OPTIMIZATION DESIGN FOR PHOTOVOLTAIC GENERATION MPPT BASED ON IMPROVED ADAPTIVE GENETIC ALGORITHM

Youche LIU*[1], Huaizhong CHEN[1]

The maximum power point of the photovoltaic cell should be tracked and controlled accurately as well as quickly in order to improve the utilization rate of photovoltaic cell. The photovoltaic power generation control strategy is the core of photovoltaic power generation system. MPPT (maxi-mum power point tracking, MPPT) control strategy is the front and key part of photovoltaic power generation system. A mathematical model of photovoltaic array is established according to nonlinear characteristics of photovoltaic cell. Standard genetic algorithm (hereinafter referred to as SGA) makes system power output reach the maximum power point through adjusting duty cycle D of Boost converter. And the better effect is achieved in application. However, standard genetic algorithm has the disadvantages of vulnerability to local optimal solution, insufficient convergence rate and gradual reduction of searching precision. To solve the shortcoming of standard genetic algorithm in MPPT control, a MPPT control method based on improved adaptive genetic algorithm (hereinafter referred to as IAGA) is proposed in the paper, which is modeled and simulated under Matlab environment. The experimental result shows that the improved adaptive genetic algorithm has excellent search speed in MPPT control, better real-time performance and control precision. It can follow desired output value quickly and steadily. The photovoltaic power generation system is steadily operated in the maximum power point.

Keywords: Generation System; Improved Genetic Algorithm; MPPT; Photovoltaic

1. Introduction

Photovoltaic power generation has the highest development prospect undoubtedly in the utilization of all renewable energy sources. However, photovoltaic power generation system has a main disadvantage that its output power is severely affected by weather. For example, the output value is changed due to changes in illumination intensity and environment temperature. In the photovoltaic power generation system, MPPT has an important role for improving the overall efficiency of the photovoltaic power generation system. The operating point of the solar cell array can be properly adjusted with external environment by

[1] Zhejiang Industry Polytechnic College, Zhejiang, Shaoxing, 312000, China, E-mail: chz702@163.com

MPPT of solar cell array. Solar photovoltaic system desires to output the maximum power at any time. Solar photovoltaic MPPT control actually belongs to an optimization problem. If the optimization algorithm with excellent performance can be utilized for tracking and control, the tracking performance can be improved. Standard genetic algorithm achieves better effect in MPPT control, such as disadvantage of premature convergence, slow convergence rate, etc. In some literature, the algorithm is improved on the basis of studying standard genetic algorithm. However, the research emphasis is always limited to the link of genetic algorithm; the standard genetic algorithm is not analyzed and improved from an overall perspective. So, the solar photovoltaic output power is affected. In the paper, an improved MPPT adaptive genetic algorithm is proposed. The crossover probability and mutation probability are automatically changed with fitness value by the improved genetic algorithm. In the optimization process, the population diversity is maintained with the change of population fitness value. Meanwhile, algorithm convergence is also guaranteed. The adaptive genetic algorithm is used for adjusting the MPPT control parameters. Simulation test results show that the algorithm can realize the optimization of control parameters in the global scope, thereby improving the control precision, dynamic and static performance of the control system [1-3].

2. Mathematical model of photovoltaic array

The photovoltaic cell has the following principle: solar radiation is directly converted into electric energy on the basis of semiconductor photovoltaic characteristic effect. The photovoltaic cell monomer can be equivalent to the circuit as shown in Fig.1 according to photovoltaic cell internal structure and output characteristics thereof.

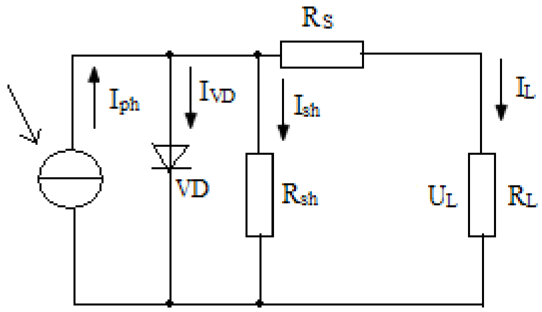

Fig.1. Equivalent model of photovoltaic cells

In Fig.1, According to the positive direction of voltage and current shown in the figure, the following relations can be obtained [4,5]:

$$I_L = I_{ph} - I_{VD} - I_{sh} \quad (1)$$

In this formula, I_L denotes load current or output current; I_{ph} corresponds to the current on photovoltaic cell excited by photon; I_{VD} corresponds to current through an equivalent diode; I_{sh} corresponds to current through resistor R_{sh};

$$I_{ph} = [I_{SC} + K_l (T - 298)] \frac{S}{1000} \tag{2}$$

In this formula, I_{SC} denotes photo generated short circuit current under standard test conditions (Temperature 298K, Illumination Intensity 1000W/m^2); K_l corresponds to coefficient of photo generated current with temperature(A/K); T corresponds to environment temperature; S represents sunlight intensity(W/m^2);

$$I_0 = I_{d0} (\frac{T}{298})^3 \exp[\frac{qE_g}{AK} (\frac{1}{298} - \frac{1}{T})] \tag{3}$$

$$I_{VD} = I_0 [\exp\{[\frac{q(U_L + I_L R_s)}{AKT}] - 1\} \tag{4}$$

$$I_{sh} = \frac{U_L + R_S I_L}{R_{sh}} \tag{5}$$

In this formula, I_0 corresponds to reverse saturated current in P-N junction of equivalent secondary transistor; I_{d0} corresponds to equivalent diode saturation leakage current; q is charge constant; U_L represents load voltage or output voltage; R_S and R_{sh} denote equivalent series and parallel resistance; A is the ideal factor of PN junction; K is Bozmann constant; E_g is bandwidth of crystal silicon.

Formula (6) can be deduced according to formula (1), formula (4), and formula (5):

$$I_L = I_{ph} - I_o \{\exp[\frac{q(U_L + R_S I_L)}{AKT}] - 1\} - \frac{U_L + R_S I_L}{R_{sh}} \tag{6}$$

In ideal case, R_{sh} can be approximated to infinity, then the upper formula can be simplified as follows:

$$I_L = I_{ph} - I_o \{\exp[\frac{q(U_L + R_S I_L)}{AKT}] - 1\} \tag{7}$$

It is inferred that the expression of photovoltaic output power is as follows:

$$P = I_{ph} U_L - I_o U_L [\exp \frac{qU_L}{AKT} - 1] \tag{8}$$

Formula (8) shows that photovoltaic cell output power is related to illumination intensity and environment temperature. It is presented as non-linear relationship.

2.1 MPPT control

MPPT refers that the control can defect the power generation voltage of the solar energy panel in real time. If suitable voltage current value is tracked, then the system can output with the highest efficiency. Fig.2 shows the photovoltaic cell characteristic curve [6].

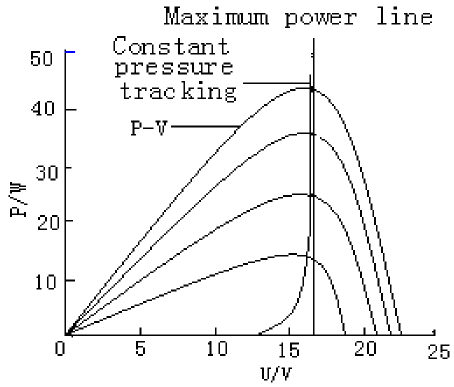

Fig.2. Voltage Tracking output characteristics

It can be seen from the figure: when the temperature is constant and under different solar irradiance of solar panels, the maximum power points are almost in the same vertical line on both sides of the adjacent, which may be the maximum power line approximately as V voltage constant of a root vertical line, and the photovoltaic panels is to a fixed voltage. Constant pressure tracking method is an approximate maximum power tracking method. How to adopt the optimal method for seeking its maximum power point and operate near the maximum power, namely the problem of the maximum power point is automatically optimized.

2.2 Photovoltaic MPPT control principle

The structure diagram of MPPT control device of photovoltaic power generation system is shown in Fig.3. It is mainly composed of photovoltaic array, MPPT controller, DC-DC converter, load, monitor, etc.

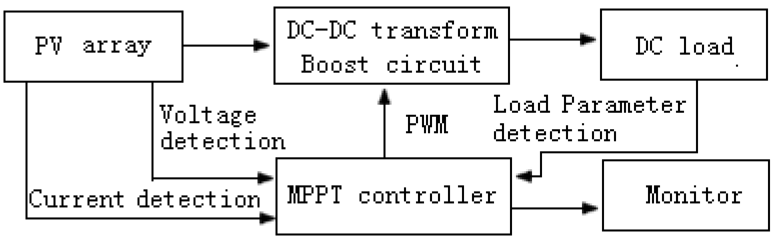

Fig.3. MPPT structure diagram of PV power generation

In Fig.3, solar cells cannot be supplied directly to the battery. First, it cannot make full use of the energy generated by solar cells. Second, it is harmful to the battery. MPPT control scheme is applied here. MPPT controller collects real-time PV array voltage, current, load operation and other parameters, and continuously adjusts MPPT to send corresponding pulse width modulator (PWM) signal, thereby adjusting DC-DC transform Boost circuit duty cycle signal. When the duty cycle signal rises, the turn-on time increases, the charging current rises, and then falls to achieve maximum power point tracking. Thus, the output power of solar photovoltaic is maximized, supplying DC load. Monitor is supplied to complete the control and display functions of the whole system.

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 [7].

Boost boosted circuit is generally adopted as the forward DC/DC converter of photovoltaic array MPPT output circuit as shown in Fig.4:

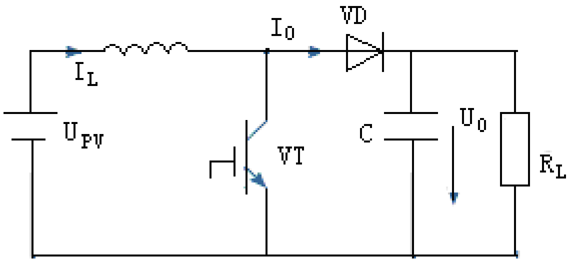

Fig.4. Boost circuit topology diagram

It is assumed that the value of inductance L is higher, the Boost circuit is operated under the CCM mode, current I_L represents basically constant, and the value of capacitance C denotes also higher. It is set that the VT turn-on time is Ton, and the energy stored on the inductance L denotes $U_{PV}I_L$ Ton. When VT is broken, U_{PV} and L charge the capacitance C jointly, and provide energy to load $R_{L.}$ It is set that the VT turn-off time is T_{off}, the inductance releases energy (U_0-U_{PV}) I_L T_{off} during the period. When the circuit is steady, the energy absorbed by the inductance is equivalent to the released energy in one cycle T, therefore:

$$U_{PT} I_L T_{on} = (U_0 - U_{PT}) I_1 T_{off} \tag{9}$$

The duty cycle of photovoltaic Boost circuit switch tube is set as follows:

$$D = \frac{T_{on}}{T} = \frac{T_{on}}{T_{on} + T_{off}} \tag{10}$$

Therefore, the mathematical relationship of photovoltaic output voltage and duty cycle can be deduced accordingly:

$$U_0 = \frac{T_{on} + T_{off}}{T_{off}} U_{PV} = \frac{1}{1-D} U_{PV} \tag{11}$$

Fig.5 shows the P-D relation curve between power and duty cycle of solar energy photovoltaic power generation system. It is obvious that the relationship between power and duty cycle is similar to the P-U relationship between power and voltage, the maximum photovoltaic power points meet the condition $d_P/d_D=0$. The Boost duty cycle is adopted as the disturbance quantity. The power before and after disturbance is utilized for comparison, thereby determining to adjust the duty cycle increase and decrease directions. The photovoltaic output voltage is constantly adjusted to reach the purpose of approaching solar photovoltaic maximum power point [8-9].

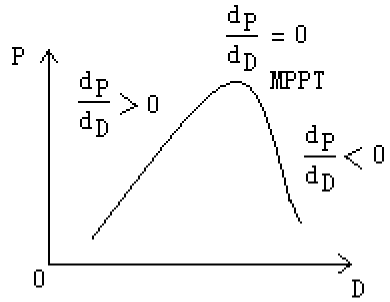

Fig.5. P-D curve of photovoltaic system

It can be concluded that the upper operation point of the solar energy cell can be controlled through adjusting duty cycle D. The current solar cell can be obtained through measuring the current output current and output voltage of the photovoltaic cell. The work output power is compared with previous output power, and different duty cycles are given according to the relationship between duty cycle and power, thereby it can approach to the maximum power point constantly. When the temperature and external illumination intensity are prominently changed, the system can be optimized repeatedly, so the output power can be controlled in a small area near the maximum point [10].

3. Extreme improvement of SGA

3.1 Standard genetic algorithm

Standard genetic algorithm (hereinafter referred to as SGA) is a random search and optimization algorithm for simulating biological group evolution. The SGA basic thought comes from Darwin evolution-ism and Mendel genetics. The knowledge about search scope can be automatically obtained and accumulate in the search process. The search process is autocratically controlled. The concept of chromosome is used for encoding the problem. One population is composed of many chromosomess. Individuals are selected in the population according to certain fitness value from the initial population; crossover and mutation are used for generating next population. The process is evolved generation by generation until the expected termination conditions are satisfied. SGA has stronger robustness. The knowledge in the professional field for parameter optimization solution is less, which is widely applied in the engineering optimization.

It is assumed that the variable of the solar photovoltaic MPPT control system is duty cycle D, D can be changed between 0 and i only. The calculative process for solving MPPT can be obtained according to the calculation process of genetic algorithm [11-12].

(1) The fitness value function is determined, and the conversion form of fitness function and objective function is shown as follows aiming at the maximum value:

$$F(f(x)) = \begin{cases} f(x) - C_{\min,} \; f(x) > C_{\min} \\ 0, \; f(x) \le C_{\min} \end{cases} \tag{12}$$

In the formula: F(x) is objective function, f(x) is fitness function.

(2) The roulette wheel selection method is selected as the selection standard;

(3) Genetic algorithm can generate new individuals through hybridization, and the generation method is shown as follows:

$$L_{i,K+1} = \alpha L_{m,K} + (1-\alpha) L_{n,K} \tag{13}$$

In the formula: a is the proportional factor that is randomly generated on the interval [0, 1], $L_{m,K+1}$ is the new chromosome, $L_{m,K}$ and $L_{n,K}$ is the parent chromosome.

(4) The variation operation has the purpose of producing new individuals distinct from the parent according to the following formula:

$$L_i = \alpha \times (L_{m,\max} - L_{m,\min}) + L_{m,\min} \tag{14}$$

In the formula: L_i is the new chromosome, $L_{m,max}$ and $L_{m,min}$ are the parent chromosomes composed during calculation of the maximum and minimum limits.

However, standard genetic algorithm has some disadvantages in practical application:

(1) When certain crossover and mutation probability is set for a specific optimization problem, since the crossover and mutation probability of the standard genetic algorithm is fixed, so the algorithm should be repeatedly tested for seeking the target value, and the diversity in the population with good solution is limited.

(2) There is a shortcoming of lower search efficiency in the late stage of evolution usually for premature convergence. The search scope is limited, and some excellent gene fragments are lost too early in the search process. It can be optimized usually in the local scope; therefore, the optimization result is not the global optimal value [13].

3.2 MPPT control strategy based on improved genetic algorithm.

An improved adaptive genetic algorithm (hereinafter referred to as IAGA) is proposed in order to improve the shortcomings of standard based algorithm. The idea is shown as follows:

(1) Coding

Chromosome coding depends on the nature of the problem and the design of genetic operators. Main variables include output voltage V, illumination intensity S and battery temperature T. The binary coding is adapted to code photovoltaic output voltage V in the formula (1) in order to study P-V characteristics within certain time under certain illumination intensity and temperature, namely the photovoltaic output voltage in some time point is determined by the timing sampling mode on the illumination intensity S and battery temperature T.

(5) Determination of initial population.

Population size affects the quality and calculation of the solution. Its size setting is related to the problem space. The optimal value is determined by experiment, the population is selected by 10 multiple values and the population scale is determined with the maximum fitness and relatively stable average fitness as principles.

(5) Calculation of fitness

Output power P=IV is regarded as the fitness value of individuals, P value is larger, the individual fitness is higher.

(5) Design of selection operator

Roulette wheel selection method is a common method, which is simple and feasible. The error is larger， and the individuals with high fitness cannot be selected into next generation, thereby leading to prematurity phenomena. In the paper, the method of sorting selection is adopted to avoid the occurrence of prematurity phenomenon. Firstly, the fitness function value of the parent individual is calculated, and the individuals are sequenced according to the calculated value. Then, the best individual preservation method can be used for avoiding early elimination of good genes of the best individual. Finally, the filial generation with worse completion and mutation operation is placed together with the reserved best individuals, thereby forming a new population. The method is beneficial for keeping the diversity of the population, accelerating the convergence rate and improving the search efficiency [14, 15].

(5) Adjustment of crossover and mutation probability

Some scholars improve standard genetic algorithm and propose adaptive genetic algorithm. The algorithm has the following main idea that the defect of fixed and consistent mutation and crossover probability in genetic algorithm is changed, therefore mutation probability and crossover probability can be changed with fitness change in algorithm recognition:

Crossover probability:

$$\begin{cases} P_c = P_{c1} - \dfrac{(P_{c1} - P_{c2})(F - F_{avg})}{F_{\max} - F_{avg}}, F \geq F_{avg} \\ P_c = P_{c1}, F < F_{avg} \end{cases} \tag{15}$$

Mutation probability:

$$\begin{cases} P_m = P_{m1} - \dfrac{(P_{m1} - P_{m2})(F_1 - F_{avg})}{F_{\max} - F_{avg}}, F_1 \geq F_{avg} \\ P_m = P_{m1}, F_1 < F_{avg} \end{cases} \tag{16}$$

In the above formula: P_c is the crossover probability. P_m is the mutation probability. F is the maximum value of fitness in the current population group; F_{max} represents that the larger value of two individual fitness values in the population waiting and crossing process; F_{avg} refers to average fitness value of current population group; F_1 refers to fitness value of to-be-mutated individual.

The method is beneficial for saving excellent individuals of subsequent population. The performance is improved compared with standard genetic algorithm. However, some individuals with better fitness can enter the static and constant state at the beginning of evolution, thereby the system can produce local convergence phenomenon [16].

The algorithm has the improvement idea that parameter optimization is closely related to evolutionary algebra. Dynamic adaptive adjustment is carried out for crossover probability and mutation probability. The adjustment formula is shown as follows:

Crossover probability：

$$\begin{cases} P_c = P_{c1} - \alpha \times \dfrac{(P_{c1} - P_{c2})(F - F_{avg})}{F_{\max} - F_{avg}}, F \geq F_{avg} \\ P_c = P_{c1}, F < F_{avg} \end{cases} \tag{17}$$

Mutation probability:

$$\begin{cases} P_m = P_{m1} - \alpha \times \dfrac{(P_{m1} - P_{m2})(F_1 - F_{avg})}{F_{\max} - F_{avg}}, F_1 \geq F_{avg} \\ P_m = P_{m1}, F_1 < F_{avg} \end{cases} \tag{18}$$

Where in, the adjustment coefficient a value is shown as follows:

$$\alpha = \frac{2.4}{1.2 + e^{\frac{n}{N}}} \tag{19}$$

In the above formulas: n refers to the current iteration number; N refers to the maximum iteration number.

The adjustment idea of the above formula: when it is discovered that the population fitness is not less than the average fitness of the population, crossover probability reduction and mutation probability control strategy are adopted for the improved adaptive genetic algorithm. Crossover probability and mutation probability are gradually reduced with constant increase of evolutionary algebra. When the population individual fitness is less than the average fitness of population, the crossover probability and mutation probability control strategy should be increased simultaneously. The control strategy can enable population individuals to obtain more suitable crossover probability and mutation probability at each stage of parameter optimization, which can make up for population individual difference and increase the search capability of the algorithm global optimization [17].

3.3 Flow of improved adaptive genetic algorithm

Improved adaptive genetic algorithm in the paper is used for optimal solution of the above solar energy MPPT control. The strategy of dynamic adjustment valuation is adopted for crossover probability and mutation probability in genetic algorithm mainly. Other constraints are considered, and the improved adaptive genetic algorithm MPPT search process is shown as follows:

Step 1. Convert problem solution objective function into adaptive function;

Step 2. Code genetic algorithm population individual, and apply the algorithm to initialize the population;

Step 3. Calculate individual fitness value and evaluate the individual on the adaptive function;

Step 4. Apply crossover operator in population, and calculate the crossover probability according to formula (17), randomly select two individuals of the population, adopt new crossover probability for cross-matching, and generate two new individuals;

Step 5. Apply population variation operator in population, calculate the mutation probability according to formula (18), carry out gene mutation operation on the matched individuals, and obtain new individuals;

Step 6.Make i=i+1 for each cycle, repeat the above steps until the algorithm operation is stopped until $i=T_{max}$.

4. Operation results and analysis

Standard genetic algorithm (SGA), the conventional adaptive algorithm (AGA), and improved adaptive genetic algorithm (IAGA), are used for Photovoltaic Generation MPPT parameter optimization. Genetic algorithm model is built under Matlab environment. The simulink model of photovoltaic cells, the application of simulink and S-Function are used to establish the photovoltaic cell mold model. The model is transmitted by artificial solar irradiance S, battery temperature T and output voltage V, and the model output is power P. The algorithm population size is 100. The maximum number of iterations is 100.Solar irradiance S is 600 W/m^2, and temperature T is 25 ^{0}C [18].

The improved adaptive genetic algorithm crossover probability is set according to formula (17). Improved adaptive genetic algorithm mutation probability is set according to formula (18). Crossover probability and mutation probability values are intimated with evolution generation. The scope is valued within certain scope. Several experiments are carried out randomly.

The optimization solution simulation results of three different algorithms on Photovoltaic Generation MPPT Optimization process are shown in Fig.6, Fig. 7 and Fig. 8.

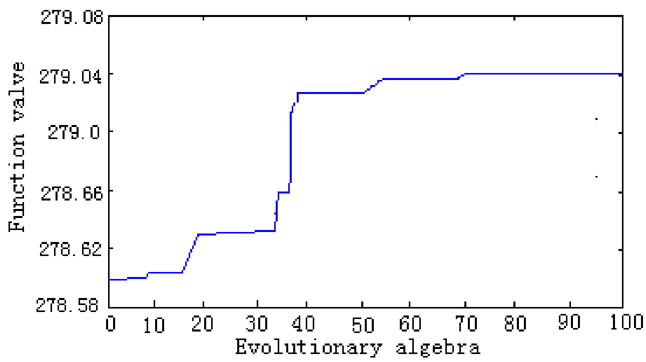

Fig.6. The SGA simulation

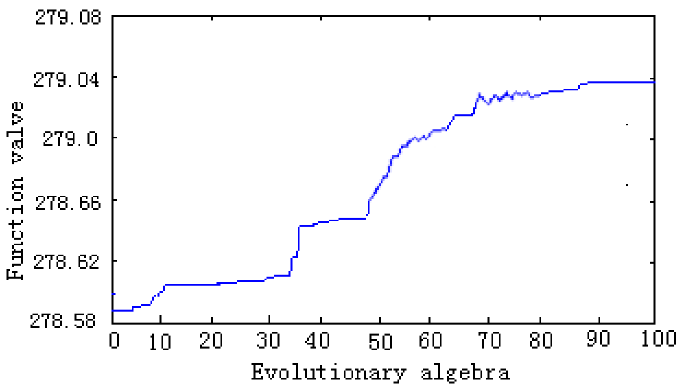

Fig.7. The AGA simulation

The IAGA simulation diagram in Fig.8 is compared with SGA simulation curves in Fig.6 and AGA simulation curves in Fig.7. It is obvious that SGA in Fig. 6 is prone to local solution process during optimal solution. The optimal solution process is completed after repeated shocks for many times. AGA is improved on the basis of SGA in Fig.7, but the effect is still not satisfactory.

However, the IAGA in Fig.8 is applied in the control strategy closely related to the evolution algebra.

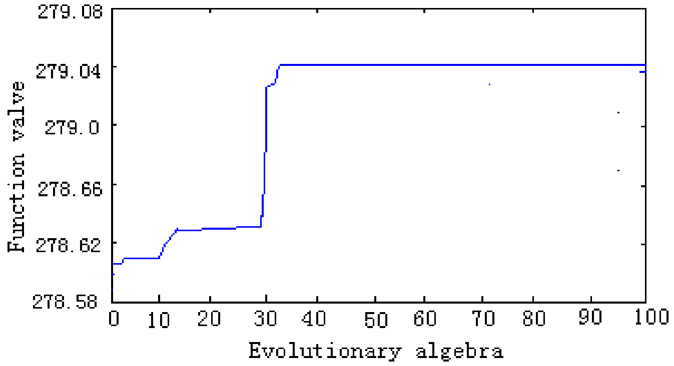

Fig.8. The IAGA simulation

In solar photovoltaic MPPT optimization solution, the falling speed of the objective function value is accelerated in the initial stage. Then it quickly enters into the automatic optimization and stabilization stage. The evolution algebra is prominently reduced compared with standard based algorithm. It indicates that the system global optimization search ability can be prominently improved in the improved adaptive genetic algorithm, thereby further improving the power generation efficiency of the solar photovoltaic system [19-20].

In order to further verify the effectiveness of the algorithm, when t=4s, the solar irradiance is abrupt. The solarlight intensity is suddenly reduced from 600W/m^2 to 500W/m^2. The tracking effect is shown in Fig.9 and Fig.10.

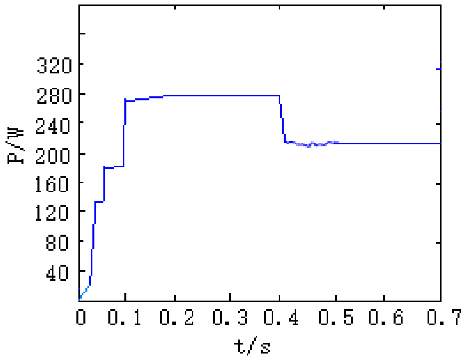

Fig.9. Output power curves of SGA

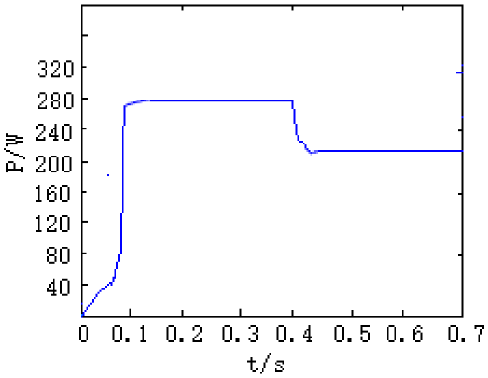

Fig.10. Output power curves of IAGA

Comparing Fig.9 and Fig.10, it is found that compared with the SGA algorithm, when the IAGA control is used, the adjustment time is short, the tracking speed is faster, the power fluctuation is smaller, and the tracking performance is further improved.

5. Conclusion

The MPPT control strategy based on the improved adaptive algorithm is proposed according to the shortcoming of standard genetic algorithm in photovoltaic MPPT control, which is simulated in Matlab. MPPT control has excellent and jamming capability and excellent search speed through improving standard genetic algorithm. MPPT can be realized from any initial value, therefore solar energy photovoltaic power generation system can improve the dynamic and static performance of the system. In the paper, the dynamic response characteristics of different MPPT control methods are tested and compared through study. The following conclusion is obtained:

(1) Compared with standard genetic algorithm, improved adaptive inheritance has better dynamic and steady performance with stronger robustness.

(2) The simulation results show that the convergence rate is greatly improved, there is basically no shock near the global maximum value point in the steady state, and the global maximum output power of the photovoltaic array can be traced in the whole process.

(3) The maximum power point has an important role to improve the overall efficiency of the photovoltaic power generation system. The method of utilizing improved adaptive genetic algorithm for MPPT, proposed in the paper, not only ensures the accuracy of tracking, but also meets the requirement on fast speed in actual application, thereby laying a theoretical basis for large scale application of solar photovoltaic MPPT control.

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