Design and Implementation of a Sun Tracking System for Cost Effective PV Power Generation *

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Abstract: It is of crucial importance for PV power generation systems to work at efficiency conditions and to maximum the electrical power output by using a sun tracking system. A novel approach using two photocells placed in a wedge shaped form as a new tracking sensor is studied and tested. The power loss caused by over long time tracking can be reduced, and the energy conversion efficiency of photovoltaic can be improved. The control and mechanism is very simple, which can reduce the cost and make the implementation easily.

Key words: polar axis tracking system; solar energy; conversion efficiency
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1 Introduction

A Sun-tracking mechanism increases the amount of solar energy that can be received by the solar photovoltaic cells. The use of a tracking system is more expensive and more complex than fixed installations. How to design a cost-effective device and provide more power output become a hot spot in research as well as in commercial markets.

The sun tracking systems can be categorized into two types: one uses sensors for active tracking, and the other uses clock circuit for real time sun movement respect to the earth. The main problems in the former is lacking of mature solar-position sensors, disturbed strongly by the suns intensity varying greatly under the random factors, as well as week in systematically robustness, and so on. The latter is simple of the control algorithm and stable of the system but lack of agility. The tracking rule, design, algorithm and practical implementation are discussed from the aspect of intelligent tracking using sensors in this paper.

2 Choice of sensors and design of position detector

Silicon photocells are selected as sensitive component for the sun tracking system as it is to be exposed to the sun in consideration of the factors for sunlight endurance and sunlight sensitivity.

Two exactly same silicon photocells are placed with an angle of α (Fig. 1), construct a two-output system with a parallel resistance for each photocell. The outputs of each cell are equal when the sunlight irradiates in parallel with the internal bisector of α. The outputs will not be equal when the incident light diverges from the balanced position. The different output can be used to discriminate the sun's position in the system. However, it may still be disturbed by the existence of unstable diffusion or reflection light in practical situations.

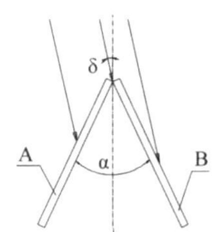

Fig. 1 Schematic layout of the main sensor components

Suppose U_1 is the corresponding power signal on the photocell caused by the direct solar radiation, and U_2 caused by the diffuse light. The angle of the two photocells is defined as α, and the angle between the sunlight and the internal bisector of the α as δ, thus the angles between the sunlight and the two photocells are $\delta + \alpha/2$ and $\delta - \alpha/2$ respectively.

First, consider $0 \leqslant \delta \leqslant \alpha/2$.

The signal on the photocell A is:

$$Y_A = U_1 \sin(\delta + \alpha/2) + U_A \qquad (1)$$

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The signal on the photocell B is

$$Y_B = U_1 \sin(\alpha/2 - \delta) + U_{1B} \qquad (2)$$

The two situations ($\delta > \alpha/2$ and $\delta < -\alpha/2$) are symmetrical, in which only one photocell has the direct solar radiation. Only one situation ($\delta > \alpha/2$) will be discussed as follow.

The signal on the photocell A is:

$$Y_A = U_1 \sin(\delta + \alpha/2) + U_{1A} \qquad (3)$$

The signal on the photocell B is:

$$Y_B = U_{1B} \qquad (4)$$

They are amplified with a gain by the ratio K in differential form as follow equations:

$$Y_z = Y_A - Y_B = 2KU_1 \sin\delta\cos(\alpha/2) + U_{1A} - U_{1B}$$
$$0 \leqslant \delta \leqslant \alpha/2 \qquad (5)$$
$$Y_z = KU_1 \sin(\delta + \alpha/2) + U_{1A} - U_{1B}$$
$$\alpha/2 \leqslant \delta \leqslant \pi - \alpha/2 \qquad (6)$$

With actual measurements at the main tracking period (from 9 am to 3 pm), little differences exist between U_{1A} and U_{2B}, so the above equations can be simplified as:

$$Y_z = Y_A - Y_B = 2KU_1 \sin\delta\cos(\alpha/2)$$
$$0 \leqslant \delta \leqslant \alpha/2 \qquad (7)$$
$$Y_z = KU_1 \sin(\delta + \alpha/2)$$
$$\alpha/2 \leqslant \delta \leqslant \pi - \alpha/2 \qquad (8)$$

It shows from the above equations that the signal caused by the diffuse reflection light at the main tracking period has been restrained.

The more the value of Y_z, the more sensitive of the sun position sensor when given a determined value for δ.

In order to keep high sensitivity and favorable increment relationship between azimuth change and the output signal, α is defined in $[\pi/4, \pi/2]$.

In the equation (1) and (2), the output signal Y_z contains the signal U_1, so the effects of the direct light intensity variation can't be eliminated by the simple differential amplifier. In order to solve the problem, two photocells (C and D) as supplement signals are used, the normal of each supplement cell is coincidence with bisector line of α. Additionally, a light barrier for direct solar radiation is placed above the photocell D. Fig. 2 shows the sketch drawing.

So, we have the following equations:

$$Y_C = U_1 + U_{2C} \qquad (9)$$
$$Y_D = U_{2D} \qquad (10)$$

The above signals are amplified with a gain by the ratio K_1 and the output signal is:

$$Y_F = K_1(U_1 + U_{2C} - U_{2D}) \qquad (11)$$

Because $U_{2C} = U_{2D}$, the above equation can be simplified as follow:

$$Y_F = K_1 U_1 \qquad (12)$$

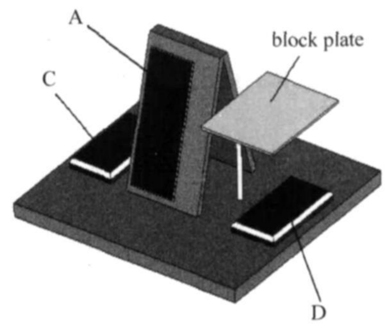

Fig. 2　Sketch drawing for the combination of main and accessory sensor components

When the signal Y_z compares with a determined threshold value M, and suppose $Y_z = M$,

$$\delta = \arcsin\frac{M}{2KU_1\cos(\alpha/2)} \qquad (13)$$

The above equation shows, δ decreases with the increment of U_1, and varies to a greater degree under various light intensities. When the signal Y_z compares with Y_F, and suppose $Y_Z = Y_F$, can be expressed:

$$\delta = \arcsin\frac{K_1}{2K\cos(\alpha/2)} \qquad (14)$$

Where δ is only determined by the factors: the main differential amplifier gain K, the secondary differential amplifier gain K_1 and the angle α, which are all given by the system. So the stability is improved greatly by this design.

All discussed above is in the case of one dimension, and another same position sensor needs to be placed on the other dimension for two-dimensional tracking.

3　Hardware and algorithm for tracking control

The main PV array power generation depends on direct sun radiation, so the value of δ has vital importance on the system. The above-discussed sensor is placed on the tracking panel with PV cells, the maximum power generate when light strikes normal to the panel is P_0. If the light strikes at an angle φ respect to the normal of the panel, the power generated by the direct radiation can be expressed:

$$P = P_0 \cos\varphi \qquad (15)$$

Considering the variation of $\cos\varphi$ in regular tracking, $\varphi < \delta$, and even $|\delta_{MAX}| = 5°$, the power generation is almost not influenced by φ. If taking δ_{MAX}, $-\delta_{MAX}$ as the maximum and minimal of the lag-back tracings algorithm, the instantaneous power obtained by the solar-powered battery board is:

$$P = P_0 \cos\varphi = P_0 \cos(5°) \approx 0.996 P_0 \qquad (16)$$

So it will not decrease the efficiency of obtaining solar energy basically.

4 Placement of PV Arrays, Prototype Mechanism and Experiment

PV arrays are combined in matrix, and each line has only one azimuth sensor and a motor. The units in the every line are connected with metal cables for synchronous tracking of the mechanism, which significantly reduce the tracking cost for the system.

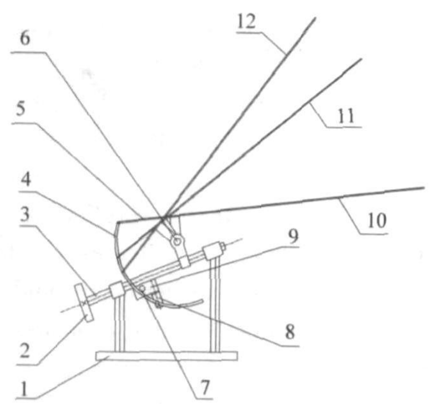

Fig.3 Sketch drawing for the electromechanical mechanism unit

Fig. 3 shows the structure configuration of the unit mechanism for which polar sun tracking is introduced. 1. strutted frame for polar axis; 2. rope sheave; 3. day tracking axis; 4. sector rack; 5. bracket for battery panel; 6. seasonal tracking axis; 7. pinion; 8. motor for seasonal tracking; 9. miniature creeper gear for seasonal tracking; 10、11、12 are the battery postures in summer, Spring and Autumn, winter in northern hemisphere.

Fig.4 shows the difference between Curve I and curve II. Curve I represents the short-circuit current of the solar panel which is placed towards north formed an angle of 30° with the ground in the manner fixed position. Curve II shows the short-circuit current of the same solar panel at the same place in the manner of polar axis tracking (Specification and type of the solar panel: TDB75－38-P, operating voltage 17 V, open circuit 21 V, and P: P20W).

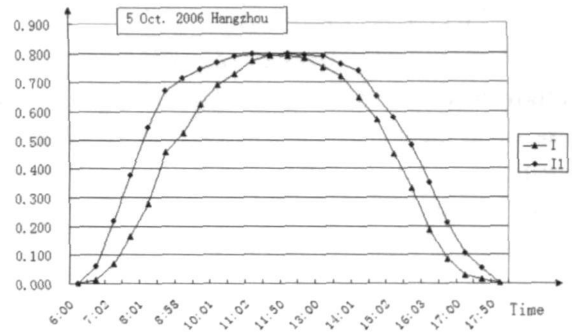

Fig.4 Experimental results of PV panel output current in fixed and in polar axis tracking implementations

5 Conclusion

The dynamic tracking system using sensors is a closed loop system having reliable and stable working characteristics in strength solar irradiations. It has been proved by the experiments that the variation of intensity of normal striking light has less influence by the tracking angle and it is reasonable to adopt large lag-back parameters in the control algorithm. The new sensor system is stable and cost effective for the tracking mechanism. Moreover, the polar axis tracking system is easy to form a matrix station and resistant to wind.

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经济型向阳跟踪 PV电站的设计与实现

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摘 要：提高光伏阵列电站的发电量和工作效率，系统实行向阳跟踪技术是关键。研制了一种新型光方位传感器，由两个布置成一定角度感光面朝外硅光电池组成，并进行实验。实验表明长时间跟踪引发的能量损失得到降低，光伏阵列电站能量转换得到改善，控制和机械装置简化，成本低应用推广方便。

关键词：极轴跟踪系统；太阳能；转换效率
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