SOLAR HEAT COLLECTION PHOTOELECTRIC TRACKING SERVO DRIVE SYSTEM BASED ON CLOUD COMPUTING

by

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In order to solve the problem of high cost and low utilization of solar power generation, the author proposed a solar heat collection photoelectric tracking servo drive system based on cloud computing. By establishing the MATLAB/SIMULINK simulation mathematical model of PID and adaptive fuzzy PID control in the core controller PLC, the authors compare and analyze the response characteristics of the tracking control system under different control strategies under the action of unit step signal and disturbance. The experimental results show that the overshoot of the adaptive fuzzy PID control algorithm is very small, almost zero, the response speed is the fastest, the transition time is the shortest, the system reaches stability at about 0.02 second. In conclusion the tracking control system of solar concentrator under adaptive fuzzy PID control not only has good tracking control accuracy, but also has the advantages of strong anti-interference ability and good stability, which greatly improves the comprehensive performance of the tracking control system of solar concentrator.

Key words*: solar concentrator tracking control system, PID control, adaptive fuzzy PID control, the simulation*

Introduction

Solar energy has huge advantages over fossil fuels, but there are still many challenges to overcome: photovoltaic power generation conversion efficiency, low economic benefits. At present, the methods to improve the utilization rate of solar energy mainly include two aspects: effective energy collection and maximum energy conversion efficiency. Traditional solar energy conversion devices usually adopt single-axis fixed tracking mode, which greatly limits the range of solar rays received by solar panels, resulting in low solar energy conversion efficiency. In order to improve the utilization efficiency of solar power generation, the design uses photoelectric detection, Sun tracking, servo control, biaxial control and other technologies to achieve accurate tracking of the Sun. The system tracks the Sun through different weather conditions, and the panels adjust to the Sun's position so that they are perpendicular to the Sun's rays.

The solar automatic tracking system combines the apparent solar orbit tracking and photoelectric tracking to solve the limitations of the traditional tracking system to a certain extent, the tracking pattern is determined by the system's judgment of weather conditions. Compared with other tracking methods, the photoelectric tracking of the system greatly improves the tracking accuracy, and the apparent orbit tracking makes up for the defects of photoelectric

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tracking that is susceptible to weather, and enables the system to cope with different weather conditions, so as to carry out all-weather tracking [1].

Literature review

The solar thermal power system mainly uses parabolic concentrator to focus and reflect the sunlight to the receiving heat collector tube, through the heat carrier in the tube to heat water into steam, and promote the steam turbine to generate electricity. It has the characteristics of large capacity, high efficiency and easy to realize standardization. In the acquisition of sunlight, in order to make the concentrator collect sunlight with maximum efficiency at all times and make the collector pipe play the maximum role, it is required that the concentrator always maintain an optimal angle with the Sun, therefore, a tracking control device must be adopted to make the concentrator track the Sun.

The efficient automatic tracking control of the concentrator can greatly improve the thermal reception rate of the system, and then improve the power generation efficiency of the solar system. Many scholars at home and abroad have done a lot of research and design work on the solar automatic tracking control system, such as Meab *et al*. [2]. A solar tracking system designed to use sensor tracking is highly sensitive, the structure design is simple, but the tracking adaptability is weak and the range is small. The Sun-looking trajectory tracking control system designed by Wang *et al*. [3] works stably with little external interference, but there is accumulated error, which cannot be eliminated by itself. The solar hybrid tracking and control system designed by Yacine [4] has been improved in tracking accuracy, range and adaptability, but it is still far from the design requirements of large disc solar power generation system. The DSP-based heliostat tracking control system designed by Jagadeesan *et al*. [5] has high tracking accuracy, accurate control algorithm and good stability performance, but the design is only for the tower solar power generation system. The PLC-based solar hybrid tracking system designed by Qi *et al*. [6] has high tracking accuracy and fast response speed, but it does not consider how to improve the comprehensive performance of the system. Therefore, for solar power systems to develop a tracking accuracy, at the same time, the concentrator tracking control system with good comprehensive performance, such as stability and anti-interference ability, is increasingly urgent.

Solar energy with its inexhaustible and environmental advantages has become one of the most promising new energy sources at home and abroad. Efficient solar energy collection is one of the key technologies of solar photovoltaic power generation, the author takes the widely used double-axis tracking servo system based on stepper motor as the research object, based on the traditional PID controller and fuzzy control theory, an adaptive fuzzy PID controller is designed, and the simulation model of azimuth tracking transmission mechanism is established in Simulink environment and the simulation is completed.

Methods

Overview of cloud computing technology

The concept of cloud technology is put forward and developed continuously under this idea. With the continuous expansion of the application scope of cloud technology, it has successfully solved many problems including network computing, utility computing, cluster technology, distributed system and so on, and has become a hot spot of social concern.

Although the rise of cloud computing as an information technology is not too long ago, but the idea has been around since the birth of the internet [7]. So in fact, the key to cloud computing is not the technology itself, but the conditions associated with cloud computing. The rapid development of computing technology makes related technologies increasingly mature, so the emergence of cloud computing technology is an inevitable choice for the development of computer technology. The concept of cloud computing has not been unified so far, from many different definitions, we summarize the concept of cloud computing It is based on the internet, in the form of services to release a variety of applications, and meet these services related hardware and software. With the continuous development of cloud computing technology, its application scope is constantly expanded, and its technological advantages are constantly reflected.

Solar concentrator tracking control system

Analysis of condenser tracking control system

The tracking accuracy of concentrator tracking control system is one of the key factors that directly affect the power generation efficiency of solar power generation system, and the accurate tracking of solar height angle and solar azimuth angle is the key to ensure the tracking accuracy of concentrator tracking control system. The Sun's altitude angle is 0° at sunrise and sunset and reaches its maximum at noon. The noontime Sun height angle reaches its highest on the summer solstice, lowest on the winter solstice, and equal on the spring and autumn equinoxes. In the summer half of the northern hemisphere the Sun rises from east to north and sets from west to north. At half the Sun rises due east and sets due west. The winter half rises from east to south and sets from west to south [8, 9]. Because the time and position of sunrise and sunset are different every day, the number of sunshine hours in the same place every day is different, and the operation situation of the Sun's altitude angle and azimuth angle is different from time to time. Therefore, the concentrator is driven by the motor and operates differently every day. After sunset, the motor should drive the concentrator to return to the initial position quickly, or the system should stop running due to the influence of bad weather and system failure, in the next startup, the system first needs to drive the concentrator by the motor to quickly locate the concentrator at the time of its normal operation, in these cases, the rotation of the concentrator needs to be realized by flexibly controlling the speed of the motor [10].

The concentrator tracking control system is affected by many external environmental factors, such as the change of seasons and the change of rainy and cloudy weather, which leads to the complex reception of solar radiation in the system, the system must be able to quickly avoid severe weather like hurricanes and hail, and there may be delays and disturbances that are unknown or difficult to measure, and the concentrator tracking control system itself is a very complex system, transmission mechanism, concentrator and heat collection device are large and heavy objects, we can't get an accurate mathematical model of it, and even if we could, it would be very crude, it cannot meet the original requirements of the design at all, which will affect the tracking performance of the system in different degrees. Although the tracking accuracy is the core problem of the whole condenser tracking control system, good comprehensive performance can ensure the accurate and effective operation of the system.

Through the analysis of a series of problems existing in the tracking control system of concentrator, it can be seen that there are still many difficulties and problems to realize the accurate tracking control of concentrator, based on this, a control system design to improve the tracking accuracy and comprehensive performance of the system is proposed.

Composition of concentrator tracking control system

Concentrator tracking control system is a key part of solar power generation system, which is generally composed of solar position positioning module (photoelectric sensor detection module, solar angle astronomical calculation module), core controller PLC module, servo driver and servo motor module, mechanical actuator module and concentrator module. The structure diagram of condenser tracking control system, fig. 1.

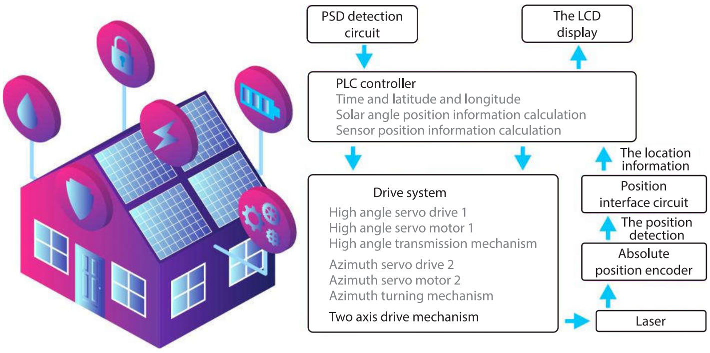

Figure 1. Structure diagram of condenser tracking control system

Control principle and tracking accuracy of concentrator tracking control system

The concentrator tracking control system adopts a hybrid tracking control method which combines open-loop tracking of the apparent Sun movement and closed-loop detection and tracking of the photoelectric sensor, it overcomes the shortcomings of the cumulative error of the apparent Sun tracking and the great influence of the sensor tracking on the weather. In the process of system operation, the system is firstly tracked by the Sun and then corrected by sensor tracking. The control flow of concentrator tracking control system, fig. 2.

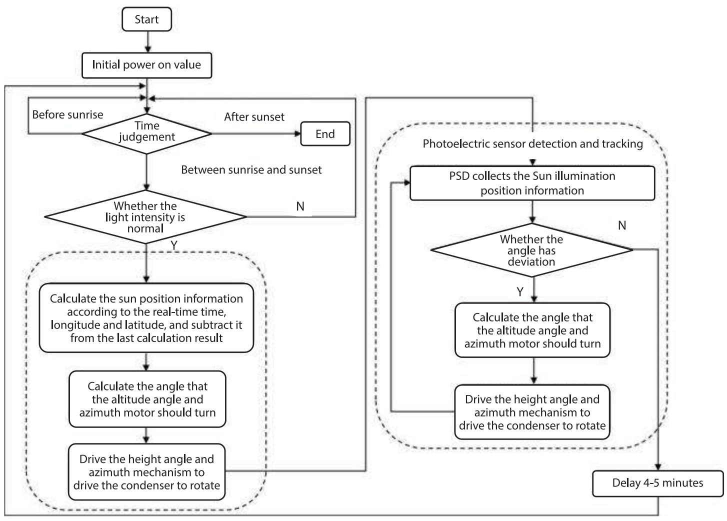

Figure 2. Control flow of condenser tracking control system

The system calculates the position of the Sun through the local time, latitude and longitude information, and drives the concentrator to rotate through the drive system. In order to ensure the accuracy of the driving system, the speed of the driving motor is measured and input to the controller, and the position of the concentrator is calculated by the encoder as a feedback quantity to form a closed-loop control. There may be errors in the speed measuring device, resulting in cumulative errors in the position feedback of the system, when the sensor finds this error, it will provide the error to the controller, the controller adjusts accordingly to the error, as long as there is a deviation signal, the tracking system continuously adjusts the concentrator's orientation until the Sun's rays are perpendicular to the concentrator. The servo motor controls the speed and acceleration of the motor by controlling the pulse frequency, so as to achieve the purpose of speed regulation. When the solar angle deviation obtained by the closed-loop system is large, PLC needs to send a high pulse frequency to the servo motor to quickly drive the concentrator rotation reduce or eliminate the angle difference. When the solar angle deviation obtained by the closed-loop system is relatively small, the pulse frequency sent by PLC to the servo motor need not be too high, in order to prevent the angle error caused by the inertia of the concentrator due to the fast speed of the motor.

The hardware composition and software control strategy design of the aforementioned system fully meet the tracking accuracy design requirements of concentrator tracking control system of 0.02°, but there is still a lot of work to be done to further improve the tracking accuracy. The concentrator tracking control system not only requires high accuracy, but also requires good stability performance during operation, and fast response speed under strong disturbance such as wind load, the system cannot only quickly return to stable state, and the original tracking accuracy of the system is not affected, which can be realized by adding control algorithm to the system. The following through the servo system model comparative analysis of PID control, adaptive fuzzy PID control algorithm on the comprehensive performance of the system, established the adaptive fuzzy PID control is more conducive to improve the comprehensive performance of the system.

Research on control strategy to improve the comprehensive performance of concentrator tracking control system

Establishment of concentrator tracking servo control system model

Figure 3 is the block diagram of the concentrator tracking control system. The given value is the solar angle value obtained from the apparent Sun tracking and sensor tracking, and the transfer functions of the power amplifier and encoder are $F(s) = K$, $H(s) = 1$, respectively. If it is an open-loop control system, errors will occur after a given value is acted upon by the system, therefore, an encoder is added to the output end of the system to form a closed-loop control, the control object is a servo motor, the regulated quantity is the output value of the motor, and the encoder realizes negative feedback.

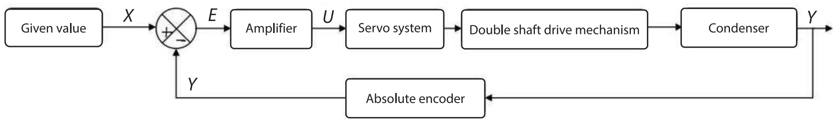

Figure 3. Block diagram of condenser tracking control system

In this servo system, the driving motor adopts the permanent magnet DC servo motor:

$$G(s) = \frac{W_a(s)}{U_a(s)} = \frac{K_t}{S^2 L_a J + (R_a J + L_a B)S + (R_a B + K_t K_v)} = \frac{\dfrac{K_t}{L_a J}}{S^2 + \left(\dfrac{R_a J + L_a B}{L_a J}\right)S + \dfrac{R_a B + K_t K_v}{L_a J}} \quad (1)$$

where $W_a(s)$ is the angular velocity of rotor rotation, $U_a(s)$ – the motor driving voltage, equivalent inductance $L_a = 2.83 \cdot 10^{-3}$H of rotor winding, equivalent resistance $R_a = 1.75\ \Omega$ of rotor winding, moment constant $K_t = 0.0924$, moment of inertia $J = 30.0 \cdot 10^{-6}$ kgm^2 of rotor and motor load, damping constant $B = 5.0 \cdot 10^{-3}$ of the whole mechanical rotation system, velocity constant $K_v = 0.093$.

According to the previous discussion, the block diagram of concentrator tracking servo control system can be easily created, fig. 4.

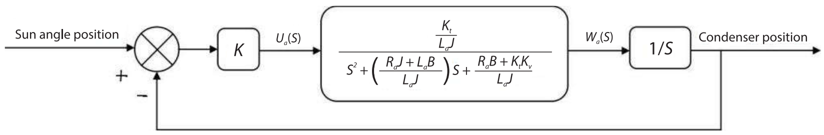

Figure 4. Control block diagram of condenser tracking control system

Traditional PID control

In the condenser tracking control system, when the value of K is too large, the transient response of the system may be poor, and the parameters of the transmission mechanism may restrict the steady-state error value of the system, *etc.*, it is obvious that such a system cannot meet the requirements, so the performance of the system needs to be improved by correcting or changing the structure of the system. In order to improve the system response to the amplifier to PID link, PID input for the solar angle deviation value, PID output for the voltage, PLC through the voltage into the pulse frequency to control the rotation of the servo motor. When the pulse frequency is very high, the motor rotates very fast, when the pulse frequency is very low, the motor rotates slowly. The proportion term is used to correct the deviation, the integral term is used to eliminate the steady-state error of the system, and the differential term is used to reduce the overshoot of the system and increase the stability of the system.

By using the stable boundary method to adjust the PID parameters:

$$K_p = 88,\ K_i = 2,\ K_d = 0.14$$

Adaptive fuzzy PID control

Traditional PID control needs accurate mathematical model, fuzzy PID is difficult to eliminate the steady-state error, and it is easy to oscillate near the equilibrium point, adaptive control will have the shortcomings of complex optimization process, large amount of calculation, slow response speed. Adaptive fuzzy PID control from the three control strategies, not only has the advantages of flexible fuzzy control and strong adaptability, it also has the characteristics of high precision PID control, but also has the advantage of adaptive control online flexible adjustment parameters. The controller can adapt to the change of the controlled object and obtain good control performance, which is a very suitable control algorithm for condenser tracking control system.

The adaptive fuzzy PID controller takes the error E and the error change rate EC as inputs, which can meet the requirements of E and EC for PID parameter self-tuning at different times, fuzzy rules are used to modify PID parameters online.

According to formula (2), K_p, K_i, K_d, K_{p1}, K_{i1}, and K_{d1} is calculated as the presetting value of K_p, K_i, and K_d obtained by conventional setting method:

$$\begin{aligned} K_p &= K_{p1} + \left\{E_k, Ec_k\right\}_p \\ K_i &= K_{i1} + \left\{E_k, Ec_k\right\}_i \\ K_d &= K_{d1} + \left\{E_k, Ec_k\right\}_d \end{aligned} \tag{2}$$

The adaptive fuzzy PID control system adopts a fuzzy PID controller with two inputs and three outputs, the error input of the controller is E, the change rate of the error is EC, the output of the controller is ΔK_p, ΔK_i, and ΔK_d, and the difference between the solar height angle given by the system and the concentrator feedback. When the deviation of the Sun's altitude angle is large, the adaptive fuzzy PID controller makes the output pulse frequency very high, and the servo motor can quickly drive the concentrator to rotate, when the deviation decreases, the adaptive fuzzy PID controller reduces the speed of the motor by reducing the pulse frequency, so that the concentrator moves to the best position, in order to improve the tracking accuracy of the system.

The discourse domain of the deviation E of height angle and the change rate of deviation EC are both {–3, –2, –1, 0, 1, 2, 3}, and the discourse domain of the output language variables ΔK_p, ΔK_i, and ΔK_d are, respectively, {0, 10, 20, 30, 40, 50, 60}, {0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2}, {0, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16, 0.18}. The input output domain of the system is divided into seven fuzzy subsets: Negative large (NB), negative medium, negative small, zero, positive small (PS), median (PM), and large (PB), the triangle function is used as the fuzzy set membership function of the language variables of the control system, according to the actual operation characteristics of the system, the appropriate fuzzy control rules and fuzzy reasoning and fuzzy resolution methods are summarized. Based on the fuzzy inference rule If A and B then C, the output C corresponding to the given input A and B can be calculated according to the fuzzy relation matrix P, namely: $C = (A \times B)^T P$. Where $(A \times B)^T$ is the $m \times n$ row vector formed by fuzzy relation matrix $(A \times B)_{m \times n}$, and T is the row vector transformation. The output information can be determined by MIN-MAX gravity center method to solve the fuzzy decision strategy, and each fuzzy control value and membership value can be obtained by off-line reasoning.

Simulation parameter value: $\Delta K_p = 85$, $\Delta K_i = 1$, and $\Delta K_d = 110$. In order to test the application of adaptive fuzzy PID control algorithm in solar concentrator tracking control system, simulation experiments are carried out and compared with proportional control and traditional PID control algorithm.

Results and discussion

When the system load is strongly disturbed by the external environment, for example, when the wind continues to act on the concentrator for a period of time, a continuous sawtooth interference signal can be added to the output of the system to simulate this situation. Assuming that the input of the system is zero, the response curve of the system under the action of sawtooth wave input signal of the disturbance link of the system is shown in fig. 5. As can be seen from fig. 5, the system error caused by the adaptive fuzzy PID control algorithm under the sawtooth wave signal disturbance is very small, close to 0, that is, the influence of the disturbance on the system can be ignored, the proportional control and PID control always have large oscillations under the interference of sawtooth wave signal. Therefore, the adaptive fuzzy PID control algorithm has better anti-interference ability than the other two algorithms, and it can quickly suppress the external interference and recover the original state of the system.

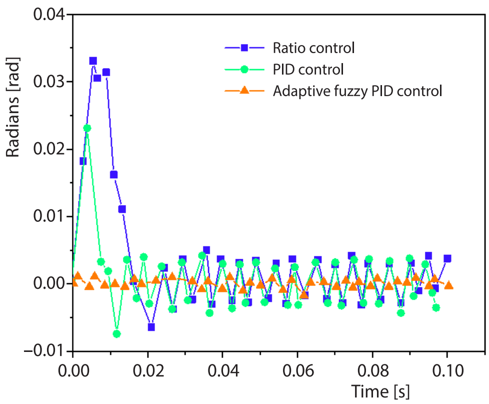

Figure 5. Simulink simulation waveform of disturbance response of the system

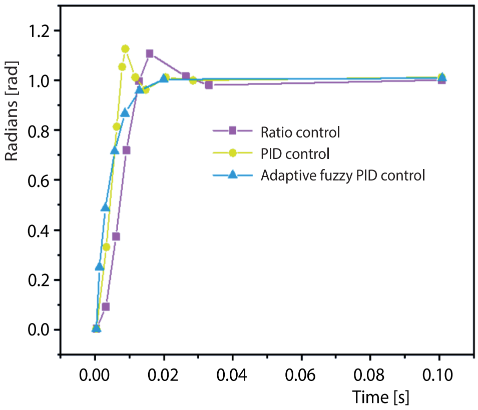

Figure 6. Simulink simulation waveform of unit step response of the system

Without considering the influence of disturbance on the system, the response curves of proportional control, PID control and adaptive fuzzy PID control of concentrator tracking control system under unit step input are shown in fig. 6. From the simulation curve, it can be seen that the steady-state error of the three algorithms is zero. The overshoot of proportional control algorithm is small, but the response speed is the slowest and the transition time is the longest, the system reaches stability at about 0.04 second. The traditional PID algorithm has the largest overshoot, medium response speed and short transition time, and the system reaches stability at about 0.036 second. The overshoot of the adaptive fuzzy PID control algorithm is very small, almost zero, the response speed is the fastest, the transition time is the shortest, the system reaches stability at about 0.02 second.

Table 1. Control effect ratio of the two control schemes

The control method	Peak	Overshoot [%]	Adjust the time [secon] (deviation 2%)	Steady-state error (absolute error)	Steady-state error [%] (relative error)
PID control	0.9995	–	0.3300	0.0005	0.05
Adaptive Fuzzy-PID Control	1.0000	–	0.2777	0	0

As shown in tab. 1, based on the aforementioned analysis and comparison, the adaptive fuzzy PID control algorithm has no obvious overshoot phenomenon, and the response speed is fast, the stabilization time is short, the adaptive ability is strong, and the stability is good, it has good dynamic and static performance and robustness, makes up for the shortcomings of traditional PID control algorithm, absorbs the advantages of fuzzy control, and can better meet the application requirements of condenser tracking control system.

Conclusion

The author proposes a solar heat collecting photoelectric tracking servo drive system based on cloud computing, as a new theory, intelligent control provides an effective way to solve the complex system process control, it has become a new research hotspot in the field of intelligent control of solar power generation. Based on the adaptive fuzzy PID control system of solar concentrator tracking control system, it does not need to establish the precise mathematical model of the controlled object, by using fuzzy control principle and fuzzy reasoning method, the PID parameters can be modified online in real time, and it has strong adaptive ability. Through MATLAB/SIMULINK simulation and experiment, the performance of the system is obviously improved by adaptive fuzzy PID control, and the effectiveness of the method for solar position tracking is verified, the adaptive fuzzy PID control can greatly reduce the overshoot and reaction time of the system, which provides a theoretical basis for further improving the speed, accuracy and stability of the concentrator tracking control system in practical application.

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