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Study on the uniformity of high concentration photovoltaic system with array algorithm

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ABSTRACT

The uniformity of the receiver surface energy flux density in the reflective high-power concentration photovoltaic system can affect the photoelectric conversion efficiency of the photovoltaic cell, and even cause the "hot spot" to damage it. In this paper, the plane mirror array algorithm is used to design a reflective high-power condenser, and TRACEPRO is used to numerical simulation study the uniformity of receiver surface energy flux density. The results show that the uniformity is greater than 99%, the experimental result (96.907%) is in agreement with the simulation results. In addition, the relationships of the effective area of the photoelectric conversion, the average irradiance, the maximum irradiance and the focal length are studied, and in the case of theoretical concentration ratio C is unchanged, the effective area of the photoelectric conversion is unchanged, the relationship of the maximum irradiance E_{max} with the focal length f is $E_{max} = a + b\ln(f - c)$, and the relationship of the average irradiance E_{ave} with focal length f is also $E_{ave} = a + b\ln(f - c)$.

1. Introduction

Environmental problems are caused by energy shortage and over-use fossil fuels have become a Long-term and major bottleneck of restricting the global economic and social development, so looking for the new energy is imminent (International Energy Agency, 2014; YaLing et al., 2016). Solar energy has the advantages of universality, richness and permanence, and development and utilization of solar energy has become a hot topic in modern society. In the photovoltaic system, the III-V group compound battery has high photoelectric conversion efficiency and high cost (Green et al., 2011a, 2011b; Perez-Higueras et al., 2010), in order to reduce the cost, the concentration photovoltaic is one of the effective way (Feng, 2015; Wang et al., 2012). Research shows that the non-uniformity of energy flux density on the receiver surface will greatly reduce the photoelectric conversion efficiency of the photovoltaic cells and even damage the photovoltaic cells, and makes the high-power concentration photovoltaic system cannot work normally (Jenkins, 2002; Narasimhan et al., 2008).

Harris and Duff (1981) proposed four kinds of calculation method of the energy flux density on the receiver surface, and gave the influence of non-ideal reflective condenser. Jones and Wang (1995) analyzed the energy flux density distribution of circular receiver surface, and considered the influence which is caused by the condenser error and the sun shape. Jenkins (2002) added a "Kaleidoscope" between the condenser and the receiver to achieve the energy flux density of the receiver surface tends to be uniform, meanwhile proved that the ratio of the length to the width plays a decisive role to achieve uniformity. Jiang et al. (2009) added the distribution between the condenser and the receiver to realize the uniform of energy flux density on the surface of the receiver. Rabady and Andrawes (2014) designed the outline of the condenser by the plane mirror array method, so that the heat on the collector tube tends to be uniform and the thermal efficiency of the system is also improved. Jing et al., (2014) designed the high-power solar condensers according to the principle of Kohler illumination, aplanatic principle and the law of reflection, which is relatively uniform of the energy flux density on the surface of the receiver and compact structure.

Scientists have done a lot of researches about the energy flux density on the surface of the receiver to promote the development of the high-power concentration photovoltaic system, such as the "Kaleidoscop", the distribution and the method of the light spot is formed by multi-condenser. Although they can make the energy flux density of the receiver surface tends to be uniform, they are difficult to be applied in practice because of the low uniformity and high cost. This paper presents a new algorithm about the plane

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mirror array, MATLAB is used to make the program, put the MATLAB date into TRACEPRO to simulate, then, the test bench is built to analyze and evaluate the uniformity of the energy flux density on the receiver surface.

2. Design principles

Sun's rays with 32′ sun angle incident to each point of the condenser, according to the law of reflection, the connecting line between the incident point and the condenser's focus is as optical axis, and the sun's rays with the same 32′ sun angle are reflected in the direction of the condenser's focus (Liu, 2010). According to the reflection law of plane mirror, the parallel incident sun's rays are parallel reflected by the plane mirror (Chen et al., 2014; Chen, 2014). The plane mirror on the condenser rotates around the central axis and symmetric distribution, each plane mirror makes the reflected sun's rays superimpose on the surface of the receiver to form the uniform distribution of energy flux density. As shown in Fig. 1.

The plane mirror condenser belongs to rotary condenser, and takes the half of it to analyze. The theoretical concentration ratio C can be expressed as follows:

$$C = \left(\frac{a}{w''}\right)^2 \tag{2.1}$$

As shown in Fig. 1, where w'' is the light spot size is formed by the sun's rays which vertical incident on the plane mirror and are reflected, and a is the opening size of the condenser. After the theoretical concentration ratio and the opening size of condenser are determined, then determine the parabola focal length f, and the parabolic equation can be determined (Liu, 2010):

$$x^2 = 4fy \tag{2.2}$$

As shown in Fig. 1, the actual sun's rays incident to condenser by the conical shape with the cone angle is 16′ (Liu, 2010), the same to reflection. So the maximum light spot size W is the sum of $w''$and w', and w' is the light spot size is formed by the sun's rays which incident on the edge of the plane mirror at 16′ and are reflected.

$$w' = \frac{4f\tan 16'\cos\theta}{(1+\cos\theta)\cos^2\theta'} \tag{2.3}$$

As shown in Fig. 1, where θ is the half-angle of condenser lighting (the half-angle between reflected light and the central optical axis), and θ' is the angle between the center light which is reflected by the plane mirror's edge and the central optical axis.

In the design of high-power concentration photovoltaic system, $\theta = \theta'$, so w' is expressed as follows:

$$w' = \frac{4f\tan 16'}{(1+\cos\theta')\cos\theta'} \tag{2.4}$$

w'' is expressed as follows:

$$w'' = w - w' = w - \frac{4f\tan 16'}{(1+\cos\theta')\cos\theta'} \tag{2.5}$$

In order to make the maximum uniformity of the energy flux density on the receiver surface, w' namely take the minimum value. As for the formula (2.4), when $\theta' = 0$, the value of w' is minimum, it is expressed as follows:

$$w'' = w - 2f\tan 16' \tag{2.6}$$

After w'', w, a and f are determined. As shown Fig. 1, the spot w'' is formed by the central line (vertical light) of sun's rays, we can simplify the sun's rays, and which vertical incident on the plane mirror and are reflected, according to the method of two lines determine a point, the position and the size of the plane mirror in the plane mirror condenser are arranged, and the plane mirror array model is shown in Fig. 2.

As shown in Fig. 2, take p_0 point's horizontal coordinate value $\frac{w}{2}$ into formula (2.2), and get the p_0 point's vertical coordinate value y_0:

$$y_0 = \frac{w^2}{16f} \tag{2.7}$$

As shown in Fig. 2, when know the coordinate value of p point and p_0 point, and get the slope k_{pp_0} of the straight line pp_0:

$$k_{pp_0} = \frac{f - \frac{w^2}{16f}}{-\left(\frac{w''}{2} + \frac{w}{2}\right)} \tag{2.8}$$

Get the coordinates value of p_1 point by establishing the equation set.

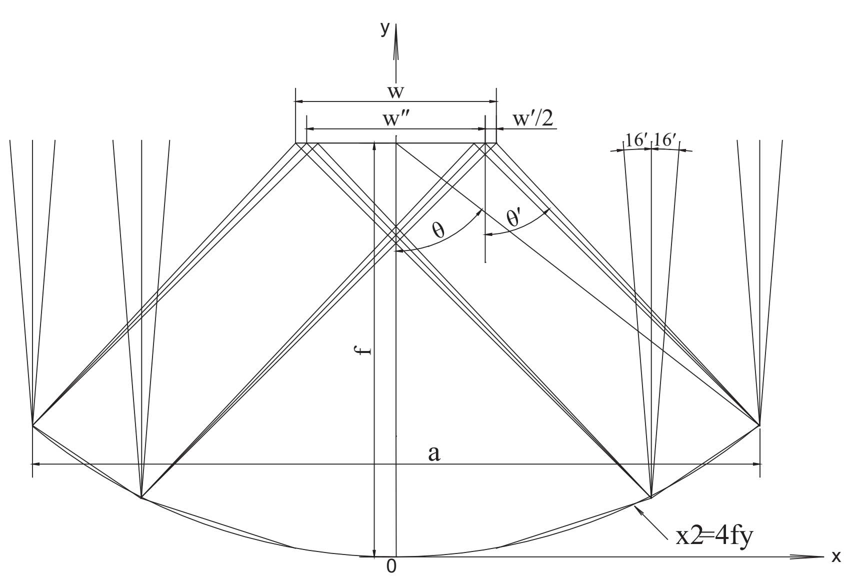

Fig. 1. The light spot is formed by the ideal plane mirror condenser.