APPLICATION OF IMPROVED PARTICLE SWARM OPTIMIZATION ALGORITHM IN MAXIMUM POWER POINT TRACKING FOR PV SYSTEM

Huaizhong CHEN[1*]

Photovoltaic array is always affected by partial shading phenomenon in photovoltaic power generation system, thereby leading to unstable operation of the system and reduction of output power. Conventional Maximum Power Point Tracking (MPPT) algorithm cannot trace maximum power points due to single-peaked optimization when P-U characteristic curve of photovoltaic array shows multi-peak value. Particle Swarm Optimization (PSO) algorithm has good multi-peak global optimization capacity. However, PSO algorithm has the defects of insufficient convergence rate and low searching precision. Therefore, Improved Particle Swarm Optimization (IPSO) algorithm is proposed in the paper, nonlinear dynamic inertia weight coefficient is introduced in the operational process. Meanwhile, learning factors are improved, global searching ability and localized amendment ability of the global algorithm can be improved effectively. Matlab simulation is utilized for verifying the feasibility of IPSO algorithm. The results showed that premature convergence problem can be avoided by IPSO algorithm, and the convergence rate and searching precision of the algorithm can be improved effectively.

Keywords: Photovoltaic (PV); MPPT; Particle Swarm Optimization; Improved Algorithm

1. Introduction

The power generation efficiency can be reduced greatly by the formed shadow since the surface of the photovoltaic array is covered by dust, surrounding building, clouds, etc. in the process of using the photovoltaic system actually. Maximum power points of the photovoltaic system must be traced and controlled in order to improve the power generation efficiency. P-U curve of photovoltaic array may produce many power maximum values under the condition of partial shading, thereby conventional MPPT algorithm can suffer from partial maximum value easily rather than global maximum value. Genetic algorithm, PSO optimization algorithm, etc. can be used in MPPT method under current shadow condition. The system cannot be operated on the maximum power point stably though genetic algorithm can be used for tracing maximum power point. In addition, the algorithm is more complex, and more parameters should be adjusted.

[1] Zhejiang Industry Polytechnic College, Shaoxing, China; e-mail: Chz702@163.com

However, PSO algorithm is simpler, and less parameter also should be adjusted. Parameters can be set according to empirical value especially in order to obtain better convergence after the weight is introduced. In addition, PSO optimization algorithm has better global searching ability. However, traditional PSO optimization algorithm has the defect that it can fall into local optimal solution easily, convergence rate is insufficient, and searching precision is reduced gradually. In the paper, an improved PSO algorithm is proposed aiming at the problem. Dynamic inertia weight coefficient and improved learning factors are introduced in the operational process, the improved algorithm can improve the global searching ability and localized amendment ability of global algorithm effectively, thereby improving the tracing speed and precision of the system [1,2].

2. Mathematical model of photovoltaic array

Photovoltaic cell has the principle that solar radiation is received and converted into electric energy by semiconductor-based photovoltaic characteristic effect; photovoltaic cell monomer can be equivalent to the circuit shown in Fig. 1 according to internal structure of the photovoltaic cell and the output characteristics thereof.

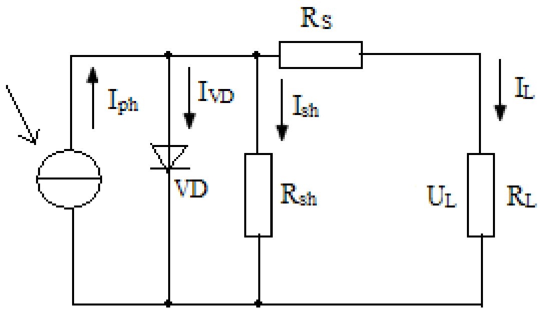


Fig. 1. Equivalent model of photovoltaic cells

In Fig. 1, R_L represents load; U_L represents load voltage or output voltage; I_L represents load current or output current; R_S and R_{SH} represent equivalent series and parallel resistance, R_S is about 1 Ohm, and R_{SH} is thousands of Ohm or so generally; I_{VD} represents dark current or diffusion current; I_{PH} represents current motivated by photons on the photovoltaic cell, its size is directly proportional to illumination intensity and temperature, I_{PH} size is not related to external load, which can be regarded as constant flow source. The output characteristic equation can be reckoned as follows according to the above equivalent circuit model and analysis on volt-ampere characteristics of photovoltaic cell:

$$I_{ph} = I_{SC} + \frac{S}{S_{ref}}[1 + C_T(T - T_{ref})] \tag{1}$$

$$I_0 = I_{d0}(\frac{T}{T_{ref}})^3 \exp[\frac{qE_g}{nk}(\frac{1}{T_{ref}} - \frac{1}{T})] \quad (2)$$

I_L can be simplified as follows under general condition since R_S is smaller and R_{SH} is larger:

$$I_L = I_{ph} - I_0[\exp\frac{qU_L}{AKT} - 1) - \frac{U_L + I_L R_s}{R_{sh}} \quad (3)$$

In the formula, S refers to illumination intensity with unit of W/m^2, S_{ref} refers to reference illumination intensity, and it is 1000 W/m^2 generally; C_T refers to temperature coefficient; T refers to environment temperature; T_{ref} refers to reference value of environment temperature, and it is 298 K generally; I_0 refers to reverse saturation current of diode with order of magnitude of 10^{-4} A; q refers to charge constant, and it is $1.6x10^{-19}$C; A refers to ideal factor of PN node. It is generally 2.8 when T=300 K; k refers to x constant of Porsz, and it is 1.38 $x10^{-23}$J/K[3].

Therefore, expression of photovoltaic cell output power can be obtained as follows:

$$P = U_L I_{SC} \frac{S}{S_{ref}}[1 + C_T(T - T_{ref})] - U_L I_0[\exp\frac{qU_L}{AKT} - 1) \quad (4)$$

Formula (4) shows that output power of photovoltaic cell is related to illumination intensity and environment temperature, and they show nonlinear relationship.

3. MPPT control of photovoltaic system

Output of photovoltaic module has maximum power point. Whether modules can be operated on the maximum power point or not depends on load connected with module under specific temperature and illumination condition. Fig. 2 and Fig. 3 are schematic diagrams of working points of photovoltaic module, Fig. 2 shows equivalent circuit diagram of photovoltaic module.

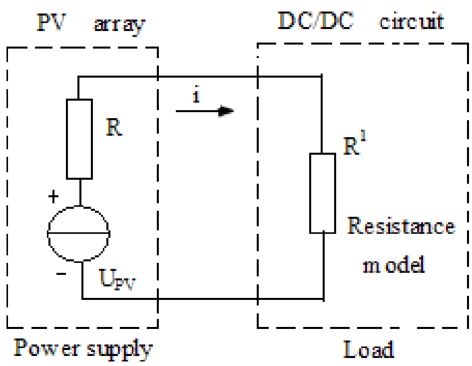
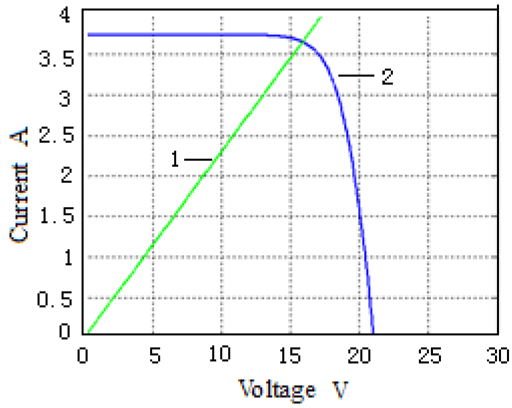


Fig. 2. Equivalent circuit of PV module

Fig. 3 shows current and voltage (I-V) curve output from photovoltaic module, the straight lines represents I-V characteristics of load resistance.



1- Load characteristic; 2- PV characteristic
Fig. 3. PV module load I-V curve

The crossed point thereof refers to the working point of the photovoltaic module. Voltage and current of the working points not only should meet I-V characteristics of photovoltaic module, but also should be consistent with own I-V characteristics of the load. Load and photovoltaic module are in mismatching state then if the crossed point of the two lines is not on the maximum power point. Electric energy produced by the photovoltaic module is not utilized sufficiently.

External environment factors cannot be manually changed generally. Illumination and temperature are changing in one day. The output characteristics of the photovoltaic array are also changing along. The array can always output the maximum power, which must adapt to change, and be connected with load [4].

The structure diagram of MPPT control device of photovoltaic power generation system is shown in Fig. 4. It is mainly composed of photovoltaic array, DC-DC converter, load, controller, etc.

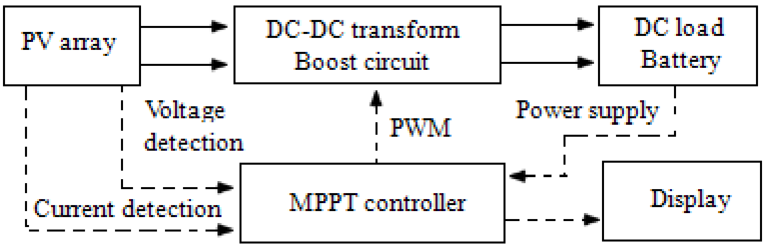


Fig. 4. MPPT structure diagram of PV power generation

The controller can form control signals (duty cycle) according to system state and internal tracing algorithm during system operation. DC-DC converter is responsible for completing MPPT. Boost circuit is selected as DC-DC converter of the system, the impedance transformation relation is shown in formula 5, wherein R': equivalent input impedance of Boost circuit; D: duty cycle of switch; R_L: load impedance, and own power loss of the Boost circuit is not considered in the formula.

$$R^1 = \frac{V_i}{I_i} = \frac{V_o(1-D)}{I_o/(1-D)} = \frac{V_o(1-D)^2}{I_o} = R_L(1-D)^2 \tag{5}$$

It is obvious that equivalent load connected with the photovoltaic array is duty cycle D of DC-DC converter and the function of the load thereof. The duty cycle of the converter can be adjusted to reach the purpose of changing equivalent load of the photovoltaic array. Therefore it can follow internal resistance change of the photovoltaic array under different external environments. The maximum output power of the photovoltaic array module can be obtained when their dynamic loads are matched, thereby realizing MPPT [5].

4. Multi-peak value characteristics of photovoltaic array

Total output power is equal to the sum of output power of all battery modules when many photovoltaic cell modules are connected in series to form the photovoltaic array. Two photovoltaic cell modules are connected in series as an example for analyzing the output characteristics of the photovoltaic array under partial shading. Fig. 5 shows photovoltaic array model composed of two photovoltaic cell modules which are connected in series.

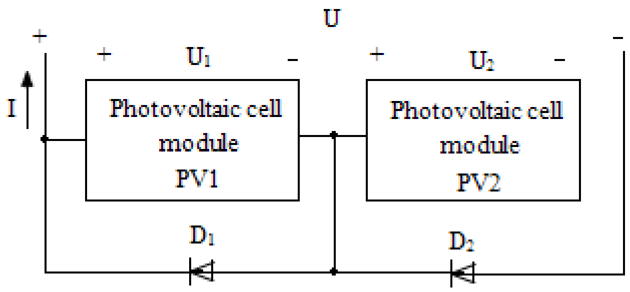


Fig. 5. PV module series model

It is assumed that two selected photovoltaic cell modules have the same model, current flows through the bypass diode D1 under the condition of the same external environment. D2 current is 0. PV1 short-circuit current Isc1 is lower than PV2 short-circuit current Isc2 if the illumination intensity of the photovoltaic cell PV1 is smaller than the illumination intensity of the photovoltaic cell PV2. D1 is forced for conducting when the array output current is between Isc1 and Isc2; output characteristics of the photovoltaic array are equal to output characteristics of PV2. D1 is switched off when output current of the photovoltaic array is lower than Isc1. Output characteristics of the photovoltaic array are equal to the sum of output characteristics of PV1 and PV2.

The above analysis shows that P-U characteristic curve is determined by piece-wise function when photovoltaic array produces partial shading. The output power of the photovoltaic array is shown in the following formula:

$$P = \begin{cases} IU_2 & I_{sc1} \le I \le I_{sc2} \\ IU_1 + IU_2 & 0 \le I \le I_{sc1} \end{cases} \tag{6}$$

In the formula, U indicates output voltage of the photovoltaic array. U1 and U2 indicate terminal voltages of photovoltaic cell module PV1 and PV2 respectively. I indicate output current of photovoltaic array. P indicates output power of photovoltaic array. P-U characteristic curve of the photovoltaic array shows two extreme points since equivalent current flows through modules connected in series under the condition of the same photovoltaic module illumination. Conventional MPPT method will become invalid. Local extremum output can be traced easily [6].

5. Extreme improvement of PSO algorithm

Principles of PSO algorithm. PSO algorithm is a swarm intelligent optimization searching method which is produced through mutual coordination and competition of each particle in the swarm. It is an effective global optimization method of multi-peak value function. All potential solutions of the optimization problem are regarded as a particle in the swarm in the PSO algorithm. Each particle has a fitness value determined by the objective function. Each 每 particle is endowed with one speed to determine their “flight” direction and distance. Then, the particle can follow current optimal position for searching in solution space.

Firstly, a group of random particles are initialized. Each particle has two attributes of speed and position. Next, the optimal value is searching iteratively. The particle is compared with two optimal values for updating own speed and position in the iteration process: the first optimal value is the optimal value searched by the particle itself currently, and it is called individual optimal value with short form of P_{best}; the other optimal value is the optimal value which is searched by the whole swarm currently. It is called global optimal value with brief form of G_{best}.

It is assumed that there are a d-dimension searching space currently and a swarm composed of N particles, wherein the position of the ith particle represents one d-dimension vector, i =1,2…N, it is recorded as follows:

$$X_i = (x_{i1}, x_{i2}, ..., x_{in}) \quad (7)$$

The “flight” speed of the ith particle is also represented as one d-dimension vector, and it is recorded as follows:

$$V_i = (v_{i1}, v_{i2}, ..., v_{in}) \quad (8)$$

Individual optimal value searched by the ith particle till present is recorded as follows:

$$P_{best} = (p_{i1}, p_{i2}, ..., p_{in}) \quad (9)$$

The global optimal value searched by the whole swarm till present is recorded as follows:

$$G_{best} = (g_{i1}, g_{i2}, ..., g_{in}) \quad (10)$$

Particles update own speed and position according to the following formula 11 and 12 after the two extremum values are searched: it is assumed that searching space is 1-dimension, and the updating equation of speed vk+1I and position xk+1 of the ith particle during the k+1th iteration is shown as follows:

$$v_i^{k+1} = wv_i^k + c_1 r_1 (P_i^k - x_i^k) + c_2 r_2 (G_i^k - x_i^k) \quad (11)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (12)$$

P_i and G_i are defined as follows:

$$P_i = \begin{cases} P_i & f(X_i) \geq f(P_i) \\ X_i & f(X_i) < f(P_i) \end{cases} \quad (13)$$

$$G_i = \max\left\{ f(P_0), f(P_1), ..., f(P_N) \right\} \quad (14)$$

$v_{i=}V_{max}$ when $v_i>V_{max}$; $v_{i=-}V_{max}$ when $v_i<-V_{max}$. w is inertia weight; k is the number of iterations.

Wherein, w size is used for determining the influence of the former iteration speed of the particle on current iteration speed of the particle, w is larger, the particle has stronger ability to inherit current speed, w is smaller, and the particle has weaker ability to inherit current speed. Inertia weight can be selected rationally for balancing the local optimization capacity and global searching ability of the particle. c_1 and c_2 refer to learning factors, and they are also called acceleration constants[7,8]..

When PSO optimization algorithm is optimized under the condition that P-V output characteristic is multi-peak, it has the defects of low precision, easy divergency and falling into local optimization, etc. The optimal value cannot be searched accurately and rapidly sometimes.

Actual condition of PV MPPT control is combined for optimization design in the aspects of setting weight coefficient, acceleration learning factors, etc. on the basis of standard PSO algorithm, and an improved PSO algorithm is proposed.

Improvement of inertia weight. Inertia weight ω can keep inertia of certain speed for particles. It is an important parameter to measure the influence of the former iteration speed on current iteration speed. The inertia weight ω is smaller, speed V is smaller, thereby facilitating precise searching in current solution space. The local searching ability of the algorithm is improved greatly; thereby the algorithm can be converged easily. However, inertia weight ω is larger; speed v is larger, thereby facilitating searching of larger optimization space. Algorithm global searching ability is improved greatly, which is beneficial for jumping out of local minimal point [9].

Inertia weight is set as a fixed constant generally in the standard PSO algorithm. Practice shows that such situation is not beneficial for rapid convergence of algorithm iteration and global optimal solution. Dynamic adjustment of inertia weight is an effective method in the searching process. A method of reducing the inertia weight gradually is proposed for the algorithm in the paper. The algorithm is endowed with a larger positive value at the beginning. The weight is reduced linearly with progress of searching, and the inertia weight is calculated with the following formula:

$$\omega = \omega_{\max} - (\omega_{\max} - \omega_{\min}) \times \exp(-20 \times \frac{t}{T_{\max}}) \tag{15}$$

In the formula, $\omega_{\max}$ -maximum weight; $\omega_{\min}$ -minimum weight; t-number of iterations; T_{max}- maximum number of iterations.

The strategy has the following advantages: inertia weight value is larger; all particles can be searched in the global scope with larger speed step length at the beginning of iteration. The searching ability is improved prominently, and new areas are searched constantly. However, inertia weight value is reduced at the later period of searching, the searching speed is reduced, the convergence ability is enhanced gradually, and thereby the algorithm can search more carefully near possible optimal solution. Therefore, algorithm can achieve larger probability, which can be converted into global optimal solution according to certain precision[10,11].

Improvement of learning factors. Value of learning factors reflects the strength of information exchange among particles in PSO algorithm, particle movement direction and final convergence results of the algorithm are determined according to values of learning factors c_1 and c_2 and proportional relation thereof. It is obvious that too large or too small learning factors are set, which are not beneficial for particle optimization. A fixed constant between [1, 2.5] is selected for inertia weight generally in the standard PSO algorithm. In the paper, a strategy of adjusting learning factors dynamically and linearly is selected in view of influence of learning factors on swarm algorithm.

$$\begin{cases} c_1 = 2.4 - 1.4 \dfrac{t}{T_{\max}} \\ c_2 = 0.9 + 1.6 \dfrac{t}{T_{\max}} \end{cases} \tag{16}$$

c_1 can be linearly decreased gradually with number of iterations through the improvement. Meanwhile, c_2 is linearly increased gradually with number of iterations. It is stressed that individual cognitive ability is reduced gradually with the increase of number of iterations at the same time, and the swarm cognitive ability is enhanced gradually. The strategy can improve the global searching ability of the particle in the whole searching space at the early stage of algorithm searching. However, it is encouraged that the particle can astringe global optimization at the final stage of algorithm searching.

The algorithm has good local searching ability through optimizing the three parameters. The optimal value can be searched precisely. Therefore, PSO optimization algorithm can achieve better global scanning ability on one hand; its local scanning ability also can be improved on the other hand. The accuracy of the algorithm is improved greatly under the precondition of ensuring the rapidness.

Improved PSO algorithm flow. IPSO optimization algorithm has the following MPPT control thinking under PV partial shading: to-be-optimized objective function is output power when IPSO optimization algorithm is used for tracing maximum power point. Particle is set as duty cycle capable for controlling voltage change. Particle movement direction and distance are determined by determination of the particle speed. The particle position is updated through updating individual extremum value and global optimal value constantly, which is iterated repeatedly until particle position is converged to maximum power point, the photovoltaic array voltage corresponding to the duty cycle under the condition is the working voltage of maximum power point that should be searched by us. Improved PSO algorithm is used for controlling optimal solution by PV MPPT. Strategies of inertia weight and learning factors are improved. The improved PSO algorithm flow is shown as follows:

(1) Select maximum number of iterations and other initial parameter, and initialize particle position;

(2) Calculate adaptive value of each particle according to objective function;

(3) Compare current target value of current ith particle with optimal value

P_{best} and global optimal value G_{best} of the particle in record, and update P_{best} and G_{best} if the target value is smaller than P_{best} and G_{best}.

(4) Update ω according to formula (15) in each iteration, update c_1 and c_1 and c_2 according to formula (16), and update position and speed of each particle according to formula (11) and (12).

(5) Check whether algorithm convergence criterion is satisfied for not, and finish optimization if it is satisfied, otherwise transfer to step (2).

(6) Set i=i+1 for each cycle, repeat the above steps until algorithm stops operation during i=Tmax;

Objective function and adaptive value of each particle are calculated. The output voltage of many photovoltaic modules is regarded as multidimensional variable, total output power of the photovoltaic array is determined as objective function, and the maximum value of total output power is optimized[12,13].

6. Operation results and analysis

MATLAB software is utilized to build PV MPPT simulation model. Important parameters are set, main control parameters of the set algorithm are shown in table 1:

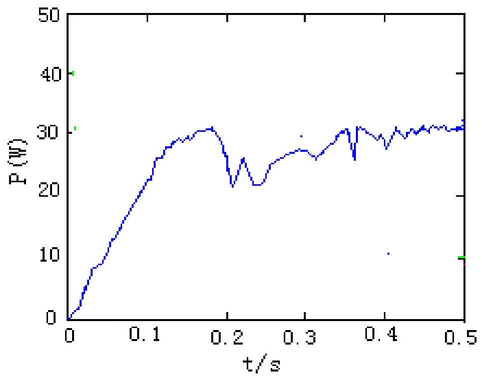
Table 1

Setting of algorithm control parameter

Nam	pop_size	max_gen	w	c_1	c_2	light intensity(W/m^2)	temperature(^0C)
PSO	100	100	1	2,1	2, 1	1000	25
IPSO	100	100	0.9-0.4	2.4↓ □	0.9↑	1000	25

A photovoltaic module is formed by connecting a plurality of photovoltaic cell monomers in series. In the maximum power point tracking of photovoltaic array, the objective function is the output power of PV array. The fitness function of each particle is defined as the output power of the PV array. Each particle has two variables, the position and the velocity. The position of the particle represents the output voltage of the array, and the velocity of the particle is the variation of the array voltage. Environmental temperature, light intensity and output voltage of PV array should be taken into account.

Both population size and maximum number of iterations are 100. Searching space dimensionis 2, illumination intensity is set as 1000 W/m^2 constantly. Temperature is set as 25^0C constantly. The universality is not lost. The inertia weight ω of PSO algorithm is set as 1, c_1 and c_2 values of simulation learning factors are 2 in experiment of the first group, c_1 and c_2 values of simulation learning factors are 1 in experiment of the second group. Improved PSO algorithm inertia weight is set according to formula (15). The scope is adjusted dynamically between 0.9 and 0.4. Learning factors are set according to formula (16). c_1 is decreased from 2.4 gradually. c_2 is increased from 0.9 gradually. They belong to dynamic values. It is believed that the optimal solution has been searched when the number of iterations reaches the maximum value. Using the traditional perturbation observation algorithm, PSO algorithm, IPSO algorithm for the above MPPT model simulation, the results are shown in Fig. 6 – Fig. 8.



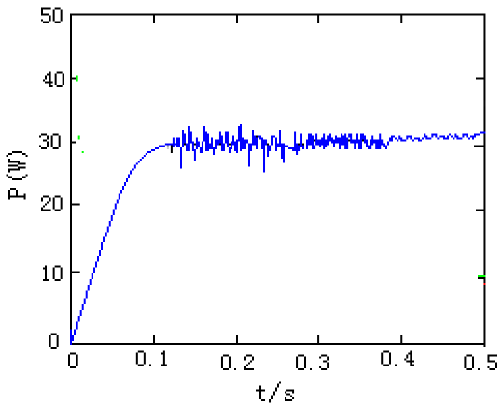


Fig. 6. Traditional interference observation method simulation

Fig. 7. The standard PSO algorithm simulation

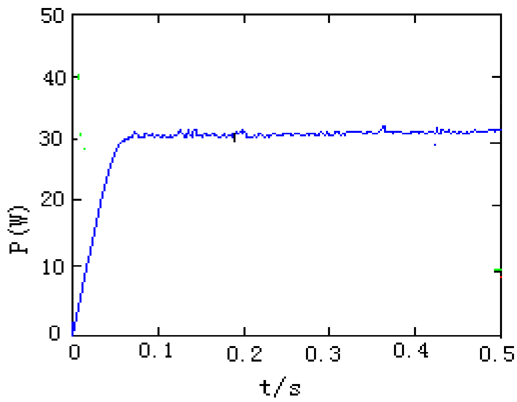


Fig. 8. The improved PSO algorithm simulation

Fig. 6 shows that the tracing time of perturbation and observation method is about 0. 45s. Fig. 7 shows that the tracing time of PSO optimization algorithm is about 0. 38s. In addition, there is certain fluctuation after the perturbation and observation method is steady, namely the steady-state mean value is smaller than maximum power value, thereby leading to energy waste. Fig. 8 shows that IPSO algorithm can eliminate fluctuation after steady state on one hand, the tracing speed is about 0.1s, and the speed is improved obviously.

Comparison of simulation curves in Fig. 6 to Fig. 8 shows that equivalent strategy of inertia weight and learning factors is adopted in standard PSO algorithm. The standard PSO algorithm falls into local solution process in optimal solution process. The optimal solution process can be completed after repeated oscillation for many times. However, the improved PSO algorithm can enter the stable optimization stage in the process of optimal solution since the strategy of decreasing inertia weight gradually and adjusting self-adaptive learning factors is adopted. The evolving algebra is reduced greatly compared with standard PSO algorithm. It is obvious that the global searching ability of the improved PSO is enhanced prominently[14,15].

In general,the dynamic response speed and steady-state accuracy of the APSO control algorithm with particle swarm optimization are better than that of the disturbance observation method and the PSO control method.

Under normal circumstances, the main grid system and photovoltaic power generation system jointly load the power supply. The using of information technology and networking technology, distributed PV system is an integral part of the main grid system. In this case, the system operates in the “on grid” mode, greatly improving the controllability of distributed PV.

When the main grid system is out of power, the photovoltaic system and the load together form a small isolated grid that operates in an isolated “island” mode. The control refers to the island control center as required to issue control instructions for different isolated island systems. The islanding control system not only can prevent the harm caused by islanding, but also can make full use of island effect to improve the reliability of power supply.

7. Conclusion

The whole output power of the photovoltaic array is reduced when external environment is changed, such as temperature, illumination, etc. P-V characteristic curve shows turning point. Output power shows local maximum value. Traditional MPPT method has poor effect under the condition. In the paper, improved PSO algorithm is proposed for MPPT control of the photovoltaic system. MPPT model of the photovoltaic power generation system is established. Simulation study is studied, dynamic response of different control methods is tested, and the following conclusion is obtained:

(1) Improved PSO algorithm has better dynamic and steady-state performance compared with traditional MPPT P&O method and PSO algorithm, and they have stronger robustness.

(2) Simulation results show that convergence rate is improved greatly. In addition, it has no oscillation basically near the global maximum value point during steady state. The global maximum output power of the photovoltaic array can be traced, thereby laying theoretical foundation for large-scale practical

application of multi-peak power tracing.

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R E F E R E N C E S

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