Design, verification and feasibility numerical study of a non-tracking concentrator with lens

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Introduction

Traditional photovoltaic cells have low surface light density and low space utilization, which limits the development of the photovoltaic industry. Increasing the power generation capacity of photovoltaic cells can concentrate a large area of sunlight to a smaller receiving area of photovoltaic cells through reflectors. As a non-imaging compound parabolic concentrator (CPC), it can obtain a higher light incidence angle than an imaging concentrator and does not require expensive tracking equipment[1]. The disadvantage is that when the incident angle of incident (AoI) changes, uneven energy flow distribution will appear on the converging surface, and as the (AoI) increases, its unevenness will increase, and even shadow areas will appear on the converging surface, affecting the battery Performance[2]. Xie[3] and Li[4] improved the optical performance by changing the structure of CPC and adding lenses. Some scholars ignore the influence of the sun's azimuth angle on the equipment when performing optical analysis. At the same time, it is also important to reduce the number of adjustments of the concentrator each year.

For CPC photovoltaic power generation, the uniformity of battery temperature distribution will directly affect power generation efficiency and operational safety. Therefore, Ju X[5] provided a fully coupled three-dimensional numerical simulation method, and used FLUENT to simulate the temperature distribution of solar cell modules for different wavebands. This simulation method will get more accurate results.

In response to the above problems, this paper proposes a new type of CPC-based non-tracking condenser module with lens and heat absorption plate. The new concentrated components were studied from two aspects: optics and thermodynamics.

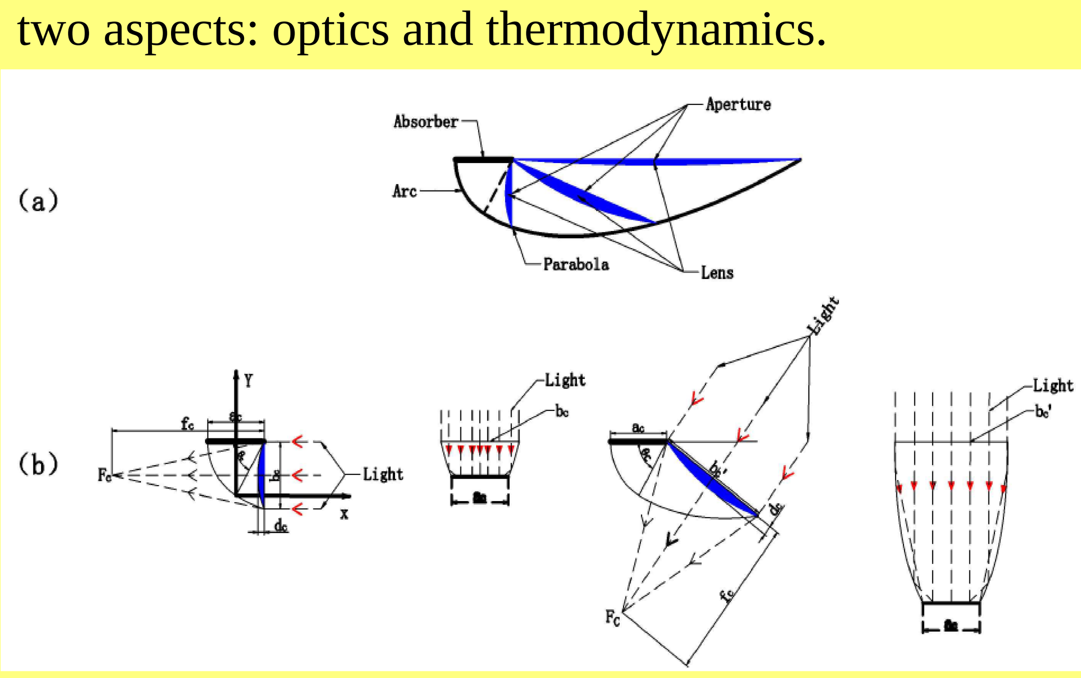

Fig. 1. The geometric structure of the new concentrator.

Optical simulation

NEW CONCENTRATED INGREDIENTS

The secondary condensing component designed in this paper mainly includes a lens, a composite reflecting surface and a receiving plane, and its geometric structure is shown in Fig.1(a). The width of the receiver is 109mm, the radius of the arc is 109mm, and the angle of the arc is 60°. In order to adapt to various environments and reduce costs, the concentrating and reflecting surfaces were intercepted, and new concentrating elements and CPC concentrating elements with a concentration ratio of 1.1 (C=1.1) and (C=2) are obtained as shown in Fig.1(b). Compare and analyze the optical and thermodynamic properties of concentrated elements. The thickness of the lens will affect the optical characteristics of the condensing component. This paper uses TracePro software to study the influence of lenses with different thicknesses on the optical efficiency and condensing uniformity after changing the height angle of the incident light. After optimization and comparison, a lens with a thickness of 15mm was selected to be combined with the concentrating component.

After research, it is found that the new condensing device after adding the lens can also increase the light receiving range. The light acceptance angle of CPC with a concentration ratio of 2 is 0° -60° , and the light acceptance angle of the new light-gathering component with the same concentration ratio is 0° - 90° . The large light receiving range makes the device only need to be adjusted four times a year, and the operating cost of concentrated components is reduced. The installation angle of CPC with C=2 and the new concentrator on a typical day of the year is shown in Fig.2.

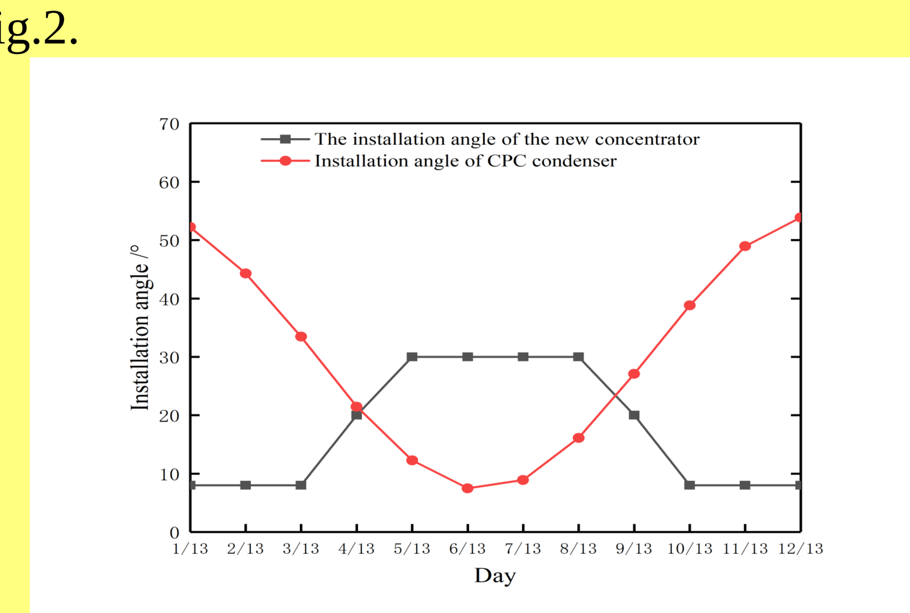

Fig. 2. Installation angle of CPC and new condenser.

FEASIBILITY VERIFICATION

In order to study the performance of the new concentrating module in the actual environment, it is now placed in Pudong, Shanghai to simulate the optical performance of 10:00-14:00 on March 13, 2021, and compare it with the tablet CPC.

When light with a low azimuth angle is incident on the condensing device, shadow areas will appear on the condensing surface due to the loss of edge light. The size and shape of the battery can be adjusted according to different light-receiving areas[6]. Therefore, heat absorbing plates of a certain length are arranged at both ends of the concentrating surface. The function of the heat absorbing plates is to absorb the uneven heat flow at both ends of the concentrating surface, reduce energy loss, and ensure efficient and uniform concentrating on the surface of the solar cell. The installation methods of the two concentrating elements with C=1.1 and C=2 are shown in Fig.3(a).

At From Fig.3(b)(c), it can be seen that at these five moments, the light efficiency of the two modules with C=2 shows a trend of rising first and then falling. The optical efficiency of the new concentrating element is similar to that of the CPC element, and is higher than that of the CPC element at the 12 o'clock position. At the same time, it is found that the influence of azimuth angle cannot be ignored. Except for 12 points, CPC cells have shadow areas, and the smaller the azimuth of the sun, the greater the proportion of the shadow area. The new concentrated composition adds lenses and heat-absorbing plates. There is no shadow area on the battery surface, and the uniformity of 10 points and 14 points is higher than that of CPC. The average luminous efficiency and uniformity of the whole machine are 0.76 and 0.74 respectively.

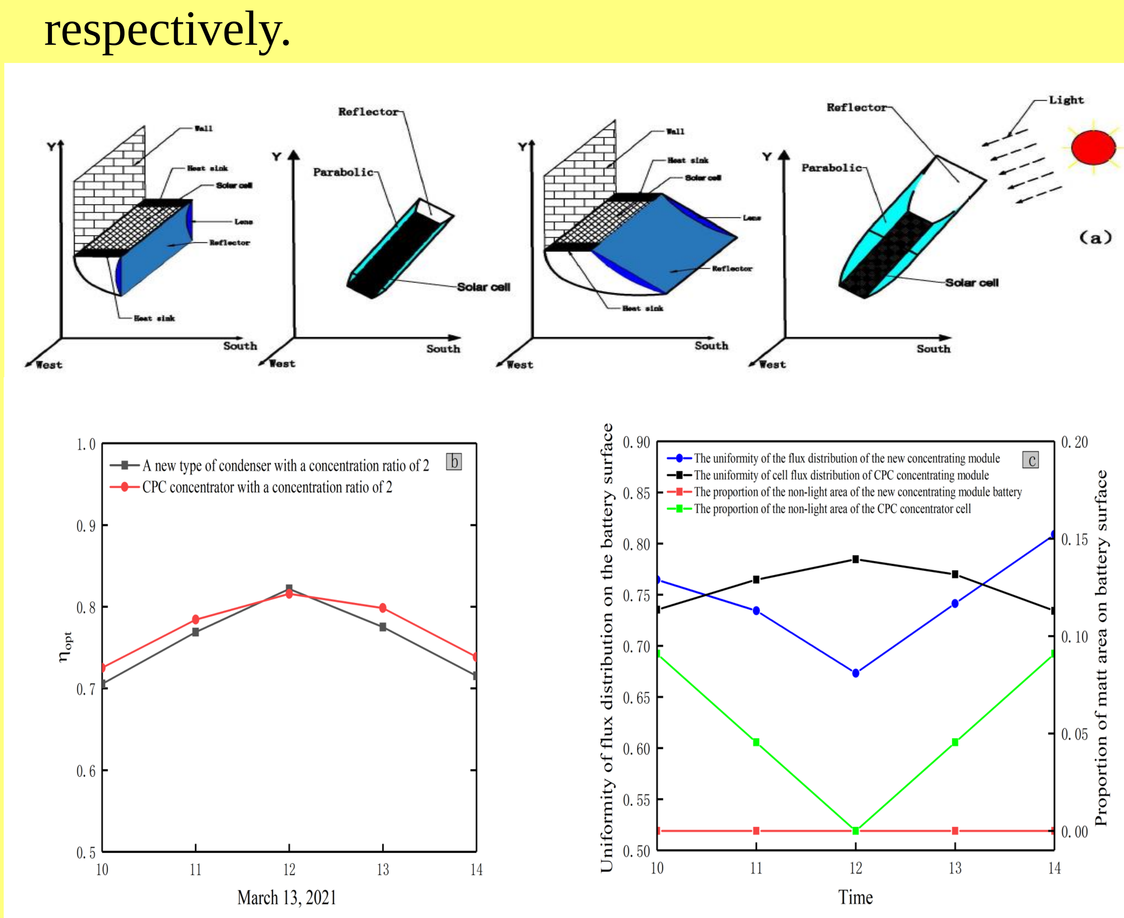

Fig. 3.(a) Installation diagram **(b)** Optical efficiency**(c)** Concentration uniformity and percentage of shadow area

Thermodynamic simulation

Use FLUENT to simulate the three-dimensional temperature distribution of two concentrated components at different times. The simulation considers the impact of different wavebands on the battery. The battery converts photons in the band (422.4~893.3nm) into electrical energy, accounting for 66% of the total energy of the entire solar spectrum, while the photons outside this region generate heat[5]. Through the FLUENT user-defined function (UDF), the energy flow density value of the receiving surface is allocated to the silicon battery and the heat absorption plate in the form of an internal heat source. The focus is on the temperature distribution of the battery under non-uniform illumination.

The battery temperature distribution is shown in Fig.4.Due to the shaded area on the surface of the CPC battery, the temperature difference at 10 o'clock and 11 o'clock is 31.82° C and 24.68° C, respectively, and the uniformity is 0.54 and 0.69, respectively. The temperature difference will seriously affect the safe operation of the battery. The surface temperature of the new concentrated battery is evenly distributed, and the maximum temperature difference on the battery surface is 12.81℃ at 12 o'clock. Compared with CPC, the uniformity of the surface temperature distribution of the battery in the new concentrator remains above 0.90 at these 5 moments, which is beneficial to photoelectric conversion.

Fig. 4. The temperature distribution of the battery surface at different times.

Conclusions

The combination of the lens and the condensing component can take into account both the optical efficiency and the uniformity of the condensing light, while expanding the light receiving range and reducing the number of adjustments of the concentrating component.

After the receiving surface is optimized, the optical loss is reduced, and the shadow area on the battery surface is improved. This makes the concentrating device have better tolerance to low-azimuth light.

The surface temperature of the new concentrating cell is evenly distributed, and the uniformity is maintained at about 0.90, which is conducive to the safe and efficient operation of the cell.

References

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