The Design of Off-grid Home Photovoltaic Power Generation System Considering Multi-weather Conditions

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Abstract. In the traditional fixed-installed off-grid photovoltaic power generation system, there are disadvantages such as insufficient solar energy collection and low solar energy utilization. In order to be able to effectively develop and utilize solar energy, the method of solar position tracking is generally used. In this paper, a single-chip microcomputer is selected as the main control chip, and a photovoltaic power generation system that combines two methods of photoelectric tracking and computational solar tracking and takes into account various meteorological factors is realized. The latitude and longitude information and time information collected by the single-chip microcomputer are used to calculate the sun position, and the photoelectric position is used to monitor the sun position. The design can automatically change the tracking scheme according to the weather conditions, so that the tracking system can run stably under various weather conditions.

1. Introduction:
At present, the world is facing a crisis of energy depletion. In order to cope with the massive reduction of non-renewable energy, more and more people are turning their attention to renewable clean energy. Because of this, solar energy has become one of the most widely used clean energy sources with its abundant resources.

The main way to use solar energy is to convert it into electricity through photovoltaic panels. The installation of solar photovoltaic panels can be divided into fixed and tracking. The tracking type can accurately point to the position of the sun and improve the efficiency of solar energy utilization, which has been more and more widely used. This paper focuses on the analysis of the tracking installation mode and optimizes its control scheme under various meteorological conditions.

2. Composition and principle of home off-grid photovoltaic power generation system
Off-grid home solar photovoltaic power generation systems are generally used in remote mountainous areas and other regions with insufficient power supply. This system effectively solves the problem of insufficient power supply in remote areas.

This system is mainly composed of solar photovoltaic panel and its control equipment, charge and discharge controllers, battery packs, inverters, AC loads and DC loads. During the working process, the solar photovoltaic panel uses the photovoltaic effect to complete the conversion of light energy to electrical energy as the energy source of the entire system; The electrical energy converted by the solar photovoltaic panel is direct current, part of which is directly supplied to the use of DC load, and the other part is converted into AC power for the use of AC loads. The battery is mainly used to store...
electrical energy. When the power generated is less than the power used, the stored power is used to power the load.

3. Calculation method of the sun position

There are two main methods for tracking the position of the sun. One is to use the photoelectric sensor to obtain the position of the sun, and the other is to use the geometric method to calculate the specific position of the sun by obtaining the local time, longitude, and latitude\cite{1}. We analyze the second method.

In astronomy, the sun's altitude (0 ° -90 ° ) and azimuth (0 ° -360 ° ) are used to uniquely describe the position of the sun. Where the height angle is the included angle between the direct sunlight rays and the ground plane, and the azimuth angle is the included angle between the projection line of the direct sunlight rays on the ground plane and the due north.

The following formulas are used to calculate the sun height angle and the sun azimuth angle.

\[
\sin \theta = \sin \alpha \sin \delta + \cos \alpha \cos \delta \cos \omega \]

\[
\cos \phi = \frac{-\sin \delta \cos \alpha + \cos \delta \cos t}{\cos \theta}
\]

In the formula, \( \theta \) is the sun height angle, \( \phi \) is the sun azimuth angle, \( \alpha \) is the local geographic latitude, \( \delta \) is the local sun declination angle, and \( \omega \) is the solar hour angle.

The declination angle can be calculated according to the following formula:

\[
\delta = 0.3723 + 23.2567 \sin \gamma + 0.1149 \sin 2\gamma - 0.1712 \sin 3\gamma - 0.758 \cos \gamma + 0.3656 \cos 2\gamma + 0.0201 \cos 3\gamma
\]

Here \( \gamma \) is the angle of the sun and the calculation formula for \( \gamma \) is shown below.

\[
\gamma = \frac{2\pi N'}{365.2422}
\]

\( N' = N - N_0 \), where \( N \) is the accumulated day, which is the date number from January 1 of the same year.

\( N_0 = 79.6764 + 0.2422 (\text{year} - 1985) - \lfloor (\text{year} - 1985) / 4 \rfloor, \) and \( \lfloor (\text{year} - 1985) / 4 \rfloor \) is the largest integer not greater than \( (\text{year} - 1985) / 4 \).

\( \omega \) is the solar hour angle, and the formula is \( \omega = 15(t_s - 12) \), where \( t_s \) is the solar hour, and the unit is hour. When the sun is at the zenith, the true solar time is 12 o'clock. At this time, the solar hour angle \( \omega \) is zero.

According to the above formula, the sunrise and sunset time of each day can be calculated. When sunrise and sunset, the sun height angle \( \theta \) is 0. At this time:

\[
\sin \alpha \sin \delta + \cos \alpha \cos \delta \cos \omega = 0
\]

In this way, the expression of \( \omega \) can be obtained as:

\[
\omega = -\frac{\sin \alpha \sin \delta}{\cos \alpha \cos \delta} = -\tan \alpha \tan \delta
\]

According to the relationship between \( \omega \) and \( t \), we can get the expression of sunrise time and sunset time as:

\[
t = -\frac{\tan \alpha \tan \delta}{15} + 12
\]

Through the above analysis, we can know that when the time, longitude, latitude and other information are obtained, the position of the sun can be uniquely determined\cite{2}.

In order to verify the above scheme, we use the above calculation method to calculate the solar position in Beijing (116 ° 25′E, 39 ° 55′N) for one day, and perform the actual situation with astronomical observations. By comparison, we get the following data:
Table 1. The calculated value and the real value

| Time | Calculated(Sun height angle) | Actual(Sun height angle) | Calculated(Sun azimuth angle) | Actual(Sun azimuth angle) |
|------|-----------------------------|--------------------------|-------------------------------|---------------------------|
| 7:00 | -3.15                       | -3.09                    | 105.94                        | 105.88                    |
| 8:00 | 7.61                        | 7.76                     | 115.74                        | 115.69                    |
| 9:00 | 17.40                       | 17.28                    | 126.70                        | 126.68                    |
| 10:00| 25.80                       | 25.87                    | 139.46                        | 139.52                    |
| 11:00| 32.09                       | 32.07                    | 154.46                        | 154.39                    |
| 12:00| 35.48                       | 35.44                    | 171.49                        | 171.56                    |
| 13:00| 35.41                       | 35.34                    | 189.35                        | 189.35                    |
| 14:00| 31.89                       | 31.92                    | 206.32                        | 206.33                    |
| 15:00| 25.50                       | 25.42                    | 221.22                        | 221.29                    |
| 16:00| 17.03                       | 17.08                    | 233.91                        | 233.86                    |
| 17:00| 7.21                        | 7.15                     | 244.83                        | 244.86                    |

The calculated value is very close to the actual value, and the relative error curves between the calculated value and the actual value of the solar height angle and solar azimuth angle are made using Matlab, as shown in the figure below:

![Figure 1. The error between the calculated value and the actual value](image)

The error between the calculated value and the actual value is very small, so it can be considered that the position of the sun obtained by calculating the longitude, latitude and time parameters can well describe the true position of the sun.

4. Tracking scheme under multi-meteorological conditions

Although the method of directly calculating the solar position using geographical location data can effectively avoid the impact of extreme weather, compared to the method of tracking using sensors, the method of calculating the solar position using geographical location information can hardly eliminate the cumulative tracking error. At the same time, it is not possible to make flexible countermeasures according to the corresponding weather conditions, so the sensorless tracking method still cannot completely replace the sensor tracking method[3,4]. In order to be able to focus on the advantages of these two methods, and use them for collaborative control, we mainly analyze the control relationship between the solar position tracking scheme using sensors and the meteorological conditions.

Firstly, we divided weather conditions into three categories, and used different tracking schemes for these three categories of different weather conditions[5].

The best weather conditions are clear and no wind or clear and weak wind. In such conditions, we choose to directly use the photoelectric sensor for tracking. In addition, for cloudy weather, when the
sun is blocked by clouds, we adopt sensorless tracking mode. When the sun appears, we adopt photoelectric sensor tracking mode. For extreme weather such as high wind, heavy rain and heavy snow, in order to ensure the safety of the system, the photovoltaic panels are retracted and the inclination Angle of the photovoltaic panels and the roof is the same.

Figure 2. Meteorological conditions and control program

5. Design of tracking system based on single chip microcomputer

Based on the above analysis, we use a single-chip microcomputer as the main control chip to track the position of the sun. The system structure diagram is shown below:

Figure 3. Control structure of solar tracking system

Among them, the weather sensor is composed of various sensors, including a temperature sensor, a humidity sensor, a wind speed and direction sensor, a rainfall sensor, and an atmospheric pressure sensor.

Manual calibration refers to the need to manually enter the angle parameter of the roof during the erection of the system in order to meet the conditions of use of various buildings. In extreme weather conditions, the system can automatically make the solar panels parallel to the roof. Due to the problems of anti-interference ability and accuracy of the two main solar tracking schemes. The program flow chart is as follows:
6. Conclusion
Due to the problems of anti-interference ability and accuracy of the two main solar tracking schemes, this paper designs a two-way solar tracking system adapted to all weather conditions. The tracking system has a simple structure, adopts a combination of open-loop control and closed-loop control, has strong stability, is suitable for various environments, can greatly alleviate the problem of difficult power supply in remote areas, and has certain promotion value.

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