Photovoltaic Generation Solar Automatic Tracking System

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Abstract. A new solar automatic tracking system is designed in this paper. The system is a closed-loop servo system with a brushless DC servomotor and a photoelectric encoder etc. Firstly, the circuit schematic, the clock circuit, the servo driver and photoelectric encoder circuit are mainly analyzed. Then, the main program flow chart, and the time obtaining subroutine, the azimuth and elevation angle calculating subroutine and the motor drive subroutine are illustrated. Moreover, the servo system transmission mechanism is designed. It adopts a planetary reducer connected to a slewing drive. Finally, experiments results show the system can track the sun position in real time. It has high precision, low energy consumption, long life and perfect protective function etc.

1. Introduction

Because solar energy is low energy density and big randomness, light direction (elevating angle and azimuth) and intensity of sun constantly change over time [1], photovoltaic power stations usually cannot fully utilize solar radiation energy. The actual test data for 30 years (1961–1990) in Arizona showed that [2]: the radiation quantity of two-axis tracking system increased by 56% in relation to horizontal fixed installations. The research shows [3]: under the same conditions, the tracking system is applied to plate photovoltaic generation array, which increases the power generation efficiency by 33% compared to the fixed mode. The annual output of the two-axis tracking photovoltaic system can be increased by 37% to 50% relative to the fixed photovoltaic generation system with the same capacity [4]. Reference [5] designed a two-axis solar tracker with a compound tracking system. The solar tracking system is adopted in many large and medium-sized solar photovoltaic power stations in the United States, Germany, and other developed countries. In recent years, many domestic scholars have also carried out research on solar tracking system. Liu Siyang of Institute of Electrical Engineering of the Chinese Academy of Sciences designed one active two-axis solar tracking controller [6]. Reference [7] proposed one hybrid two-axis solar automatic tracking device, the first order uses program control tracking, and the second stage uses sensor tracking correction. Reference [8] uses the DSP to calculate the pulse and control the rotation angle of the stepping motor to realize the automatic tracking of the sun. Therefore, China's solar tracking device has great market potential and application prospects in the future. At present, the sun tracking systems at home and abroad mainly use stepping motor or direct-current machine to drive, the transmission mechanism uses ordinary reducers, moreover, generally there is no angular transducer, which belongs to open-loop control system, and the precision is low. The precision of the domestic solar tracking device is
generally about 5°, and the energy consumption is 5% of the generated energy of the driven photovoltaic array.

In allusion to the shortcomings of domestic solar tracking systems, for example, small tracking range, low precision, single function, high power consumption and poor practicality of the project and so on, a solar two-axis tracking system with high precision and low energy consumption is designed in this paper. First of all, the hardware circuit design of the tracking system is analyzed, which mainly includes circuit schematic diagram, clock circuit, servo driver and photoelectric encoder circuit. Then, the software part is analyzed; the main program flow chart, time reading subprogram, azimuth and elevating angle calculation program, and motor driver program are explained, respectively. Then, the design of the servo system drive mechanism is introduced. Finally, the system's actual debugging experiment is carried out.

2. Overall Design of Automatic Tracking System

The overall design structure of the automatic tracking system is shown in Fig.1. The tracking system belongs to a two-axis turntable system and mainly includes azimuth axis servo system and height axis servo system. The system mainly includes solar photovoltaic array and its bracket, left support frame, right support frame, installation column, azimuth axis servo system, height axis servo system, time acquisition module, display module, light intensity sensor, wind speed sensor and so on. The solar photovoltaic array and its bracket are connected with the height rotation reducer through left and right support frames. The combined rotation reducer is connected to the installation column. Through the height axis servo system and the azimuth axis servo system, respectively, the system adopts dual axis linkage method to adjust the elevating angle and azimuth of the photovoltaic array, so as to automatically track the elevating angle and azimuth of the sun.

![Figure 1. Overall design structure drawing of tracking system](image)

The photoelectric encoder is the feedback component of the servo system, which can measure the rotary angle of the photovoltaic array in real time, output A, B and Z three-phase pulses, the signals of elevating angle and azimuth are sent to the microcontrollers, thus forming a closed-loop control. The pulse capture port of the microcontroller counts the A-phase or B-phase pulses, and compares with the PWM pulses of the azimuth and elevating angles calculated by the program, until the two are equal, the control motor stops and ensure photovoltaic array accurately track position of the sun.

In actual use, in order to protect the safety of photovoltaic generation array, wind speed sensor is added to the system to measure the wind speed. Once the wind speed has reached the limit set by the
microcontroller, the microcontroller will send a reset signal, so that the photovoltaic panels move to a horizontal position to achieve protection.

In the rainy weather, the intensity of the sun's rays is not suitable for power generation; the output voltage of the light intensity sensor is lower than the set value, at this time, the microcontroller will shut down the motor driver and the microcontroller will enter into a sleep state to reduce energy consumption.

3. Hardware Circuit Design of Tracking System

Hardware circuit is the core part of the system. The functions are mainly to complete the control of the servo driver, acquisition and display of the time, the acquisition of the photoelectric encoder signal, the measurement of the wind speed and the light intensity, and the response of the zero position switches and the limit switch signal and so on. The hardware circuit mainly includes: 9S12XS128 microcontroller, servo driver, DS12C887 digital clock chip, 1602 liquid crystal display module wind speed sensor, light intensity sensor, encoder circuit, limit switch circuit and so on.

3.1. Clock circuit design

In figure 2, the data output terminals AD0 to AD7 of the clock chip DS12C887 are connected to the general-purpose IO port PA of the microcontroller. AD0 to AD7 are reusing address data buses. In the first half of the bus cycle, address information appears on AD0 to AD7, and the latter half of the bus cycle is data information.

Only cooperated with the chip select signal CS, mode selection signal MOT, read/write signal RW, address gating signal AS, data selection signal DS and interrupt request input signal IRQ, etc., DS12C887 can correctly output the time information to the microcontroller.

3.2. Servo drives and photoelectric encoder circuits

The control method of this solar automatic tracking system is: the pulse control mode of the servo driver is used; the frequency of the PWM wave is used to control the rotation speed of the motor; and the high and low electrical levels is used to control the steering of the motor. The servo driver uses differential interface circuit, the system uses a common-cathode circuit. The interface of the driver and the microcontroller is shown in Figure 3.

The 1 and 2 pin of the socket CON8 are used to receive the pulse signals sent from the height and azimuth photoelectric encoders, respectively in Figure 3. The signal output from the encoder is sent the PT2 and PT3 pulse catchers of the microcontroller for counting through the interface. The rest 3-8 pin are used to control the rotation and height, the speed, steering and enable of the servo motor, respectively. PUL: PWM output port; EN: enable port; DIR: direction port. The current-limiting...
resistance R2 and R8 are connected between the CON8 interface and the microcontroller to reduce the attenuation of the square wave signal output by the encoder from the port of the microcontroller.

4.软件系统设计

4.1. 时间读取子程序

该子程序的主要功能是为系统提供一个时间信息，用于计算指定光伏板的仰角和方位角。首先，通过软件设置DS12C887的寄存器，然后在主程序中调用DS12C887的时间读取子程序。DS12C887的编程关键是正确地读写它。根据写入序列图和读取序列图，编写了DS12C887子程序的写入函数void write_ds(uchar add, uchar date)和读取函数uchar read_ds(uchar add)，分别用于写入和读取。

读写子程序完成后，芯片的寄存器可以设置。设置寄存器的过程是将对应的数据写入对应寄存器的地址。只要寄存器被设置，就可以写入读取时间数据的功能。图4显示了时间读取子程序的流程图。

图4. 时间读取子程序流程图 图5. 跟踪系统结构图

此功能可以直接在主程序中调用，获取如世纪、年、月、日、时、分、秒等参数。

4.2. 仰角和方位角计算程序

太阳仰角的计算公式为:

$$GD = \frac{\sin(\sin(La \cdot \pi /180) \cdot \sin(CW \cdot \pi /180) \cdot \cos(La \cdot \pi /180) \cdot \cos(CW \cdot \pi /180) - \cos(SJ \cdot \pi /180))}{180 / \pi}$$

(1)

太阳方位角的计算公式为：

$$
GD = \frac{\sin(\sin(La \cdot \pi /180) \cdot \sin(CW \cdot \pi /180) \cdot \cos(La \cdot \pi /180) \cdot \cos(CW \cdot \pi /180) - \cos(SJ \cdot \pi /180))}{180 / \pi}
$$
FW = asin(sin(SJ \cdot PI / 180) \cdot cos(CW \cdot PI / 180) / cos(GD \cdot PI / 180)) \cdot 180 / PI \tag{2}

Among them: PI = 3.1415926, La is the latitude of the installation location of the photovoltaic array, CW: the declination angle of the sun, SJ: the hour angle of the sun.

4.3. Motor drivers
First of all, the PWM wave output by microcontrollers is sent to the servo driver, then, the servo driver outputs the corresponding A, B, C three-phase square wave signal in accordance with the frequency of PWM wave and other control signals, thus driving the brushless DC servo motor to rotate.

In combination with the parameters of the motor, the parameters of the PWM program are designed as follows: PWM frequency is 25KHz, amplitude is 5V, duty cycle is 50%, left justifying, and SA is used as the clock source.

5. Transmission Mechanism Design of Servo System
In general, domestic solar tracking devices all use DC motors or stepping motors as driving elements at present, and the transmission mechanism adopts common reducers and precision is low. At the same time, there is brush wear phenomenon in DC motor and the brush need to be replaced frequently. Stepping motor may fall out step, and the control precision is affected. Brushless DC motors use electronic commutation replaces mechanical commutation devices, and it not only has the advantages of small size, high efficiency, long life, and high control precision and so on. Therefore, this solar automatic tracking system uses brushless DC servo motor as drive element. The tracking system's angular and azimuth axis servo systems all use a planetary reducer to connect the transmission structure of the slewing reducer.

The transmission mechanism of servo system adopts the two-axis linkage mode; the schematic diagram of the automatic tracking system is shown in Figure 5 [5]. The column 1 supports the entire track panel as a support component in Figure. 5. The combined rotary reducer 3 adopts a anchor ring enveloping worm gear structure, amplify the drive torque of brushless DC servo motor 2 with planetary reducer, drive support frame 4, make the photovoltaic panel 5 achieve rotation in position and height direction. In addition, there are two limit switches 7 and 8 along the elevating angle, prevent photovoltaic panel from exceeding the limit to crash the body and cause danger, The coordinates of photovoltaic panel are set up by the original point switch 6 and 9. Before each work, the tracking system is automatically start to zero, and the position and coordinate relationship between the photovoltaic panel of tracking system and the sun's angle are established.

A combined rotary reducer with planar enveloping hourglass worm gear is adopted in the system. Because the enveloping hourglass worm gear is multi tooth contact at the same time, it has the average error effect and further improves the precision. Moreover, this transmission is easy to establish dynamic oil film, small friction coefficient and high transmission efficiency, which can increase 10-15% transmission efficiency and save energy. The combined rotary reducer can also be applied to the design of two-axis turntable and radar antenna servo system.

The reduction ratio of the rotary speed reducer of this system is $i_2=62$, the main parameters are as follows: (1) rated output speed: <3.0 rpm; (2) rated output torque: 400 Nm; (3) maximum torque: 500 Nm; (4) Axial load: 30kN; (5) Radial load: 15kN.

Therefore, the total transmission ratio of transmission mechanism of servo system transmission is $i=i_1 \times i_2=18600$.

The low-speed stability of the brushless DC servo motor is relatively poor, and it is prone to speed fluctuations. Therefore, the entire transmission mechanism must adopt a large gear ratio to increase the working speed and transmission precision of the servo motor. In addition, the large transmission ratio reduces the rotational inertia of the transmission mechanism and can achieve final motion, which is conducive to the real-time adjustment of the tracking board and accurate positioning. Two servo systems use transmission mechanisms with a large reduction ratio, which significantly reduces the
rotational inertia of the solar photovoltaic array, the motor with a very low power can drive the rotation of the solar photovoltaic array.

6. Actual Debugging Experiment of System

6.1. Time reading debugging

The debugging is divided into two steps: First, the time set for the DS12C887 is carried out, after setting the register, connect the control board and the computer, start the program in the microcontroller development environment, if the program runs normally, the value of the time register in the operating environment can be observed, this is the setting content. For example: the displayed content is shown in Figure.7

![The actual debugging effect diagram of the system](image)

**Figure 6.** The actual debugging effect diagram of the system

| variable       | type   |
|----------------|--------|
| time_century   | 20     |
| time_year      | 13     |
| time_month     | 10     |
| time_date      | 27     |
| time_week      | 7      |
| time_hour      | 9      |
| time_minute    | 50     |
| time_second    | 0      |

**Figure 7.** Operation diagram of time register

6.2. Calibrations of height axis and azimuth servo systems

The calibration method azimuth servo system is: first, rotate the azimuth of the tracking system to one side of the limit switch and as a starting point; then drive the motor rotates 360°, when touch the limit switch again, the motor automatically stops, at this time, read the total number of pulses input by the encoder, then compare with theoretically calculated encoder pulse values, the error can be found. The calibration of the height axis is the same as that of the azimuth axis. The initial horizontal position of the rotation is determined by the high-precision level meter.

Theoretically, the reduction rate of the mechanical transmission mechanism of servo system is 18600:1, the actual measured rotation error of azimuth axis is 0.015°, and the rotation error of height axis is 0.0131°, which can meet the design requirements. The actual debugging effect of the system is shown in Figure.6.

The experiments show that the photovoltaic solar tracking system can track the position of the sun in real time, the precision≤0.1, energy consumption is only 1% of the generated energy of the driven photovoltaic array, and has a long life and a perfect protection function and so on.
7. Conclusion
A new type of two-axis solar tracking system is designed in this paper; brushless DC servo motor and photoelectric encoder and so on constitute the sun tracking closed-loop servo system, which improves the tracking precision and reliability of the system. The high-performance 9S12XS128 series microcontroller is adopted as the core controller to simplify the design of the circuit and increases the performance-price ratio of the system. The brushless DC motor is used as an actuator, which has the advantage of long life. The transmission mechanism adopts a planetary reducer to connect the rotary reducer, which has high precision and large upsetting moment. The reduction ratio of transmission chain is large and the energy consumption ratio is 1%. The protection function of system is perfect; it can detect rainy weather and wind force, and implement corresponding protection and control for photovoltaic panels. This system has important engineering application value and good market prospects. The hardware, software and transmission mechanism design of this tracking system also have important reference value and reference significance for the design of two-axis turntable, photoelectric platform and tracking radar servo system.

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