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Optimal Design of Solar Photovoltaic Power MPPT——Based on Fuzzy PID Control and Improved Particle Swarm Algorithm

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Abstract: The maximum power point tracking technology for photovoltaic power generation has achieved fruitful results after years of development, However, the balance between the rapidity and stability of the maximum power point tracking and the tracking effect when the external environment is abrupt is poor. The purpose of this paper is to study a new variable step admittance increment method, and on this basis, optimize the design to achieve fast and stable tracking of the system. This paper proposed an improved fuzzy PID control algorithm, through algorithm combining fuzzy control and fuzzy PID to realize hierarchical control. This paper integrate the hierarchical idea in CSO algorithm and learning methods of part of the same generation into PSO algorithm, and obtained the improved PSO algorithm. Optimized the fuzzy PID parameters of solar photovoltaic system, and improved the software flow of the system. Using Simulink for modeling and simulation, the results show that the fuzzy PID controller optimized by PSO can smoothly reach the steady state in a short time when the step response occurs, which improved the response speed of the system, and there is no obvious overshoot, dynamic and steady-state performance performed well.

1. Introduction

With the exhaustion of existing energy sources, the development of new energy sources to replace part of traditional energy sources has become an urgent requirement of the new era. New energy has the advantages of safety, renewable, pollution-free, recyclable and high development potential, which has been recognized and promoted by many countries [1-3]. The advantages of solar energy make it stand out among the new energy sources. It is recognized as one of the new energy sources that can replace the traditional fossil energy in the future. If the energy provided by the sun every year is far greater than human consumption, the problem of energy shortage and environmental pollution can be solved [4]. Therefore, no matter in terms of energy or environment, the potential of solar energy utilization is infinite. At the same time, from the perspective of photovoltaic power subsidy policy, both at home and abroad are vigorously promoting and actively promoting the photovoltaic power industry [5]. At present, the photovoltaic power industry is growing rapidly at the rate of 35% per year, which benefits from the policy support and recognition of governments. In scientific research, countries also invest a lot of research funds, and give financial support to photovoltaic enterprises [6-7]. At present, China's solar power generation has accounted for 76% of the global solar power generation, more than four times that of the whole European and American countries, and according to statistics, China's current annual growth rate is still nearly 20% to 30%.

MPPT of solar photovoltaic power generation refers to the technology that solar panels charge batteries with the highest efficiency by adjusting the angle and voltage and current under the control of the control system, so as to improve the efficiency of solar photovoltaic power generation [8]. The surface temperature of solar panels and the angle of solar irradiation affect the output voltage and current of solar photovoltaic power generation, and then affect the power of photovoltaic power generation [9-10]. MPPT not only detects the output voltage and current of solar photovoltaic power generation, but also calculates the output power of solar array, and controls the output current according to the optimal control scheme, so as to realize tracking the maximum power point [11]. According to the judgment method and criterion, MPPT method can be divided into two modes: open-loop mode and closed-loop mode. The output characteristics of photovoltaic cells are affected by external temperature, light and load, humidity and even other climatic environments, so the system modeling is complex [12-14]. There is an approximate linear relationship between the maximum power point voltage of photovoltaic cells and the open circuit voltage of photovoltaic cells [15]. Therefore, optimizing the open-circuit voltage of photovoltaic cells is the key to solve the problem.

The innovations of this paper are as follows: (1) On the basis of using power error and error variation as input of dual-mode control algorithm, this paper introduces illumination intensity as input, and illumination intensity s (n) as input variable is the voltage value obtained by single-chip computer processing, and chooses the corresponding control method according to the voltage value. According to the control rules, MPPT control is realized by adjusting the three quantization parameters of the fuzzy PID controller and adjusting the output of Boost converter circuit. The voltage and current collected by the photovoltaic MPPT controller are processed by a single chip computer to get two inputs of the fuzzy PID control system. Fuzzy controller is mainly used to control error near zero, so variable universe is adopted in this paper. After been fuzzy, according to the fuzzy control rules, the control amount can be fuzzy and output. (2) This paper integrates the hierarchical idea of CSO algorithm and the learning mode of some contemporary individuals into PSO algorithm, and obtains the improved PSO algorithm, optimizes the fuzzy PID parameters of solar photovoltaic power generation system, and improves the software flow of the system.

In the first part of this paper, the background of solar energy development and utilization, as well as the innovation and organization structure of this paper are introduced; in the first section of the second part, the related research in this field is introduced; in the second section, the improved method of particle swarm optimization is introduced; in the third section, the principle of fuzzy PID control is introduced; in the third part, the main introduction is given. The first section introduces the experimental settings and data acquisition, the second section introduces the determination of input and output, the second section introduces the optimization steps of IPSO algorithm; the fourth part first analyses the performance of fuzzy PID control, and then analyses the performance of improved PSO optimization fuzzy PID algorithm; the fifth part carries on the full text. Summary is made.

2. Proposed Method

2.1. Related Work

The world's electricity consumption is 17 TW, which is lower than 3.6 x 10(4) TW. Photovoltaic (PV) cells are an essential element in converting solar energy into electrical energy. Hosenuzzaman comprehensively reviews photovoltaic cell technology, energy conversion efficiency, economic analysis, energy policy, environmental impact, various applications, prospects and progress. This work compiles the latest literature on photovoltaic power generation, economic analysis, environmental impact and public awareness policies (journal articles, meeting minutes and reports). From the review, PV is a convenient way to capture solar energy, and PV-based power generation has also increased rapidly [16]. Sun proposed an energy storage photovoltaic power generation system based on qZS-CMI. The system combines qZS-CMI and energy storage by adding energy storage cells in each module to balance random fluctuations in PV power. Sun also proposed a control scheme for energy storage photovoltaic systems based on qZS-CMI. The proposed system can achieve a distributed maximum power point trajectory of the PV panel, balance the power between the different modules, and provide the required power to the grid. A detailed design method of controller parameters is disclosed [17]. By using the latest manufacturing data and technology roadmap for mixed life cycle assessments, Bergesen compared the existing and projected two common thin-film photovoltaic technologies - (GIGS) - influences of generated electricity on the environment, human health and natural resources. Combined with the United States (USA) cadmium telluride (CdTe) and current US power. Bergesen also assesses how to reduce the effects of thin films through technological changes that may reduce costs: (1) increased module efficiency, (2) dematerialization of modules, (3) changes in upstream energy and material production, and (4) end of life cycle systems (Recovery of BOS) [18]. Maximize the potential benefits of the structure and function of the grid-connected inverter, integrate the filtering and reactive power compensation functions into the PV power plant inverter, and realize the multi-function complex of active power grid, harmonic suppression and reactive power compensation. Dongdong and other scholars have studied the control strategy, power quality characteristics and control methods of the inverter, and improved the topology of the photovoltaic power plant. Based on this, the reactive power of the inverter is proposed. Power allocation strategy and proposed reactive power allocation strategy [19]. Fonseca and other scholars have studied four prediction methods, two of which are new methods proposed in this paper. Together they describe a set of prediction methods that can be applied to different scenarios of the infrastructure for data availability and prediction. The prediction method is based on support vector regression and weather forecast data. The one-year hourly forecast was evaluated using data from 273 PV systems installed in two adjacent areas in Kanto and Central Japan [20].

2.2. Improved Method of Particle Swarm Optimization

Compared with the PSO algorithm, the IPSO algorithm mainly has the following changes:

(1) Perform particle classification. According to the degree of fitness, all the individuals in the particle group are ranked in good or bad, and the greater the serial number, the worse the fitness.

Then, according to the serial number of each particle, the individual particles are classified into high-level particles AP, intermediate particles MP, and low-level particles LP, thereby preparing for learning between the particles. The distribution ratio can be determined by the algorithm writer. In this paper, the total number of particles N is a multiple of 3 and the number of particles of three grades is evenly distributed, that is, the ratio of the number of particles of all grades is 1:1:1. Each particle learns from the optimal particle individual, the optimal particle of this level, and any higher-level particle that the algorithm finds when performing positional migration.

(2) Continuously update the particle level. After all the particle fitness calculations are performed, the particle sorting and level update are performed immediately, instead of directly simulating the CSO algorithm, and the Gc generation is updated once every interval, thereby speeding up the individual level update frequency and avoiding the adaptation of high-level individuals. The degree of fitness is worse than that of low-level individuals.

(3) Replace the fixed inertia factor with a random linear variable weight inertia factor. As shown in the formula (1), the inertia weighting factor gradually decreases as the individual number of the particle increases, that is, the individual with poor fitness has a smaller inertia weight, while the individual with better fitness has a larger one. The inertia weights further reduce the likelihood of falling into local optimum.

$$w_i = w_{\max} - \frac{(w_{\max} - w_{\min}) \cdot g}{G} \tag{1}$$

(4) Cancel the particle migration speed. Individual particles migrate directly under the action of inertia factor and learning factor when performing positional migration, instead of first updating the particle velocity and then performing positional migration. This measure can simplify the algorithm execution process and improve the speed of the algorithm. Assuming that the algorithm asks for the problem of finding the global minimum of the function, the particle migration method is shown in equation (2).

$$\begin{cases} x_{i,j}^{g+1} = w_{i,j} x_{i,j}^{g} + l_{s1} \cdot rand_{1,j}^{g} \cdot (x_{s1,j}^{g} - x_{i,j}^{g}) + l_{s2} \cdot rand_{2,j}^{g} \cdot (x_{s2,j}^{g} - x_{i,j}^{g}) \\ \qquad + l_{pgb} \cdot rand_3 \cdot (pgbest_j^g - x_{i,j}^{g}) \\ l_{s1} = \exp(\dfrac{fit_{s1}^{g} - fit_i^g}{|fit_i^g| + \varepsilon}) \\ l_{s2} = \begin{cases} 0 & , i \le round(NP/3) \\ \exp(\dfrac{fit_{s2}^{g} - fit_i^g}{|fit_i^g| + \varepsilon}), & i > round(NP/3) \end{cases} \\ l_{pgb} = \exp(\dfrac{fit_{gbest}^{g} - fit_i^g}{|fit_i| + \varepsilon}) \\ s1 = \begin{cases} 1 & , 1 < i \le round(NP/3) \\ round(NP/3) & , round(NP/3) < i \le round(NP \cdot 2/3) \\ round(NP \cdot 2/3) & , round(NP \cdot 2/3) < i \le NP \end{cases} \end{cases} \tag{2}$$

Where s1 is the individual particle with the best fitness in the rank of the particle individual i;

S2 - any individual at a higher level than s1;

$pgbest^g$ - The global optimal position obtained by the optimization process after the iteration of the gth;

fit_{gbest}^g - The global optimal fitness corresponding to $pgbest^g$;

ε – A very small positive number, used to prevent the denominator from being 0. This article takes 1e-300.

(5) Change the particle learning object and learning style. Cancel the learning of the particle's optimal position, instead of learning the position of any higher-level particle; cancel the learning of the global optimal particle position of the same generation instead of learning the historical individual particle position; learning factor Imitate the way the hen learns in the CSO algorithm. This measure aims to enhance the exchange of information between individual particles and improve their overall search ability.

2.3. Fuzzy PID Control Principle

(1) Principle of fuzzy logic control

Fuzzy control is based on the fuzzy set theory, and the fuzzy set theory is applied to the fuzzy control theory formed by automatic control. The fuzzy control method is a kind of natural control method. It is a kind of nonlinear control, which is based on fuzzy linguistic variables, fuzzy logic reasoning and fuzzy set theory. Fuzzy control is mainly to imitate the way people think, especially in the calculation of control to imitate the way people think, thus, more adapt to more complex systems. It is based on the fuzzy information of the parameter, does not need the exact value of the parameter, but is fuzzified by the variable, according to a certain fuzzy rule, and then the process of defuzzification, and finally outputs a specific control amount, which is controlled by the principle block diagram is shown in Figure 1.

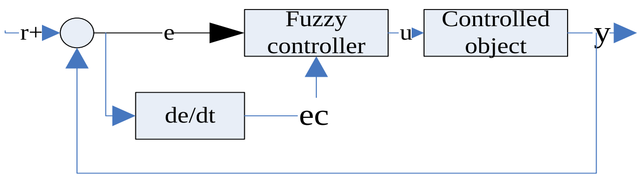

Figure 1. Schematic diagram of the fuzzy controller

The fuzzy controller in the above figure is composed of fuzzification, fuzzy reasoning and defuzzification. In general, the fuzzy process is a process in which the input content matches the knowledge base content, so that the membership of the input content in the knowledge base is also determined. In other words, the input and output are matched according to the affiliation.

The knowledge base of the fuzzy controller is mainly composed of control rules. The ultimate goal is to form a relatively complete rule base and make it realistic. In fuzzy control, fuzzy rules are the main content and play a key role. The contents of the rule base are given in cluster rules or rectangles, and the input information is assigned to different membership sets via if-then control rules. Finally, through the reasoning of the control rules, the fuzzy control result set is obtained, and the fuzzy process is used to make the result clear and processed for the controlled object. The detailed schematic diagram of the fuzzy controller is shown in Figure 2.

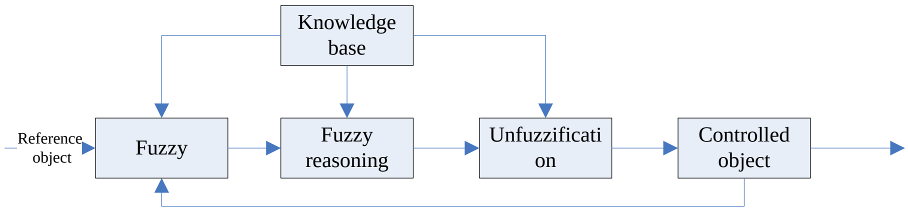

Figure 2. Internal block diagram of the fuzzy controller

(2) Determination of fuzzy subset domain

In the fuzzy controller, the domain of E is usually defined as $\{-m,-m+1,\ldots,-1,0,1,\ldots,m-1,m\}$; the domain of EC is defined as $\{-n,-n+1,\ldots,-1,0,1,\ldots,n-1,n\}$; the domain of U is defined as $\{-l,-l+1,\ldots,-1,0,1,\ldots,l-1,l\}$. Where m, n, and l are all integers. The specific process is shown in Figure 3.

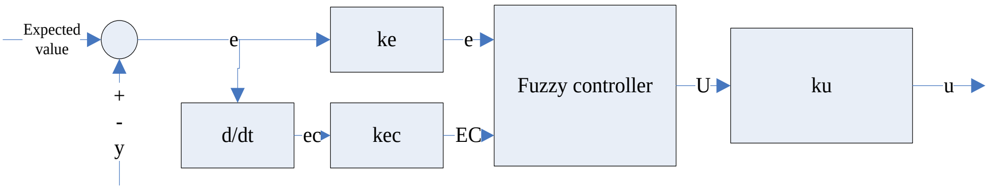

Figure 3. Blurring/clarification process

In Figure 3 above, ke and kec are quantization factors, and ku is a scaling factor. Ke=2m/(eH-eL), the error range is e=[eL, eH]. Similarly, kec=2n/(ecH-ecL), the error change rate is in the range of ec=[ecL, ecH]. Ku=(uH-uL)/2l, the control value ranges from u=[uL, uH].

$$E = \langle ke * [e - (eH + eL)/2] \rangle \quad (3)$$

$$EC = \langle kec * [ec - (ecH + ecL)/2] \rangle \quad (4)$$

Where <> represents the rounding operation.

The fuzzy output value U can be converted into a specific accurate output value u by the formula (5):

$$u = ku * U + (uH + uL)/2 \quad (5)$$

(3) Anti-fuzzification of fuzzy output variables

The final control output of the system can only be an accurate quantity, so it needs to be defuzzified, also called clearing, which is the process of fuzzification. There are two types of de-fuzzing interfaces: proportional mapping and defuzzification. There are many ways to support fuzzy quantity to precise quantity conversion. Two of them are described below.

1) Maximum membership method

Select the element with the highest degree of membership in the fuzzy set and then control this particular element. If there are multiple of this particular element, then the exact amount of control output is taken as the average of this particular element, called the maximum averaging method. For example, the conclusion of fuzzy reasoning is:

$$U = \frac{0.7}{2} + \frac{0.8}{3} + \frac{1.0}{4} + \frac{1.2}{5} + \frac{1.4}{6} + \frac{1.1}{7} \tag{6}$$

According to the principle described above, take the control amount:

$$u^* = 6 \tag{7}$$

This method is simple, and is more suitable for the control accuracy that is not required. The method does not need to contain too much information, but it can be used easily, and the occasion where the control precision is relatively high is not ideal or even fails.

2) Center of gravity

The membership function and the selected domain are combined into a geometric figure, wherein the value calculated by the center of gravity of the geometric area is equivalent to the value we need to control, which is also a mathematically weighted average, in other words, the degree of membership. The center of gravity method expresses different forms for different variables, and presents different forms for continuous variables and discrete variables. The continuous variables are as follows:

$$u = \frac{\int_{MIN}^{MAX} u\mu(u)du}{\int_{MIN}^{MAX} \mu(u)du} \tag{8}$$

The discrete variables are as follows:

$$u = \frac{\sum_{i=1}^{p} u_i \mu(u_i)}{\sum_{i=1}^{p} \mu(u_i)} \tag{9}$$

(4) Conventional PID control

The conventional PID requires only one input, and the deviation ratio (Kp), integral (Ki), and derivative (Kd) are adjusted. The linear combination is a control amount to achieve the required control of the controlled object. The selection of the three parameters Kp, Ki, and Kd directly affects the effect. In the conventional PID control, the ideal PID controller can determine the control deviation e(t) according to the reference value r(t) and the actually obtained output value y(t), and the expression is as shown in the formula (10):

$$e(t) = r(t) - y(t) \tag{10}$$

By linearly integrating the deviation signal e(t), the proportional, integral and differential are changed into a control quantity, and the controlled object is more conveniently controlled. The expression of the linear combination is shown in formula (11).

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{de(t)}{dt} \right] \tag{11}$$

3. Experiments

3.1. Experimental Setup and Data Collection

The system selected lead-acid battery is a silicon energy deep cycle power battery, model is 12V22Ah/10hr. In order to prevent overcharging of the battery, the charging protection design is carried out in the single-chip microcomputer program, and the maximum voltage of the battery is set, and the charging state of the battery is determined according to the charging voltage value of the collecting battery. Because the rated power of the photovoltaic panel used in the experiment is relatively small, in order to have obvious experimental results, it is necessary to select the test when the illumination is strong. The test condition is that the illumination intensity is 1500 w/m 2 and the temperature is about 32 °C. The main experimental equipment of the photovoltaic controller is: a 50W photovoltaic panel, a photovoltaic MPPT controller, 4 12V battery series, temperature sensor, universal meter, oscilloscope and a computer. In order to prevent the battery from overcharging, the battery is discharged by the equalization discharge method, and the voltage at both ends of the battery emptied state is 31.25V. The battery charging waveform and voltage waveform under the control of the photovoltaic MPPT are displayed by an oscilloscope. The OLED display on the PV controller displays the PV output voltage, the PV output power value and the voltage value of the battery input. The battery charging characteristic curve can also indicate that the battery terminal voltage can be charged under the control of the photovoltaic controller to complete the power-off in time to prevent the battery from overcharging.

3.2. IPSO Algorithm Optimization Steps

The IPSO algorithm optimization process is shown in Figure 4. The main steps are as follows:

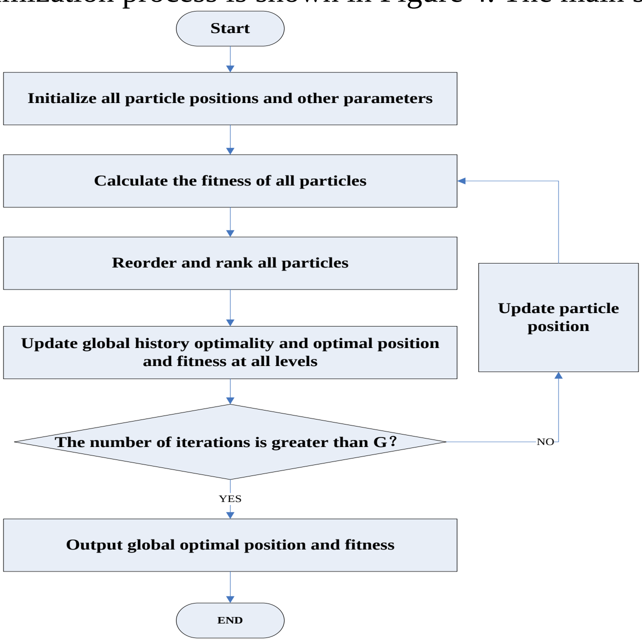

Figure 4. Schematic of improved particle swarm optimization algorithm

Step 1: Initialize the position of all the individual particles and the number of iterations G, the maximum value of the inertia coefficient w-max and the minimum value w-min.

Step 2: Substituting individual particle positions into the fitness function Fit to calculate the corresponding fitness value.

Step 3: Sort all the individual particles according to the fitness value. The better the fitness, the higher the serial number. All particles are divided into 3 levels according to the order of the individual particles. The better the fitness of the individual particles, the higher the level. Record the position and fitness of the individual particles with the best fitness in each level.

Step 4: Determine whether the number of iterations reaches the upper limit value G. If yes, go to step (6), if no, go to the next step.

Step 5: Update the position of all particle individuals according to formula (2), and judge whether the position of the generated new particle individual meets the specified range. If not, re-randomly generate a particle individual to replace it. Go to step (2).

Step 6: Output the finally obtained global optimal particle position $pgbest^G$ and global optimal fitness fit_{gbest}^G.

4. Discussion

4.1. Fuzzy PID Control Performance Analysis

(1) Comparative analysis of various controllers

In order to prove the effectiveness of the photovoltaic controller of this design, the controller under study is compared with other photovoltaic controllers. For the SS4820A solar controller, SC4830A solar controller and fuzzy MPPT controller, the self-made improved MPPT controller was used for MPPT comparative analysis. The test conditions were selected to be an illumination intensity of 1500 w/m ^{2} and a temperature of about 32 $^\circ$C. The output power characteristic curve of the photovoltaic power generation system is shown in Figure 5 under different controller contrast control. It can be seen that the output power of the photovoltaic cell is higher, but the overall improvement of the photovoltaic output power is not much, and the average output power is 21.5W. The output power of the fuzzy MPPT controller is 34.2W on average. Compared with the SS4820A controller and the SC4830A controller, the photovoltaic output power is increased by 8.5%. The average power output of the improved fuzzy PID control photovoltaic power generation system is 36.8W, which is 7.7% higher than that of the fuzzy MPPT controller. It shows that the improved fuzzy PID-based photovoltaic MPPT controller improves the photovoltaic cell output power.

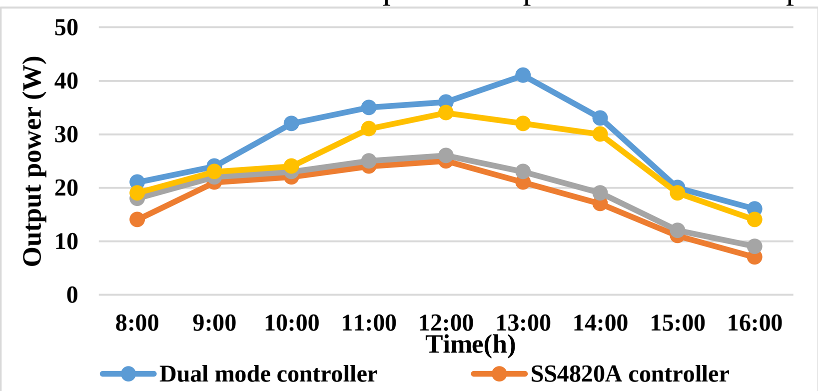

Figure 5. PV controller power output graph

(2) Comparison of MPPT simulations when the light is suddenly changed

In order to compare the tracking conditions of several methods when the light intensity is abrupt, under the standard test conditions, the light intensity suddenly drops to 1000w/m2, and decreases to 800w/m after a period of time. The simulation results of the conventional PID algorithm and the fuzzy PID control algorithm as shown in Figure 6:

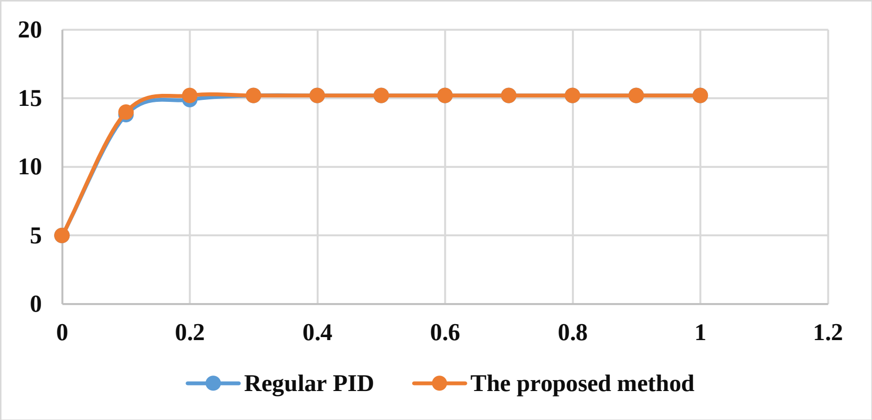

Figure 6. Simulation waveforms of different MPPT

Table 1. MPPT time under the light intensity changes

Light Intensity	Conventional PID	Fuzzy PID
600w/m^2	0.31s	0.25s
800w/m^2	0.24s	0.18s
1000w/m^2	0.19s	0.15s

4.2. Improved PSO Optimization Fuzzy PID Algorithm Performance Analysis

(1) Comparison of PSO optimized fuzzy PID step response improved in this paper

The fuzzy controller optimized by the improved PSO parameters, the fuzzy PID controller set by the empirical method and the traditional PID controller set by the engineering method are simulated and compared. The results are shown in Figure 7. It can be seen from Fig. 7 that the fuzzy PID controller optimized by PSO improved in this paper can smoothly reach the steady state in a short time when the step response occurs, and the reaction speed of the system is improved, and there is no obvious overshoot. Both dynamic and steady state performance performed well.

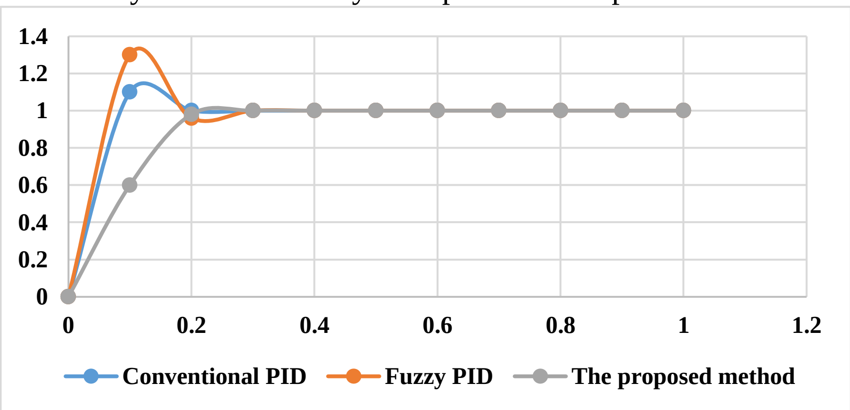

Figure 7. Step response comparison curves of three algorithms: conventional PID, fuzzy PID and PSO optimized fuzzy PID

(2) Improved PSO optimization fuzzy PID algorithm convergence curve analysis

Figure 8 shows the convergence curves of the improved PSO-PID and BP-PID. It can be seen that the BP-PID can reach the network mean square error of about 0.15 after about 30,000 iterations. The improved PSO-PID only needs to be about 1000 generations of computational iterations, the network mean square error of about 0.03 is achieved, indicating that the improved PSO-PID network converges faster than the traditional BP-PID and the network mean square error is smaller. Network processing the accuracy of the problem is higher. The results of the integrated data simulation experiment show that the improved PSO-PID network model is greatly improved compared with the traditional BP-PID model in terms of model accuracy and convergence speed.

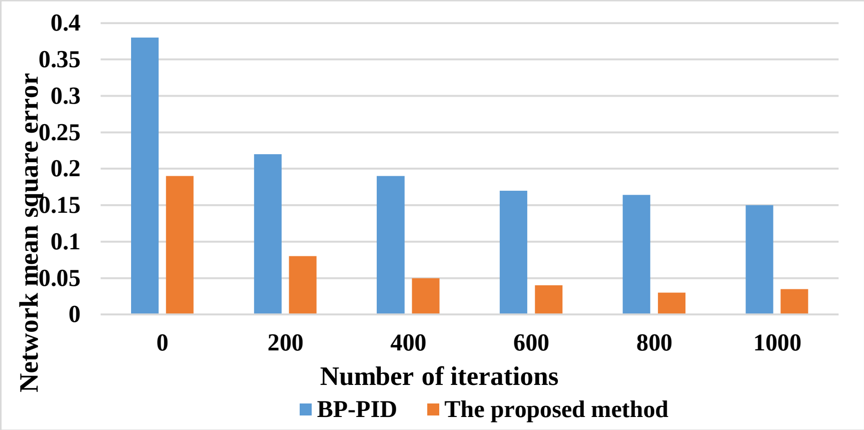

Figure 8. Improved PSO-PID and BP-PID convergence curve comparison chart

5. Conclusion

This paper introduces fuzzy PID, fuzzy control and traditional PID for object control, which shows some advantages of intelligent control over traditional. Based on this, an MPPT control based on fuzzy PID and soft switch is proposed. The fuzzy PID algorithm is written by MATLAB, and the fuzzy PID is compared with the general MPPT using simulation software. The experimental results show that in most cases, this paper proposes that MPPT control based on fuzzy PID and soft switch combination can improve the maximum power of photovoltaic system and shorten the time to reach the maximum power point to some extent.

In this paper, based on the power error and error variation as the input of the dual-mode control algorithm, the illumination intensity is introduced as the input quantity, and the illumination intensity s (n) as the input variable is the voltage value obtained by the single-chip processing, according to the voltage value. Select the appropriate control method. According to the control rules, the three quantization parameters of the fuzzy PID controller are adjusted, and the output of the Boost conversion circuit is adjusted to implement MPPT control. The photovoltaic MPPT controller processes the collected voltage and current through the single-chip microcomputer to obtain two inputs of the fuzzy PID control system. The fuzzy controller is mainly used to control the error near zero, so this paper uses the variable universe. After the fuzzification, according to the fuzzy control rule, the fuzzy control is performed and the control amount is output.

In order to realize the maximum power point tracking and solve the problem of low solar energy utilization efficiency, a fuzzy proportional-integral-derivative (referred to as PID) control method is proposed, and the particle swarm optimization algorithm is used to realize the timely updating of control parameters. The particle swarm algorithm is used to optimize the fuzzy PID parameters of the solar photovoltaic system, and the software flow of the system is improved. Simulink is used for modeling and simulation. The results show that the design improves the control effect.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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