Design and Testing of Transmissive Fresnel Concentration and Thermoelectric Power Generation System

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Abstract: In this paper, a concentrating photovoltaic and temperature difference combined power generation device is designed. The device is guided by the problem of low power generation efficiency of solar cells at high temperature, and transfers the heat of photovoltaic cells to thermoelectric cells to achieve secondary power generation. The research takes the cold end of the thermoelectric battery as the entry point, and studies its influence on the device by controlling the flow rate and temperature of the cooling liquid in the water-cooled radiator. The results show that when the flow rate is 0.5L/min ~ 2.5L/min, the photovoltaic current increases linearly and then increases nonlinearly, while the photovoltaic voltage decreases linearly and then increases nonlinearly. When the water temperature increases from 15°C to 27°C, the photovoltaic current, photovoltaic voltage and thermoelectric voltage decrease with the increase of water temperature, while the thermoelectric current increases with the increase of water temperature. Therefore, selecting the appropriate flow rate and water temperature can further improve the power generation efficiency and performance of the system.

Keywords: Linear Fresnel lens, Concentrating photovoltaic, Thermoelectric power generation, Generating efficiency, Pyroelectric effect, Water cooling.

1. INTRODUCTION

With the strategic needs of the country 's industrial west migration, energy has its important position in the industry. The western part of China is rich in solar irradiation resources and has certain potential for photovoltaic power generation [1]. Among them, photovoltaic power generation will become the pillar of the energy system in the 21st century.

The use of concentrators can make photovoltaic cells work under strong light, increase the output power of photovoltaic cells per unit area, and reduce the power generation cost of photovoltaic power generation systems [2].

However, when the photovoltaic cells work under concentrated light conditions, the heat generated will reduce the efficiency of the photovoltaic cells and affect the service life [3-4]. The heat generated under the concentrated light condition is more and concentrated. How to make rational use of the heat generated and maintain the working efficiency of the battery without reducing the service life of the battery is a problem worth exploring. The thermoelectric battery is a device that uses temperature difference to directly convert thermal energy into electrical energy, so that the above part of the heat can be used for secondary power generation, thereby improving the power generation efficiency of the system. At this time, the condition of satisfying the temperature difference still lacks a stable cold end.

Therefore, a transmission Fresnel concentrating and thermoelectric power generation system is proposed in this paper. The Fresnel lens is used to gather the light to the upper surface of the thermoelectric cell, and then the lower surface is connected to the water cooling system, so as to make rational and efficient use of sunlight. The heat is gathered on the upper surface of the thermoelectric cell and the water cooling system continuously cools the lower surface to form a temperature difference, realizing the conversion of heat energy into electrical energy. The integrated power generation device of concentrating photovoltaic and thermoelectric power generation is tested to study the factors affecting its power generation efficiency and performance, and to explore the relationship between them.

2. OPERATING PRINCIPLE

The principle of the concentrating system is shown in Figure **1**. The concentrating lens efficiently converges and focuses the originally dispersed solar rays, and these highly concentrated beams are focused on the surface of the solar cell. Under the action of strong light, solar cells not only receive more intensive light radiation energy, which improves the efficiency of photoelectric conversion, but also increase the temperature due to the accumulation of a large amount of light absorption.

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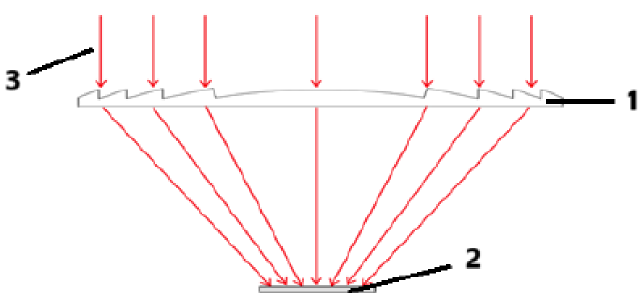
In order to effectively manage the temperature rise caused by the strong light effect, the high temperature generated by the solar cell is conducted out by the thermal conductive silica gel. The heat generated by the thermally conductive silica gel is then further transferred to the upper surface of the thermoelectric cell. The upper surface of the thermoelectric cell absorbs the high temperature from the solar panel, while the lower surface is maintained at a relatively low temperature through the water cooling system. The water cooling system carries out heat exchange through the lower surface of the thermoelectric cell to take away heat and maintain the low temperature state of the lower surface.

Thus, the shape between the upper surface and the lower surface of the thermoelectric cell is It becomes a significant temperature difference. This temperature difference is the key to the power generation of thermoelectric batteries. Based on the principle of thermoelectric effect, the thermoelectric battery can directly convert thermal energy into electrical energy in the presence of temperature gradient. With the increase of the upper surface temperature and the decrease of the lower surface temperature, the thermocouple pair inside the thermoelectric cell will generate the corresponding electromotive force, which will drive the generation of current and realize the conversion of thermal energy to electric energy.



1-Fresnel lens, **2**-Solar cell, **3**-Sunlight

Figure 1: The process of light passing through the concentrating lens to the surface of the solar cell.

3. SYSTEM DESCRIPTION

The hardware of the device mainly includes concentrating power generation system and thermoelectric power generation system, and the specific structure is shown in Figure **2**.

Considering that the light after the linear Fresnel lens is concentrated is rectangular, a rectangular solar cell of 120mm × 38mm is selected to effectively utilize the concentrated sunlight. After the solar light is focused by Fresnel lens, a large amount of heat is collected on the area of the spot. Therefore, the thermal conductive silica gel is used at the bottom of the photovoltaic cell to stick to the hot end of the thermoelectric cell, and the heat is transmitted to one end of the thermoelectric generator as its hot end. Four 30mm × 30mm thermoelectric power generation chips are connected in series and pasted on the back of the photovoltaic cell for power generation. The other end of the thermoelectric generator is cooled by a low temperature constant temperature water tank as its temperature cold end. Thus, the temperature difference is generated at both ends of the thermoelectric generator to perform secondary power generation. In order to synchronously detect the temperature at both ends of the thermoelectric cell during the experiment, a K-type thermocouple was inserted into the upper and lower thermal conductive silica gel layers to facilitate the detection of its temperature stability.

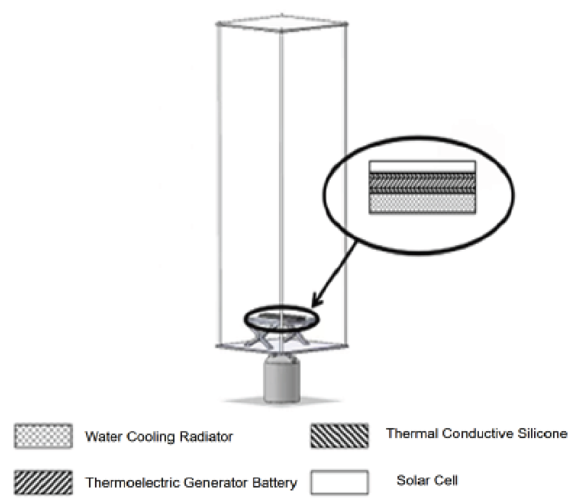


Figure 2: Physical model structure diagram.

The low temperature constant temperature water tank can set the specified temperature and maintain it stably after reaching the target temperature, so as to realize the temperature control of the cold end of the thermoelectric generator. Considering the volume of the device and the best concentrating effect [5-6], the concentrating power generation module is placed on a ray tracing shelf along with the thermoelectric power generation module. The ray tracing shelf is based on a three-axis turntable and fine-tuned by a ray tracing device, so that the gathered light has been concentrated on the photovoltaic cell [7]. The size of the Fresnel lens is 200mm × 200mm. In the experiment, the effective concentration area of the

Fresnel lens is 200mm × 38mm, and the geometric concentration ratio is 5.26. The main component parameters of the specific system are shown in Table **1**.

Table 1: The Specific Parameters of the Experimental Element

Linear Fresnel Lens	Width (mm)	200
	Length (mm)	200
	Focal Length (mm)	650
Thermoelectric Cell	Matching load voltage / V	4
	Matching load current / A	0.6
Cold end 30 °C hot end 200 °C	Matching load power / W	2.4

In order to facilitate the experimental test, water is selected as the coolant, so circulating water cooling is used in the system for testing. The light of solar radiation is concentrated on the solar cell through a linear Fresnel lens and directly converted into electrical energy.

4. OPTICAL SIMULATION ANALYSIS AND EXPERIMENTAL STEPS

4.1. Simulation Verification and Analysis

As shown in Figure **3**, the TracePro optical software is used for simulation. By changing the distance between the device and the Fresnel lens, the spot just completely covers its surface, and the data is used to adjust the distance between the device and the Fresnel lens. In order to ensure that photovoltaic cells can work under strong light. After simulation test, the effect is the best at 496 mm, and the specific spot simulation results are shown in Figure **4**.

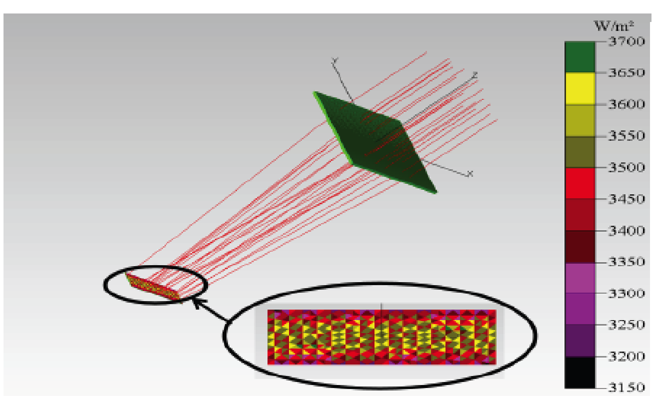


Figure 3: Simulation effect of optical simulation.

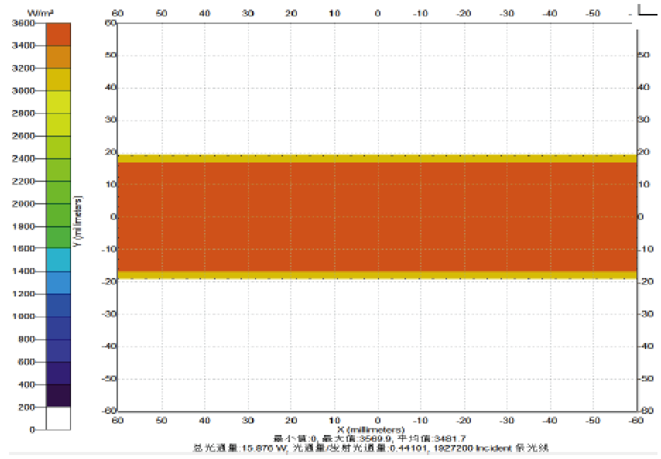


Figure 4: Spot simulation diagram.

4.2. Experimental Procedure

As shown in Figure **5**, the water temperature is controlled by a low-temperature thermostatic water tank, and the water valve controls the flow rate. When the temperature difference between the upper and lower temperature tends to be stable, the short-circuit current and open-circuit voltage of the photovoltaic cell and the thermoelectric battery pack are measured respectively, as shown in Figure **6**. Since each test group cannot be performed at the same time, the recorded irradiation value is the average of the total irradiation value during the experimental time.

The data collector is used to collect the total solar radiation value of the current, voltage and experimental time of the thermoelectric power generation system and the concentrating power generation system.

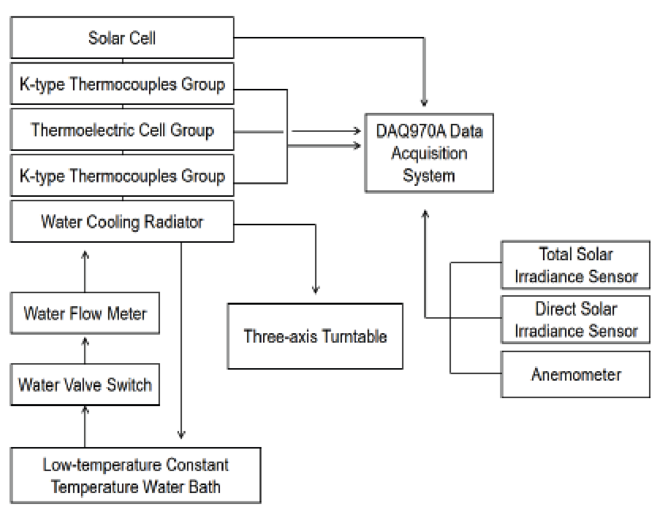


Figure 5: Physical experiment platform structure diagram.

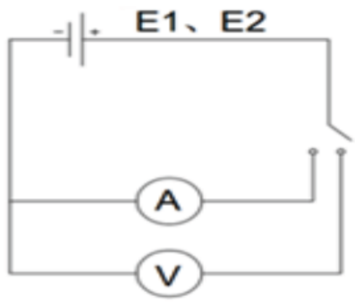


Figure 6: Electrical schematic diagram.

5. EXPERIMENTAL RESULTS AND ANALYSIS

5.1. Water Velocity

As shown in Figure **7**, at different flow rates (0.5L/min to 2.5L/min), photovoltaic current, photovoltaic voltage, temperature difference current and temperature difference voltage all change, but the change range is relatively small.

In the flow rate range of 0.5L/min to 2.5L/min, the photovoltaic current, photovoltaic voltage, temperature difference current and temperature difference voltage all show a certain change trend. The photovoltaic current increases linearly in the first part of the flow rate range, but the rising rate decreases significantly after 2L/min. The photovoltaic voltage decreases linearly before 2L/min, and then rebounds. With the increase of flow rate, photovoltaic power and temperature difference power are on the rise.

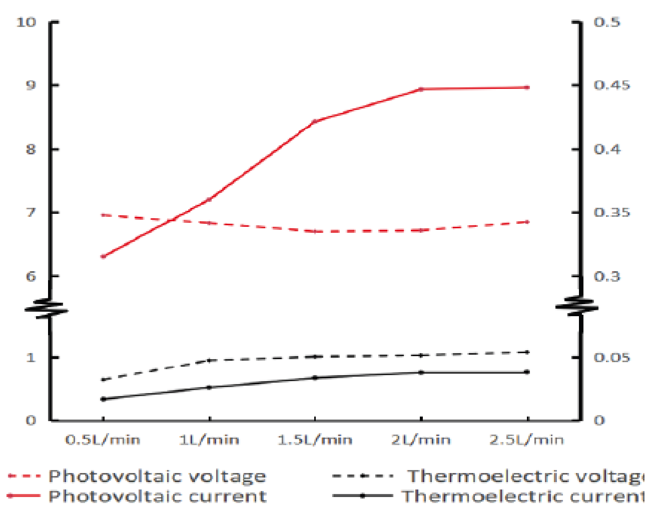


Figure 7: Flow rate group data chart.

5.2. Water Temperature

As shown in Figure **8**, the photovoltaic current gradually decreases with the increase of water temperature, from 0.19A at 15°C to 0.1802A at 27°C. The photovoltaic voltage also shows a decreasing trend with the increase of water temperature, from 7.566V at 15°C to 7.244V at 27°C. The thermoelectric current increases slightly with the increase of water temperature, from 0.009A at 15°C to 0.0117A at 27°C. The thermoelectric voltage decreases with the increase of water temperature, from 0.701V at 15°C to 0.4998V at 27°C.

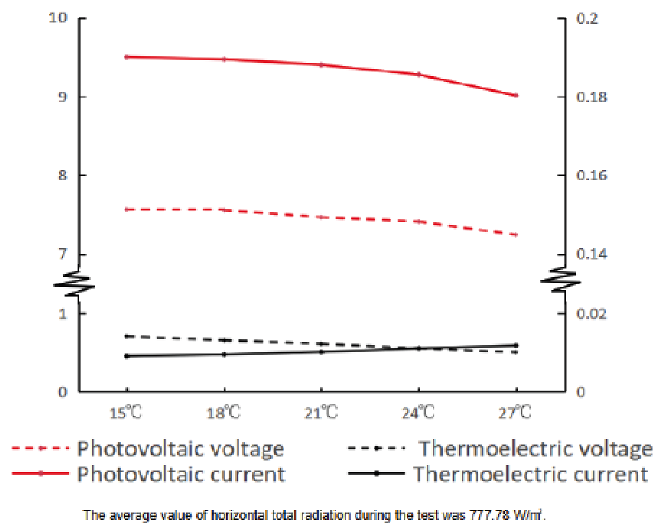


Figure 8: Water temperature group data chart.

6. CONCLUSION

In this paper, we studied the effects of different flow rates and water temperatures on the performance of transmissive Fresnel concentrating and thermoelectric power generation systems in detail. Through simulation and experiment, the photovoltaic current, photovoltaic voltage, temperature difference current and temperature difference voltage of the system are analyzed from the flow rate and water temperature. Draw a conclusion:

(1) When the flow rate range is 0.5L/min ~ 2.5L/min, the flow rate of 2L/min is the boundary value of photovoltaic current and photovoltaic voltage change. The photovoltaic current rises linearly before 2L/min, and then the rising speed slows down. The photovoltaic voltage decreases linearly before 2L/min, and then rises slightly. With the increase of flow rate, both photovoltaic power and temperature difference power increase, and the increase of temperature difference power is more significant. This may be because the increase of flow rate improves the heat exchange efficiency, thus enhancing the effect of thermoelectric power generation. However, for the thermoelectric

battery, it does not need to increase the flow rate as much as possible. Therefore, it is necessary to adjust to the appropriate flow rate according to the actual situation.

(2) When the water temperature increases from 15°C to 27°C, the photovoltaic current, photovoltaic voltage and temperature difference voltage decrease with the increase of water temperature. The temperature difference current increases with the increase of water temperature. The photovoltaic current, photovoltaic voltage and temperature difference voltage decreased by about 5.16%, 4.25% and 28.71%, respectively. The thermoelectric current is increased by about 30%. Low water temperature has little effect on the improvement of the system, and too low cooling water may reduce the overall efficiency. Therefore, for the water temperature, the temperature can be reduced appropriately, and a suitable water temperature range needs to be found in practical applications.

(3) The flow rate and water temperature have an impact on the performance of the photovoltaic temperature difference combined power generation system. Adjusting these parameters appropriately according to the actual working conditions can further improve the power generation efficiency and performance of the system.

In summary, the use of Fresnel lenses to concentrate sunlight to solar panels, temperature difference battery upper surface to absorb the high temperature of the solar panels, the lower surface of the water cooling system to maintain the low temperature so that the temperature difference generator to generate temperature difference for secondary power generation of the transmissive Fresnel Concentration and thermoelectric power generation system, according to the actual working conditions to adjust the appropriate flow rate and water temperature can produce a stable difference in the temperature of the current and voltage and thus to carry out the Secondary power generation.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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