. (3)Maximum power tracking of the particle swarm algorithm flow chart

The specific process of optimization is as follows:

(1)Set the initialization parameter. Set the number of the swarm particles as n=20, the maximum number of iteration as M=50, the number of dimension of search space as D=2, w linear decreases from 0.9 to 0.4, c1 =2, c2 =2[8];

(2)Calculate the adaptive figure of each particle;

(3)Compare and define both the individual and global extremum. Compare these two numbers with the adaptive figure on the optimal position. If the current adaptive figure is larger, set it as the new pbest. Then compare the adaptive figure of each particle with the optimal adaptive figure of the whole swarm and set the max figure as the gbest.

(4)Update the position and the speed of the particles according to the formula (6) and (7).Limit the max speed of the particles at the same time.

(5)Stop searching when the numbers of iteration reach the maximum M. Test the termination condition. If the condition is reached, stop the iteration and then the optimum solution Um of this algorithm will be obtained. If not, recalculate the adaptive figure.

The algorithm of the maximum power point of the adaptive particle swarm is charted as follows.

4. The simulation and validation

In the MATLAB/Simulink platform, combining with the Simulink existing photovoltaic cells and M function ,we build the simulation model. This article select models for Solarex MSX60 60 w photovoltaic cells, the basic parameters as shown in Tab.(1):

Tab.(1) Parameters of Solarex MSX60 60 w

Pm	59.9W
Im	3.5A
Um	17.1V
Ics	3.74A
Uoc	21.0V
Gnom	1000W/m^2
T1	25℃

4.1 Two pieces of arrays of photovoltaic cells in series

The simulation diagram of two series of photovoltaic battery array shows in Fig. (4) [9]:

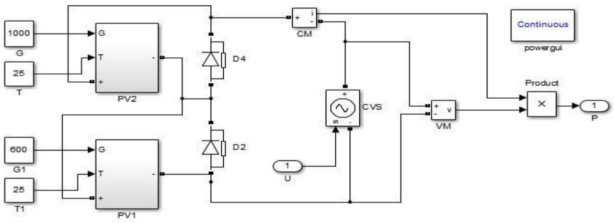


Fig. (4) The simulation diagram of two series of photovoltaic battery

Parameter setting: The illumination intensity of Pv1 in the figure is set as G1=1000W/m^2 and temperature as T1=25℃ which of Pv2 is set as G2=600W/m^2 and T2=25℃.The simulation time is set to 70 s. The curve of P-U is shown in the following Fig. (5), the simulation results are shown in Fig. (6):

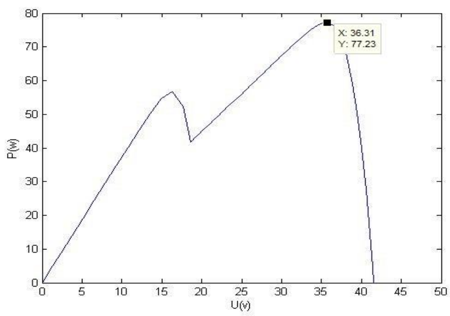
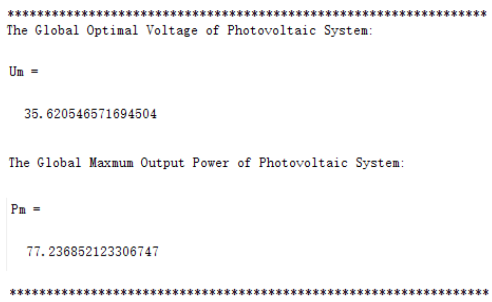


Fig. (5) P-U curve



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****************************************************************
The Global Optimal Voltage of Photovoltaic System:

Um =

   35.620546571694504

The Global Maxmum Output Power of Photovoltaic System:

Pm =

   77.236852123306747

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Fig. (6) The simulation results

According to the simulation results, the particle swarm algorithm optimization to track the maximum output power is 77.2368 w, theoretical maximum output power is 77.23 w. It shows that the improved particle swarm optimization algorithm can effectively find the global maximum power point under the condition of partial shadow.

When the PV array is at a certain temperature, the maximum power point voltage on the curve of the PV array output is almost distributed near a fixed voltage value. Therefore, the constant voltage method is to stabilize the output voltage of the PV array in the fixed voltage value. In this case the PV array will approximately work on the maximum power point.

4.2 Comparative verification

The total simulation image of the control system is shown in Figure 7.The tracing process can be divided into two steps. The first step is to search out the optional voltage U_m corresponding to the maximum power point with the particle swarm arithmetic. The second step is to make the output voltage of the photovoltaic system with the optional voltage through the Boost circuit. The illumination intensity of PV1 in the figure is set as G1=1000W/m^2 and temperature as T1=25℃ which of pv2 is set as G2=600W/m^2 and T2=25℃.

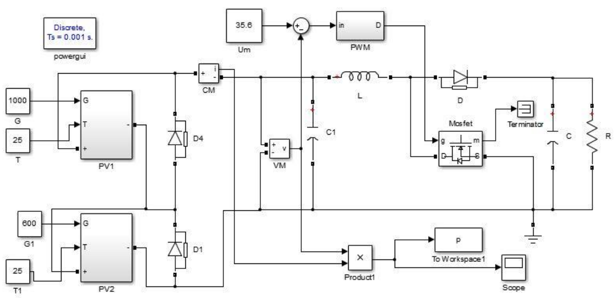

Fig. (7) MPPT simulation model based on pso

To show the superiority of the particle swarm arithmetic when tracing the maximum power point in the condition of being partly overshadowed, we compare and analyze its simulation result with that of perturbation and observation method [10]. The results are shown in Fig. (8) and Fig. (9).

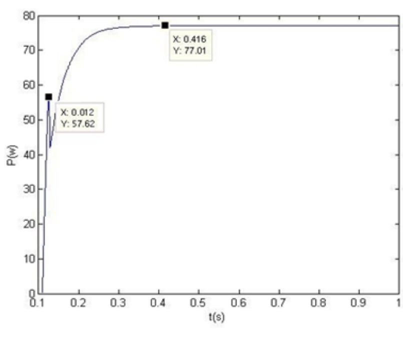

Fig. (8) Particle swarm optimization (pso)

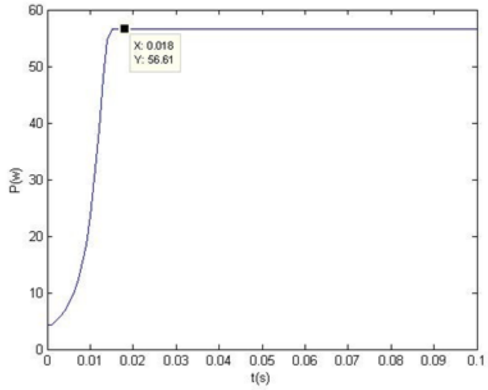

Fig. (9)Perturbation and observation method

The results of simulation data is shown in table2

Tab.(2) The results of simulation

	Local maximum power (w)	T1(s)	Global maximum power（w）	T2(s)	Theoretical value（w）	Percentage error（%）
PSO	57.62	0.012	77.01	0.416	77.23	0.284
P & O	56.61	0.018	56.61	0.018	77.23	26.7

According to the Tab.(2), output power of the maximum power point of the particle swarm based on inertia weight is 77.01w which matches the whole maximum power found by the PSO. The output power traced by the perturbation and observation method is 56.61w .This method is easily caught in the local extremum value and unable to output the whole power .The improved particle swarm arithmetic have better accuracy than the conventional perturbation and observation method while the former one has a longer searching time than the latter. which is only 0.398s.In practical use the weakness can be ignored in consideration of the maximization of output power. Considering the time when tracing the local maximum power point, the particle swarm arithmetic is superior to the perturbation and observation method.

5. Conclusions

By studying the characteristics of particle swarm optimization, using its global optimization properties in the maximum power point tracking in photovoltaic system, this article proposes the improved particle swarm algorithm based on inertia weight to track the maximum power point in the PV array under shade. Simulation results show that the algorithm can make the photovoltaic array in partial shade effective to find the global maximum power point, and output the maximum power combined through Boost circuit. At the same time, compared with the traditional perturbation and observation method, the algorithm under unshaded conditions can also track the maximum power point. In conclusion , improved particle swarm algorithm is better than the traditional one.

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