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A multipurpose dual-axis solar tracker with two tracking strategies

Yingxue Yao [a], Yeguang Hu [b,*], Shengdong Gao [b], Gang Yang [b], Jinguang Du [b]

[a] Shenzhen Graduate School, Harbin Institute of Technology, HIT Campus, University Town of Shenzhen, Xili, Shenzhen 518055, Guangdong Province, PR China

[b] School of Mechanical and Electrical Engineering, Harbin Institute of Technology, 92 West Dazhi Street, Harbin 150001, Heilongjiang Province, PR China

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ABSTRACT

This paper deals with a multipurpose dual-axis solar tracker that can be applied to solar power systems. This tracker employs a declination-clock mounting system that locates the primary axis in east-west direction. Based on this mounting system, normal tracking strategy and daily adjustment strategy are developed for flat Photovoltaic (PV) systems and Concentrating Solar Power (CSP) systems respectively. While the former strategy keeps the tracking errors smaller than the pre-specified values, the latter one simplifies the tracking process by adjusting the primary axis once a day and driving the secondary axis to rotate at a constant speed of 15°/h. Results of the accuracy test indicate that the tracking error of the normal tracking strategy is within 0.15°. The other strategy may have greater tracking errors, but its annual average cosine loss for flat PV systems is estimated to be below 1.3%. Furthermore, in the test on the output of the PV modules, it is found that the average energy efficiency of the normal tracking PV, compared with the fixed PV, is more than 23.6%. And the average energy efficiency of the daily adjusted PV is more than 31.8%. Results of the experiment show that the two tracking strategies are both feasible for the developed tracker.

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1. Introduction

As a kind of clean and renewable energy source, solar energy has been drawing more and more attention, especially in the field of electricity generation, due to the shortage and pollution of fossil fuels. The process of converting solar energy to electric energy is realized mainly through flat PV systems or CSP systems. The power output that these systems could produce depends on various factors, including the amount of the energy they receive from the solar radiation. Some researchers have studied the optimal angle of solar collector to increase the power output [1,2]. As the sun's position changes throughout the day, the solar tracker is a more efficient method of increasing the energy production. So the solar tracker is being studied by more and more researchers.

Currently, there are mainly two types of solar trackers based on movement capability: single-axis tracker [3–5] and dual-axis tracker [6–9]. Different single-axis and dual-axis trackers have been presented by the previous studies. Clifford and Eastwood [10] presented a passive solar tracker activated by aluminium/steel bimetallic strips and controlled by a viscous damper. Poulek and Libra [11] designed a simple single-axis solar tracker based on a new arrangement of auxiliary bifacial solar cell connected directly to DC motor. Kim et al. [12] proposed a single polar axis tracker with the solar collector rotating at a speed of 15°/h round the polar axis. Roth et al. [13] proposed an altitude-azimuth dual-axis tracker which, guided by a closed loop serve system, could operate automatically. Batayneh et al. [14] proposed a dual-axis sun tracking system with altitude-azimuth mounting controlled by the designed fuzzy controller. Mavromatakis and Franghiadakis [15] presented a novel single-axis azimuthal tracker with the ability to move the collector's plane in two directions through a special support structure. According to the previous studies, solar trackers have been used in different solar collector systems. C.S. Chin et al. [16] presented an active single-axis solar tracker used in flat PV systems. The experimental test showed that the efficiency over the fixed solar panel was around 20%. Chang [17] tested the flat PV system mounted on a single-axis tracker and found that the gain of the single-axis tracking panel installed with the yearly optimal angle was 17.5%, compared to a traditional fixed panel. Kim et al. [12] applied the single polar axis tracker to CPC solar collector. The study of Kacira et al. [18] showed a daily average of 34.6% gain in generated power with two-axis solar tracking compared to a fixed PV panel on a particular day in July in Sanliurfa, Turkey. Abdallah and Nijmeh [19] designed a two axes sun tracking system for PV

* Corresponding author. Tel.: +86 451 86413557.
E-mail address: xiaohu3745@163.com (Y. Hu).

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system. The system surface showed a better performance with an increase in the collected energy of up to 41.34% compared with the fixed surface.

When analyzing the current literature, the authors found no available trackers that are developed properly for both flat PV systems and CSP systems. Flat PV systems and CSP systems have different demands for tracking accuracy. On the one hand, current low accuracy trackers, such as the single-axis tracker designed for flat PV systems, cannot be used in CSP systems because their low accuracy will lead to a great loss of the solar energy intercepted by the receiver. On the other hand, if a tracker, designed for high-accuracy tracking purposes, is used in a flat PV system, there will be extra operational costs imposed by control process. This paper takes into account the two types of demands for accuracy and develops a dual-axis tracker employing declination-clock mounting system (This mounting system has been used by Bakos [20] for the efficiency improvement of parabolic trough collector (PTC) in practice. However no available analysis is made for the principle of this mounting system in the literature. The main new contributions of this paper compared to [20] are summarized as follows: The tracking formulas for the declination-clock mounting system have been derived and also a much simpler tracking strategy has been proposed for the flat PV system; A linkage mechanism, which provides with a simple and light-weight structure, has been designed for the motion of the primary axis; The belt transmission is employed for the motion of the secondary axis, which can reduce the dynamic load occurring in the mechanism; Mechanical group-control, which allow the solar tracker to accommodate more collectors to track the sun, is achieved in the proposed structure; A sun position sensor with high resolution is designed and employed in the presented solar tracker.). This mounting system would allow the presented tracker in this paper to move under two tracking strategies, namely normal tracking strategy and daily adjustment strategy. Normal tracking strategy shows a good tracking performance with the error remaining below 0.15°. Daily adjustment strategy is used for simple tracking purpose instead of high-accuracy tracking. Its annual average cosine loss for flat PV systems is calculated to be below 1.3%.

2. Description of the solar tracker

2.1. Analysis of declination-clock mounting system

The developed tracker employs a mounting system named as declination-clock mounting which has fine motion ability. The declination-clock mounting system has two rotation axes (Fig. 1(b)): primary axis, located in east-west direction and secondary axis, perpendicular to the primary axis and able to rotate around it. Rotation angles for the primary and secondary axis are defined as declination angle and clock angle respectively. The declination-clock system is obtained from the pseudo-azimuthal system [21] by inverting the order of the rotation axes – regarding the latter system, the primary axis is for the azimuthal motion (which, in terms of the former system, generates a corresponding clock angle), while the secondary axis is for elevation (which, in terms of the former system, generates a corresponding declination angle). The tracking schematics for the developed tracker and the pseudo-azimuthal tracker are shown in Fig. 1(a) and (b) for comparison.

The rotation angles of the tracker are determined by the sun's position. So the unit normal vector of the solar collector is given by

$$\mathbf{n} = \mathbf{v}_s \tag{1}$$

where $\mathbf{n}$ is the unit normal vector of the solar collector; $\mathbf{v}_s$ is the unit vector incident to the sun. In general, the vector $\mathbf{v}_s$ can be determined by the solar azimuth angle γ_s and altitude angle α_s [22].

Two coordinate systems, namely XYZ-O and IJK-O, are established for the analysis of declination-clock mounting system, (Fig. 2). XYZ-O is located on the ground and IJK-O is on the declination-clock tracker. The vector $\mathbf{v}_s$ can be expressed in the coordinate system of XYZ-O as

$$\mathbf{v}_s = (\sin\gamma_s \cos\alpha_s, \cos\gamma_s \cos\alpha_s, \sin\alpha_s) \tag{2}$$

According to the relations in the figure, vector $\mathbf{n}$ can be expressed in the coordinate system of IJK-O as

$$\mathbf{n}_{IJK-O} = (\sin\theta_{CL}, \cos\theta_{CL}, 0) \tag{3}$$

Then through the rotation transformation from the system IJK-O to the system XYZ-O, the vector $\mathbf{n}$ can be expressed in the coordinate system of XYZ-O as

$$\mathbf{n}_{XYZ-O} = (\sin\theta_{CL}, \sin\theta_{DE}\cos\theta_{CL}, \cos\theta_{DE}\cos\theta_{CL}) \tag{4}$$

So the formulas of the angles θ_{DE} and θ_{CL} can be expressed as

$$\begin{cases} \tan\theta_{DE} = \cos\gamma_s \cot\alpha_s \\ \sin\theta_{CL} = \sin\gamma_s \cos\alpha_s \end{cases} \tag{5}$$

Similarly, through the rotation transformation, the angles θ_{AZ} and θ_{EL} for pseudo-azimuthal system can be derived from

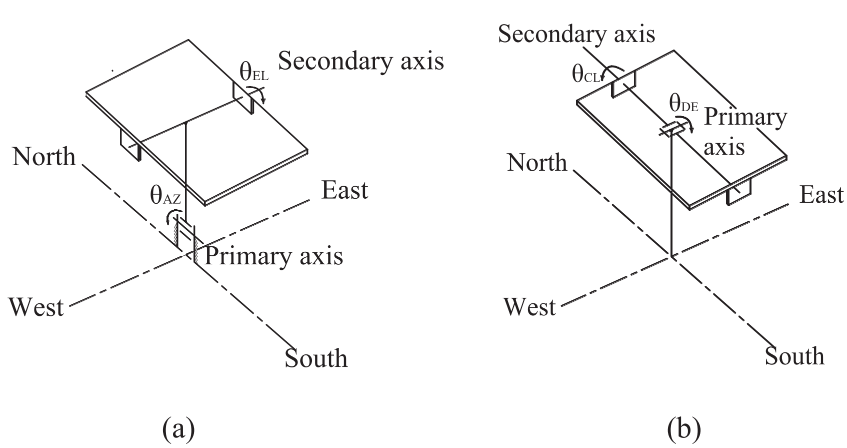

Fig. 1. Comparison of tracking schematics of: (a) pseudo-azimuthal mounting; (b) declination-clock mounting.

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