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Tracking control and output power optimization of a concentrator photovoltaic system with polar axis

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ABSTRACT

The tracking control and output power optimization of our concentrator photovoltaic (CPV) system with polar axis has been studied. The close-loop automatic control based on real-time optical feedback is proposed to implement accurate sun-tracking of our CPV system, in which the hybrid tracking algorithm, making use of the tracking tolerance and timing, is presented. Hence, the strict requirement for the incident angle of sunlight can be satisfied to the maximum extent and the operating costs of our CPV system can be reduced. The power output maximization and tracking control optimization are achieved under the real irradiance of 910 W/m^2, which is verified by the corresponding data measurement and error analysis.

1. Introduction

Compared with conventional fixed panel photovoltaic technology, CPV technology as the third generation has lots of advantages [1], such as incomparable high efficiency, low cost, low power dissipation, etc. Currently, the photoelectric devices used for CPV systems, especially for the high CPV systems, are mostly monolithic integrated triple junction solar cells fabricated on a Ge substrate [2]. However, owing to the characteristics of triple junction solar cells [3], only when the sunrays' incident direction is perpendicular to the CPV module, will the intensity distribution on solar cells be uniform for photoelectric conversion [4].

Besides optical structures with high efficiency, the concentrator cells must take biaxial tracking method [5]. Therefore, a tracking approach with polar-axis biaxial linkage is put forward to overcome the shortcomings of the general biaxial tracking method. It not only avoids the shading problem between concentrator modules, but also ensures the consistency of concentrator modules' tracking structure. In addition, the impact of different solar altitude and azimuth in four seasons on generated power is eliminated [6].

Contraposing the CPV system controlled by polar-axis biaxial linkage, this paper proposes a close-loop control method [7,8] based on real-time optical feedback, taking advantage of a hybrid tracking control method combining tolerance and timing. It can maximumly satisfy the concentrator photovoltaic system's strict requirements for tracking accuracy and reduce the operating cost. Furthermore, by series of comparative analysis of the actual measurement data, the proposed strategies are proved.

2. General scheme

To maximize the photoelectric conversion efficiency, the system is installed with polar-axis biaxial linkage. Fig. 1 shows the trajectory of the earth around the sun. The latitude (Φ) of location is the angle made by the radial line joining the location to the center of the earth and the projection of the line on the equatorial plane. The angle between the line joining the centers of the sun and the earth and its projection on the equatorial plane is called the solar declination angle (δ). What's more, the angle between the earth's axis and the ecliptic plane is constantly 66.55° during the earth revolution [9]. When the system is installed with polar axis linkage [10], the tilt angle of the polar axis is just decided by local latitude. In addition, the inclined polar axis is parallel to the earth's axis. In that case, the polar axis tracking method can eliminate the impact caused by earth rotation.

On the basis of guaranteeing the tracking accuracy, the tracking with polar-axis biaxial linkage converts the sun's elliptical moving trajectory to solar azimuth spinning on east–west single tilt axis and declination angle pitching in north–south direction. The

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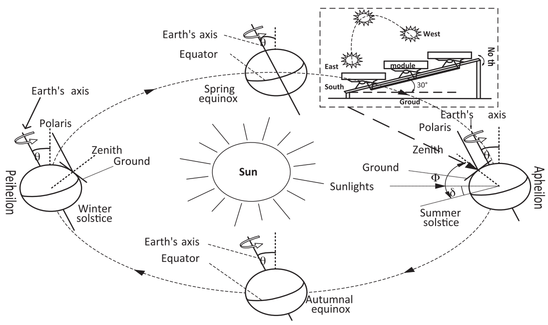

Fig. 1. The trajectory of the earth around the sun.

Fig. 2. The physical configuration of the CPV system.

physical configuration of the CPV is shown in Fig. 2, which has been assembled on the rooftop of Scientific and Technological building in Hubei University of Technology. For the specific scheme, three columns of parallel tilt polar axis which is at an angle of 30° with the ground, rotates in east–west direction driven by a stepping motor with linkage system [11]. Meanwhile, another stepping motor controls the rotation in north–south direction whose rotation angel range is up to 80°. Combining with the circuit configuration of the close-loop automatic control, the system can realize linkage control with biaxial polar axis. Indeed, under the operating condition, it is proved that this kind of installation can greatly eliminate the impact of earth rotation by the rotating polar axis, avoiding power consumption owed to frequent rotation in relatively short period. And the mechanical structure and installation resolve the conflict between tracking accuracy and operating cost.

3. Tracking control system

3.1. The hardware design of the tracking system

A CPV system should take many aspects into account, and the most important thing is the overall power generation efficiency [12]. The automatic control system must be designed to satisfy the high accuracy requirements for sun positioning and meanwhile the synchronicity of 9 modules in the tracking process should be ensured. The parameter measurement and working mode of the automatic control system are showed in Fig. 3. To meet the prerequisite for the CPV system's maximum power, a tracker designed by photosensitive cells is used to track the incident direction of the sunlight. Then, the central control unit drives the stepping motor. What's more, relevant parameters measurements, such as light intensity, environmental temperature, battery temperature, air quality, air velocity and so on, are carried out simultaneously. Moreover, in order to avoid other light interference and emergency which may lead to accident, the central control unit limits the running time of the system, and every stepping motor is installed with feedback limit switches.

Our CPV system can be regarded as three paralleled connection units and each unit is composed of three modules connected in series. After concentrator modules being series–parallel electrical connections, for visually showing the maximum generated output of CPV system, the final output terminal is linked with the electronic load (IT6860A used here). Later, when photosensitive control tracking remains stable, PC communicates with electronic load by RS232 serial port, and controls the electronic load working in the constant resistance pattern by software. When the changing step length of the current is set, the whole system's *I–V* discrete points and *P–V* discrete points at every corresponding moment can be obtained. Eventually, the corresponding graphs are shown in external LED display.

3.2. The tracking accuracy of the control system

Photosensitive chips applied in automatic tracking sensor are the BH1603FVC of Rohm Semiconductor Company. The corresponding distribution in four quadrants [13] is shown in Fig. 4. And the distance of the chips is determined by tracking accuracy. Four silicon photocells, on the surface of the outer cover, generate current under the radiation. After the light being transformed, amplified, filtered, and processed by electronic control system, the stepping motors are driven to make the trackers move towards the direction where the photocurrent is bigger until the photocurrent of the four silicon photocells is roughly equal. Then, the incident

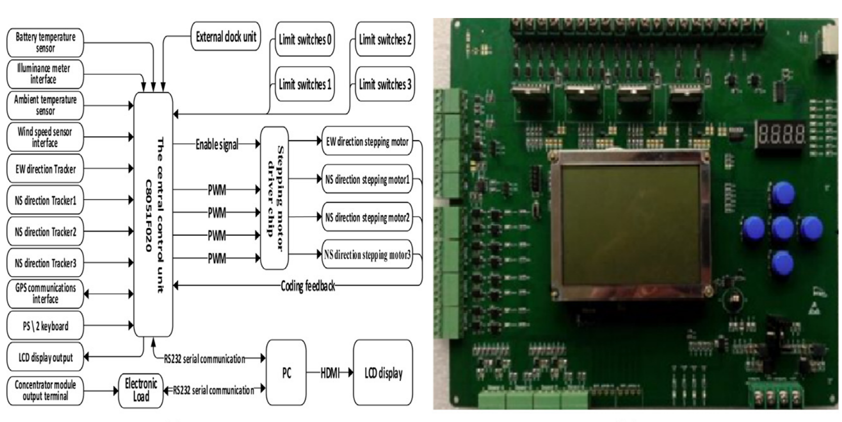

Fig. 3. The principle of diagram (a) and hardware design (b) of the tracking system.