Pine-like concentrating power generation device

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Abstract. Today, when energy problems are increasingly prominent, the development and utilization of solar energy has become the focus of achieving sustainable energy development. However, due to the dispersion of solar radiation energy and atmospheric absorption, the radiation intensity directly reaching the surface of the earth is relatively weak. The existing linear Fresnel concentrators in engineering are huge in size and have low concentration ratios. In order to increase the concentration ratio of the CSP device, the pine-like CSP device combines the advantages of both the CSP device and the tree-like structure. It has the advantages of low cost, high efficiency, and small footprint, which will solve the problem. This will be a useful attempt to solve the problem of urban solar energy utilization and give new ideas to solve the problem.

1. Introduction

1.1. Research background
Since the beginning of the 21st century, with the increase in population and economic output, the total energy demand will continue to grow. According to research, oil and natural gas will be exhausted in the middle of the 21st century. Fossil energy has the disadvantages of serious pollution and non-renewable. It is imperative to develop clean and renewable energy to replace fossil resources. With abundant solar energy reserves, it is an environmentally friendly and clean renewable energy source. At present, the global total installed capacity of CSP is about 5 GW, of which trough CSP stations account for about 4.5 GW, accounting for about 90%. Figure 1 is a table of changes in the installed capacity of global CSP systems in recent years.

Figure 1. Changes in installed capacity of the global solar power industry.
1.2. Significance
At the end of 2014, the National Energy Administration issued the "Notice of the Comprehensive Department of the National Energy Administration on the Preparation of the 13th Five-Year Plan for Solar Energy Development". Among them, solar thermal power generation is mentioned as an important content. This means that CSP will become an important industry that my country will focus on during the 13th Five-Year Plan period.

In the project, sunlight is concentrated, and the existing solar thermal power generation devices are divided into two categories: following systems and non-following systems. The two types of CSP have their own shortcomings. The shortcoming of the CSP with the follower system is that the light-receiving area per unit area is not high. This shortcoming also leads to the larger area of the ordinary CSP, Is not conducive to installation and use in cities and other places with dense buildings and high traffic. However, the solar thermal power generation device without following system changes with the latitude, longitude and time of the installation position, and the power generation efficiency is always lower than that of the thermal power device with following system. Experiments have shown that the efficiency of a CSP without a follower system is about 33.7% compared to a CSP with a follower system.

2. Design ideas
Based on the current status of low concentration ratio and large floor space, in order to improve the concentration ratio and space utilization of photovoltaic heating devices, the research team of this device has absorbed The experience and deficiencies of the predecessors use the idea of bionics. We select pine as the research object. The angle between the different branches of the pine tree is 137.5 degrees in the projection direction, the branches extend horizontally, and the overall shape is conical. This device imitates the structure of a pine tree, and intends to install a fan-shaped concentrator at the end of each branch to imitate the leaves to absorb sunlight. The fan-shaped concentrator is installed on a horizontal bracket with an angle of 137.5 degrees in the vertical projection direction, imitating the branches of a pine tree. The fan-shaped concentrators on different branches are all part of the parabolic surface of revolution, and the focal points are all located at the top of the tree-shaped bracket. A Stirling engine and a generator are installed at the top of the tree-shaped support. The Stirling engine is started by the concentrated solar energy to drive the generator to rotate and complete the conversion of solar energy to electrical energy. The following system adjusts the angle of the fan-shaped condensing sheet at all times to ensure that sunlight can be concentrated on the heated end of the Stirling engine under the irradiation of sunlight at different times and at different angles, and the Stirling generator drives the generator to remove the light. It can be converted into electrical energy, after the voltage is stabilized, the battery is charged and converted into chemical energy in the battery.

3. Scheme analysis
3.1. Module function
The concentrating power generation device is composed of a concentrating module, a power generation module, a power storage module and a control module. The specific functional division and composition are shown in Table 1.

| Module                  | Function                                      |
|------------------------|-----------------------------------------------|
| Condenser module       | Gather sunlight together                      |
| Energy absorption module | Absorb heat and transfer it to the engine    |
| Power generation module | Stirling engine drives generator to generate electricity |
| Power storage module   | Stabilize and store electrical energy         |
| Control module         | Control the device                            |
3.1.1. Condenser module
On top of the shortcomings of the traditional linear Fresnel solar power system, this device innovatively uses a ring-shaped linear Fresnel high-power concentrator, which is based on a flat lens and surrounded by a new ring mirror. Surrounded by the structure, a new type of concentrator device is formed. We divide it into different fan-shaped surfaces and distribute them on the support frame proportional to the golden ratio, forming a pine tree structure from bottom to top, using the largest area of light energy in the space, greatly increasing the concentration ratio, after gathering The high-density sunlight can be used to drive a Stirling engine to generate electricity. The distribution map of the condenser is shown in Figure 2.

Figure 2. Distribution diagram of the condenser.

3.1.2. Power generation module
The function of the power generation module is to efficiently convert heat energy into electrical energy, and the Stirling engine is the core of the module. Stirling engine, also called hot air engine, is a closed-cycle piston engine that can use multiple energy sources as fuel, and is also a reciprocating power equipment.

3.1.3. Power storage module
The power storage module is composed of a 12V voltage stabilizer and a battery. The function of the voltage stabilizer is to stabilize the voltage output by the generator at about the charging voltage of the battery to ensure the stability of the charging current of the battery. The voltage stabilizer consists of a voltage regulating circuit, a control circuit. When the input voltage or load changes, the control circuit will sample, compare, and amplify, and then drive the servo motor to rotate to change the position of the carbon brush of the voltage regulator, and automatically adjust the coil turns ratio to maintain the output Voltage stability.

3.1.4. Control module
The control module adopts active single-axis tracking and is mainly composed of three parts: Stm32 control system, steering gear drive system, and angle sensor. First, the angle sensor transmits the measurement signal to the Stm32 control system. The real-time position of the sun is calculated by the corresponding formula and parameters, and the real-time angle $\rho$ is calculated from the real-time position of the sun, and then the reflector is tracked to the rotation of the sun. Calculate the deviation between the angle $\rho$ and the reflector position feedback angle $\phi$ measured by the angle sensor: In the program execution cycle, if $\rho-\phi>0$, and its absolute value is greater than the set angle threshold, the system will generate a motor-driven action Command to make the mechanism run from east to west to track the sun; if $\rho-\phi<0$ and its absolute value is greater than the set angle threshold, the system will generate a motor-driven action command to make the mechanism run from west to east to track the sun; If the absolute value of the deviation is less than the set angle threshold, it means that the reflector has tracked the sun.
3.2. Stm32 control program flow
Stm32 needs to complete initialization, data acquisition, data processing, and steering gear drive. First of all, system initialization requires setting of system time and system parameters, including local longitude and latitude, time zone, tracking effective sun angle, interval tracking interval time and other parameters. In order to shorten the action time of the steering gear, the program is usually executed every 1 minute. The execution cycle is set to 20 s. The program must first determine the control mode of the system. If it is in automatic mode, the program will execute the logic program of automatic control. If it is not in automatic mode, it will enter manual mode. After reading the local latitude, longitude, time and other data, the Stm32 program calculates the tracking angle of the reflector according to the above mathematical formula, and compares it with the current reflector angle measured by the angle sensor. When the error between the two is greater than 0.4 degrees, the program executes Follow instructions. The working time of the system is set from 6 am to 8 pm. The clock chip of the controller wakes up the controller at 6 am every day. After sunset, Stm32 issues an instruction to quickly return the reflector to the initial position and wait for it to start again. The control logic flow chart is shown in Figure 3.

![Control logic flow chart](image)

3.3. Work process
The concentrating power generation device is composed of the above modules, and the overall configuration is shown in Figure 4. When the device is working, the control module controls the angle of the steering gear to rotate the condenser to a proper angle. Then the condensing sheet concentrates the sunlight on the energy absorbing device. The Stirling engine drives the generator to rotate under its action, and the generated current is stored in the battery through the function of the voltage regulator module.
4. Innovation advantage
The pine-like concentrating power generation device mainly has the following innovations:

4.1. Make full use of light energy per unit area
The light-concentrating device of this device imitates the golden section arrangement of the branches of pine trees. Through the effective use of space, the light energy is maximized and the floor space is effectively saved. Improve the efficiency of solar thermal power generation.

4.2. Small footprint, can be deployed in public places
The device looks like a pine tree, has a beautiful shape, a small area, and a large deployment range, which will not deface the environment in the city.

4.3. High degree of automation, can automatically track the sun
This device uses Stm32 microcontroller as the main controller. By controlling the steering gear to control the angle of the Fresnel condenser lens, the light is always concentrated on the energy absorbing device. Then we let the Stirling engine continue to absorb energy and drive the generator to generate electricity. This can maximize the conversion of solar energy.

5. Conclusions
The development and utilization of solar energy is of great significance to alleviating the world energy crisis and improving the national energy structure. With the advancement of solar power technology in my country, CSP will be further developed. The imitated pine CSP device will make a useful attempt to solve the problem of urban solar energy utilization and give new ideas to solve the problem.

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References
[1] Yin, W.H. (2017) Research on the status quo and problems of my country's renewable energy development. J. Finance and Economics, 23: 3-4.
[2] Liu, M.Y., Qi, H.Q., Zheng, J.T., etc. (2016) Economic analysis of Fresnel solar thermal power station. J. Energy Conservation Technology, 34:353-381.
[3] Luo, C.H., Zhang, H., Li, Y.H. (2018) Design of ring-band Fresnel lens with uniform image surface illumination. J. Journal of Applied Optics,39: 7-11.
[4] Pu, C., Zhang, G.Y. (2011) The design of Fresnel solar condenser. J. Applied Optics, 32:23-16.

[5] Du, C.X., Wang, P., Ma, C.F., etc. (2010) Optical Geometric Method for LFR Mirror Field Arrangement Without Shading and Blocking. J. Acta Optica Sinica, 30:3276-3282.

[6] Yang, J.H. (2017) Application technology of solar photovoltaic power generation. Electronic Industry Press, Beijing.