Experimental Study on Distributed Household Solar Power Generation and Heating Integrated System

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Abstract. The current researches on the utilization of solar energy resources are mostly for the purpose of efficient utilization, ignoring the actual energy demand based on user needs. Therefore, this paper designs a new type of concentrated solar power generation system, taking user needs as the first goal and achieve full and effective use of energy. Calculate and analyze the structure size of the reflective condenser in the condenser system. Use the optical simulation software Trace-pro to simulate the condenser to find out the best reflection installation angle and the most reasonable condenser of the condenser reflector. Light efficiency. At the same time, a 100W distributed household solar power generation system experimental bench was set up to study the output power of the concentrating system of the experimental system. The results show that: when the incident angle of the light reaches above 60°, the uniformity will obviously increase, and the intensity of solar radiation will have a significant effect on the improvement of the uniformity of light concentration; The output power is about 87.58W. Compared with non-concentrating systems, the power increase is about 11.42%.

1. Introduction

Concentrating Photovoltaic/Thermal (CPV/T) technology is an innovation of ordinary PV/T technology. This technology combines a PV/T system with a concentrating system and enhances the solar energy The radiation intensity method is used to increase the output efficiency of the system. It is hoped that a relatively low-cost concentrator can be used to replace relatively expensive components and increase the output power of the system, thereby improving the cost-effectiveness of the system.

Gag\textsuperscript{[1]} and other scholars combined CPC with a flat PV/T collector and cooled the module with air as the cooling fluid. Experimental results show that the collector has higher photoelectric performance than non-concentrating collectors. Coventry\textsuperscript{[2]} and other scholars have experimentally tested a concentrating PV/T system on the output performance of the system. The experiment found that the system's photoelectric conversion efficiency can reach 11% and the concentrating and collecting efficiency can reach 58%. Othman\textsuperscript{[3]} and other scholars conducted heat exchange in the PV/T collector by means of air-fluid circulation. The heat exchange fins were placed under the collector and the collector was tested. As a result, the thermal efficiency was significantly improved. Tchinda\textsuperscript{[4]} and other scholars used air as a coolant to test the thermal performance parameters of the CPC-PV/T collector, and the results showed that the change of air humidity and air mass flow rate at the outlet of the collector is opposite. Karathan-assis IK\textsuperscript{[5]} and other scholars\textsuperscript{[6]} designed a CPV/T (Concentrated Photovoltaic Photothermal) system, that is, a solar panel with plate-fin cooling channels is adhered to
the base plane of the CPC. The instantaneous electrical and thermal efficiency of the entire system can be reached 6% and 44%, respectively. Wang Yinfeng[7] optimized and improved the traditional compound parabolic concentrator and added a single-axis tracking system. The condensing ratio of the concentrator is 2.3. The test results show that the device's efficient heat collection time is 1.7 times longer than that of the fixed condenser.

At present, most of the researches on integrated light-concentrating systems have connected the light-concentrating system and the power generation/heating system together in terms of energy distribution and utilization. At the same time, the two parts of power generation and heating are performed simultaneously. Users have different demands for electrical energy and thermal energy. At the same time, concentrated energy supply may cause the supply energy to exceed the user's needs. This not only causes waste of solar energy resources, but also increases the space utilization and manufacturing cost of the concentrated system. Therefore, how to take the user's needs as the root, and according to the user's wishes, to improve the efficiency of energy production and rationally allocate energy supply is the focus of this study.

2. Theoretical Analysis

2.1. Dimensions and calculation of reflective condenser
The principle of the V-type reflective concentrator is shown in the figure. The sunlight is reflected on the energy absorbing component through a reflecting plate to increase the output power per unit absorption area, thereby improving the solar energy utilization rate. Based on the simplicity and practicality of this concentrator, suitable for residents and household users, this article will focus on this type of concentrator. Its main body consists of two aluminum reflectors. The specific structure is shown in Figure 1:

![Figure 1. Reflective concentrator principle](image)

In the figure, a- the width of the energy-absorbing component; b- the width of the reflecting plate; h- the vertical height of the reflecting plate from the energy-absorbing component; x- the angle of incidence; y- the angle between the reflecting plate and the energy-absorbing component.

According to the geometric relationship in the figure, analyze the movement trajectory of the sun's rays. Assuming that the condenser is oriented north-south and the sun moves from left to right, the light preferentially passes through point A. After that, the light is refracted by the reflection plate and falls on the energy-absorbing component. When the incident angle of sunlight is greater than x, it is guaranteed that the surface of the module can absorb solar radiation. After that, the component surface is partially blocked until the sun reaches point B, and between point B and point E, the component is fully condensed, and between point E and point F.

The component is in a partially occluded state again. For solar modules, if the light is not uniform, the temperature of the surface of some cells will be significantly higher than other parts, which will easily form a hot spot effect and reduce the output performance of the module. Therefore, the uniformity of the radiation intensity will affect the design of the condenser. This is particularly important. To ensure that the duration of the fully condensing state is sufficient, the incident angle x must be sufficiently small. According to the formula:
It can be found from the formula (1) that the parameters affecting \( x \) mainly include the width \( a \) of the component, the width \( b \) of the reflective plate, and the angle \( y \) between the reflective plate and the component. Since the component has been determined, the component width is a fixed value, that is, \( a = 1000 \text{mm} \). The condensing conditions of the condenser on the left and right sides are exactly the same, so the range of \( y \) is 0° to 90°, and the rate of change of the incident angle of the light is 15°/h. For the convenience of calculation, the interval of 15° is used as value. In order to follow the simple and practical principle of the condenser, the width of the reflector should not be too large, and a larger reflector will increase the instability of the condenser, while ensuring that the shadow of the reflector will not affect other components, the reflector The vertical projection \( m \) cannot be too large. Therefore, when designing the structure size of the condenser, comprehensive consideration should be given to the values of \( x \) and \( m \). Combining the above calculation formulas, the calculation results are shown in Table 1 and Table 2:

### Table 1. Horizontal angle and vertical projection of reflectors under different widths and different solar elevation angles

| \( y/° \) | \( b \) | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| | m/m | m/m | m/m | m/m | m/m | m/m |
| 15 | 1.35 | 97 | 2.48 | 194 | 3.45 | 290 | 4.27 | 387 | 4.99 | 483 |
| 30 | 2.63 | 87 | 4.87 | 174 | 6.79 | 260 | 8.45 | 347 | 9.9 | 433 |
| 45 | 3.78 | 71 | 7.06 | 142 | 9.93 | 213 | 12.43 | 283 | 14.64 | 354 |
| 60 | 4.72 | 50 | 8.95 | 100 | 12.73 | 150 | 16.11 | 200 | 19.11 | 250 |
| 75 | 5.38 | 26 | 10.41 | 52 | 15.05 | 78 | 19.3 | 104 | 23.16 | 130 |

### Table 2. Horizontal angle and vertical projection of reflectors under different widths and different solar elevation angles

| \( y/° \) | \( b \) | 600 | 700 | 800 | 900 | 1000 |
|---|---|---|---|---|---|---|
| | m/m | m/m | m/m | m/m | m/m | m/m |
| 15 | 5.61 | 580 | 6.17 | 677 | 6.67 | 773 | 7.11 | 870 | 7.5 | 966 |
| 30 | 11.17 | 520 | 12.29 | 607 | 13.29 | 693 | 14.19 | 780 | 15 | 867 |
| 45 | 16.59 | 425 | 18.32 | 495 | 19.87 | 566 | 21.26 | 637 | 22.5 | 707 |
| 60 | 21.79 | 300 | 24.18 | 350 | 26.33 | 400 | 28.26 | 450 | 30 | 800 |
| 75 | 26.64 | 156 | 29.79 | 182 | 32.63 | 207 | 35.19 | 293 | 37.5 | 259 |

Properly shortening the concentrator can increase the area for condensing the stack, reduce the height of the concentrator, and improve the efficiency and economy of concentrating the light. Therefore, according to the characteristics of Hohhot area and the user's energy demand, according to the 100w modular power generation and heating integrated system as the standard, the horizontal angle of the reflector is selected to be 60° and the width to be 500mm.

### 2.2. Simulation of Concentrator Ray Tracing

Trace-Pro simulates the distribution of light flux on the model by tracing the light path. Since the light absorption of the light reflected by the reflectors at different angles on the receiving surface of the condenser is to be simulated, the front surface of the receiver is selected as the receiving surface. The properties (position, direction, luminous flux), radiation intensity and Three aspects of light intensity were analyzed. Figure 2 (a ~ f) shows the light trajectories at different angles of incidence (15°,30°,45°,60°,75°,90°) and the radiation intensity distribution on the receiving surface of the condenser. The situation is shown in Figure 2 (a ~ f).
Figure 2. Ray tracing diagrams with different incident angles

Table 3. Concentration of concentrators with different solar height angles

| Angle(°) | Spotlight situation | Angle(°) | Spotlight situation |
|----------|---------------------|----------|--------------------|
| 15       | No effect           | 60       | parallel           |
| 30       | Partial spotlight   | 75       | Full focus         |
| 45       | Partial spotlight   | 90       | Full focus         |

It can be seen from Table 3 that when the incident angle of the light reaches 30°, the condenser can produce a light-gathering effect. As the incident angle of the light is too low, the solar radiation intensity will not be very high, so even if only part of the light is concentrated, it will not have a great impact on the efficiency of the power generation module. When the incident angle of the light reaches 60°, the reflected light is parallel to the horizontal plane, and then the full condensing condition can be satisfied.

Tracing simulation of light rays with different incident angles on the condenser, to obtain the radiation distribution on the receiving surface of the light condenser with different incident angles, according to the radiation intensity distribution map, the optical performance of the condenser analysis.

Figure 3. Luminous flux under different conditions
According to the figure 3, it is found that with the increase of the incident angle, the total luminous flux on the receiving surface continues to increase; under the condensing condition, the full coverage of the light on the surface of the photovoltaic cell can be guaranteed when the light angle is $\geq 60^\circ$, and when the incident light angle is $90^\circ$. At the radiation intensity of the receiving surface reaches the maximum value, and the increase of the luminous flux is about 49.5%.

3. Outdoor Experimental Research on Distributed Household Solar Power Generation and Heating Integrated System

3.1. Experimental program
This experiment mainly tests the performance of solar power generation and solar heating systems with and without concentrators. The experiment was performed in Hohhot. The performance comparison test is mainly performed on two solar panels and heat collector panels with the same performance parameters under the same conditions (except with/without condenser). The rated power of the module used in the experiment was 100W. The output power of the photovoltaic module and the inlet and outlet water temperature and heat collection efficiency of the heat collecting plate were measured. The experimental site layout is shown in Figure 4:

![Figure 4. Experimental site layout](image)

3.2. Experimental results and analysis
It can be seen from Figure 5 that before 10:30, the output power of the concentrating power generation system is lower than that of the non-concentrating system. The main reason is that the incident angle of the light is too low, and the reflecting plate blocks the sun's rays, causing the light to fail Converged on solar panels. But because the solar radiation intensity is not high at this time, it has little effect on the power generation. After 10:30, the output power of the concentrated solar power system is higher than that of the non-concentrated system. When the radiant intensity reaches a maximum of 922w/m$^2$, the power increase of the solar panel at this time is about 11.42% higher than that of the non-concentrated solar panel. The output power decreases when the radiation intensity is maximum. The reason for this phenomenon is that the surface temperature of the battery panel rises after the light
is collected, and the temperature is too high, which causes the output power to decrease. Between 11:45 and 12:00, power generation declined. This is mainly due to the reduction of solar radiation intensity caused by cloud occlusion and thus the output power decreases. After 12:45, the output power started to decrease because of a decrease in solar radiation intensity. After 14:30, the output power under condensing conditions is lower than non-condensing, because the incident angle of the light gradually decreases with time, and the shielding effect of the reflector on the light becomes more and more obvious, resulting in condensing The rate of decrease of the output power of the panel is higher than that under the non-light-condensing condition.

![Figure 6. Change in water temperature difference](image)

It can be seen from Figure 6 that the inlet temperature is increasing over time. This is because the water at the inlet of the collector comes from the circulating water tank. The temperature of the water passing through the collector rises and flows to In the circulating water tank, it is pumped out by the water pump, and then reheated into the collector, so the water temperature at the inlet of the collector is constantly rising. When it reached 12:30 noon, the radiation intensity was about 943w/m², and the temperature of the inlet water reached the highest, about 33.8°C. After that, the temperature of the inlet water began to decrease due to the decrease in radiation intensity. With the increase of the radiation intensity, the difference between the instantaneous temperature difference under condensing conditions and the instantaneous temperature difference under non-condensing conditions becomes significantly larger, reaching the maximum at 12:30, about 2.8°C and 2°C, respectively, which also reflects the concentration Advantages of optical systems. After 13:00, as the radiation intensity and ambient temperature decrease, the light-gathering effect gradually decreases, so the instantaneous temperature difference between the inlet and outlet of the collector gradually decreases. Between 9:00 and 11:00, due to the low temperature of the inlet water, the endothermic effect of the working fluid is very good at this time, so the instantaneous temperature difference change rate (that is, the slope of the temperature difference curve) continues to decline until it reaches a minimum at noon, which condenses The rate of change of instantaneous temperature difference under non-light-gathering conditions is basically zero. However, the rate of decrease of the instantaneous temperature difference change rate under condensing conditions is significantly higher than that under non-condensing conditions, which indicates that the performance of the condensing system is excellent. When the radiation intensity reaches a maximum of 922w/m², the output power of the concentrating solar panel is about 87.58w. Compared with non-concentrating systems, its power increase is about 11.42%;The highest heat collection efficiency is about 0.459 and 0.415, with an increase of about 10.6%. At this time, the solar radiation intensity is about 943w/m², the maximum instantaneous temperature difference is about 2.8°C, and the average heat collection efficiency is 0.388.

4. Conclusion
(1) Adopting a V-type reflective condenser, this method of condensing greatly reduces the cost of production, installation and maintenance, and improves convenience. Design calculation and analysis of the structure size of the condenser, the results show that: proper truncation of the condenser can increase the area of the superposition of the condenser, reduce the height of the condenser, improve the efficiency and economic efficiency of the condenser. Therefore, according to the characteristics of the
Hohhot area and the user’s energy needs, according to the 100W modular power generation system, the horizontal angle of the reflector is 60° and the width is 500mm.

(2) The optical performance of the condenser is simulated through Trace-Pro. The geometric focusing ratio is about 1.75, and the focusing performance is good, and the light distribution is relatively uniform. When the incident angle of the light reaches above 60°, the uniformity will obviously increase, and the intensity of solar radiation will have a significant effect on the improvement of the uniformity of the light concentration.

(3) The experimental bench of the integrated photovoltaic-thermal system shows that when the incident angle of the light is too low, the light-gathering effect is poor, and the output power is basically not improved, but because the solar radiation intensity is low at this time, the impact is not great. During the experiment, when the radiation intensity reached a maximum of 922w/ m², the output power of the concentrating solar panel was about 87.58w. Compared with the non-concentrating system, its power increase was about 11.42%, and the photoelectric conversion efficiency was small. It is about 2.15%; the maximum heat collection efficiency is about 0.459 and 0.415, with an increase of about 10.6%. At this time, the solar radiation intensity is about 943w/m², the instantaneous temperature difference is about 2.8°C, and the average heat collection efficiency is 0.388.

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