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Enhancing Heliostat Field Performance: A Comprehensive Study on Optical Efficiency and Annual Thermal Power

Kunzheng Wang*, Yao Liu, Haolin Qin

School of Software, Henan Normal University, Xinxiang, 453007, China
*Corresponding author: 2228524051@stu.htu.edu.cn

Abstract: The many advantages of solar photovoltaic technology make it bound to be commercially competitive in the coming years, and its development is strategically important. The parameters of the heliostat field, including the positional coordinates of the absorber tower, the size and mounting height of the heliostat mirrors, as well as the number and position of the heliostat mirrors, are designed according to the requirement of the rated annual average thermal power output of 60 MW so that the heliostat field will have the largest possible annual average thermal power output per unit of mirror area under the condition of reaching the rated power. Larger sizes and higher mounting heights of heliostats help to capture more solar energy and thus increase the annual average output thermal power per mirror area. The efficiency and output thermal power of heliostats of different sizes and mounting heights are evaluated by simulating the numerical calculation method and the best combination is found.

Keywords: Transformation of the energy structure, Comprehensive utilization of solar energy, large resource utilization, Output thermal power.

1. Introduction

The establishment of new clean energy-led power systems is one of the key strategies for the transformation of the energy mix in developing countries [1]. The heliostat is an important basic concentrator unit in the tower-type photovoltaic power generation system, and its accuracy in tracking the sun and reflecting the sunlight directly affects the power generation efficiency of the whole photovoltaic power plant [2]. Firstly, the settlement is calculated by wind tunnel test and numerical simulation to compare the calculation results of simulation and wind tunnel [3]. The simulation results are in good agreement with the test results, fully verifying the reliability of the CFD simulation method used [4]. At the same time, in order to investigate the changes of the sun's azimuth and altitude angle, the date, geographic location and other data will be integrated into the matlab simulation software to obtain simulation results. In this work, we use the CFD simulation method model to build the model [5]. Data for this study was obtained from (http://www.mcm.edu.cn/)

2. Fundamentals of A Fixed-sun Mirror Field

2.1. Structure of the heliostat field

As can be seen in Figure 1. The heliostat is the basic component for collecting solar energy in tower solar thermal power plants (hereinafter referred to as tower power plants), and its base consists of a Its base consists of a longitudinal rotating axis and a horizontal rotating axis, and the plane reflector is mounted on the horizontal rotating axis. The axis of the longitudinal rotary axis is perpendicular to the ground, which can control the azimuth of the mirror. The axis of horizontal axis is parallel to the ground, which can control the pitch angle of the mirror, and the heliostat and base are shown in Figure 1. The height of the intersection of the two axes (which is also the center of the heliostat) from the ground is called the mounting height of the heliostat. Tower Power stations utilize a large number of heliostats to form an array, called a heliostat field. Fixed sun mirror will reflect the sunlight convergence to the mirror field installed in the absorbing Collector mounted on the top of the tower, heating the heat-conducting medium, and the solar energy in the form of thermal energy storage, and then after heat exchange. The conversion of thermal energy into electrical energy is realized through heat exchange. Sunlight is not a parallel ray, but a conical ray with a certain cone angle, therefore , the reflection of the incident light from the sun at any point of the mirror is also a conical ray. When the heliostat works, the control system According to the position of the sun, the control system controls the normal direction of the heliostat in real-time, so that the light emitted from the center of the sun is reflected by the center of the heliostat and pointed to the center of the collector. The center of the collector. The height of the center of the collector above the ground is called the height of the absorber tower.

Figure 1. Schematic diagram of heliostat and base (https://baike.baidu.com/item/%E5%AE%9A%E6%97%A5%E9%95%9C/9109957)

2.2. Determination of the optimal mirror field arrangement

In the context of the rated power level of 60MW, if all the heliostats have the same size and mounting height, the following parameters of the heliostat field are designed: the positional coordinates of the absorber tower, the size of the heliostats, the mounting height, the number of heliostats, and the position of the heliostats, so that the heliostat field will have as large an average annual thermal power output per unit of mirror area as possible under the condition of reaching the rated power level.

3. Results

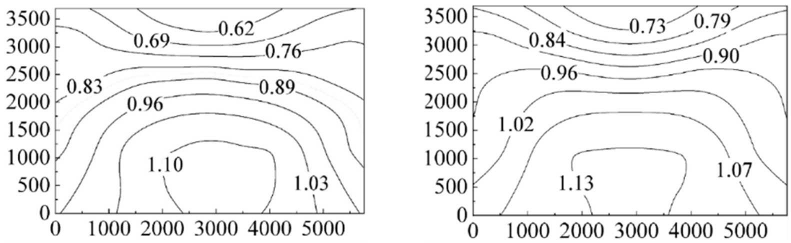
3.1. The establishment of the simulation model

To simulate the variation of the sun's azimuth and altitude, the date and geographic location data are entered into the Matlab software to realize the simulation.

3.2. Analysis of experimental results

Figure 2 shows the distribution of the mean wind pressure coefficients on the surface of the heliostat for the wind tunnel test and numerical simulation with the elevation angle of the heliostat at 60° and the wind direction at 0°. Figure 3.10 shows the distribution of the average wind pressure coefficient on the surface of the sidereal mirror for the wind tunnel test and numerical simulation at 60° elevation and 0° wind angle. In this paper, the average wind pressure coefficients are the net average wind pressure coefficients superimposed on the upper and lower surfaces of the structure.

From the figure, it can be seen that the mean wind pressure coefficient of the mirror surface of the heliostat is symmetrically distributed at a 0° wind angle. The average wind pressure coefficients of wind tunnel test values range from 0.62 to 1.13, with the maximum value occurring at the lower center of the mirror and the minimum value at the upper center of the mirror. The maximum value occurs at the lower center of the mirror and the minimum value occurs at the upper center of the mirror. The results of the numerical simulation ranged from 0.73 to 1.14, and the distribution of maximum and minimum wind pressure coefficients was consistent with the test results. The distribution of maximum and minimum values of wind pressure coefficient is consistent with the test results. Comparing the results of the simulation and wind tunnel calculation, they are in good agreement, indicating that the simulation method is reliable.

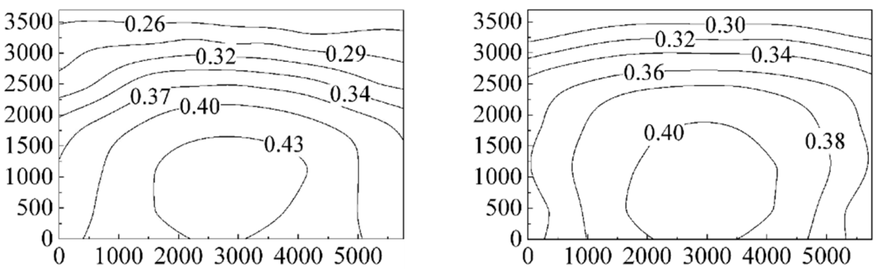


a.wind tunnel experiment b.CFD data simulation

Figure 2. Distribution of mean wind pressure coefficients on the surface of the heliostat

Figure 3 shows the distribution of the pulsating wind pressure coefficient on the surface of the heliostat mirror in the wind tunnel test and numerical simulation at an elevation angle of 60° and a wind angle of 0°. From the figure, it can be seen that the surface pulsation wind pressure coefficient of the heliostat gradually increases from the upper edge to the lower edge of the mirror under the wind angle of 0°, and is symmetrically distributed. The values of the pulsation wind pressure coefficient on the surface of the heliostat mirror in the wind tunnel test are between 0.26 and 0.43, and the values of the pulsation wind pressure coefficient in the numerical simulation are between 0.30 and 0.41, and the results of the two methods are in good agreement, and the distribution of pulsation wind pressure coefficient on the surface of heliostat mirror is in good agreement.

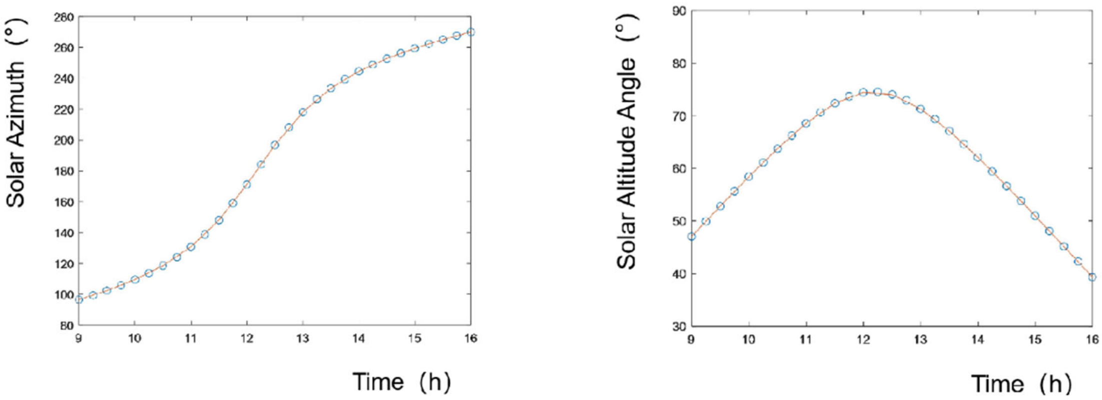
The results of the two methods are in good agreement, and the distribution trends of the pulsating wind pressure coefficients are also consistent. Comparing the distribution patterns of the average wind pressure coefficient and the pulsating wind pressure coefficient on the mirror surface of the heliostat, it can be seen that the distribution patterns of the two are the same, with the minimum value appearing at the upper edge of the mirror surface and the maximum value appearing in the middle of the mirror surface at the lower position.



a.wind tunnel experiment b.CFD data simulation

Figure 3. Distribution of pulsating wind pressure coefficients on the surface of heliostats

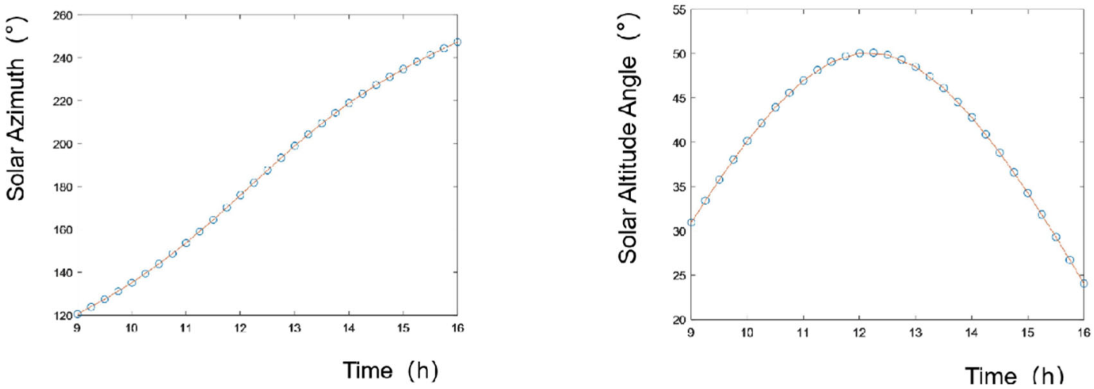
To simulate the sun's movement, we may take Baoding City, Hebei Province (38.873891°N,115.464806°E) as the target for simulation to study the changes of the sun's azimuth and altitude on September 22, 2020, and June 21, 2020, and input the data of the date and the geographic location into the simulation program to obtain the simulation results. We take 9:00 to 16:00 as the study period of a day to imitate the movement of the sun in a day, observe the simulation results every 15 minutes, record the simulation data, and input the data into MATLAB simulation to get the image of the change of altitude angle and azimuth angle in a day on the summer solstice:



a.Graph of solar azimuth change b.Solar altitude angle variation graph

Figure 4. Summer solstice solar altitude angle azimuthal variation plot

The data were integrated and fed into Matlab simulation to obtain an image of the change in altitude angle azimuth throughout the day on the fall solstice.



a.Graph of solar azimuth change b.Solar altitude angle variation graph

Figure 5. Curve of variation of solar altitude angle azimuth on the fall solstice

From Figure 4 and Figure 5, it can be seen that the sun's altitude angle is increasing and then decreasing throughout the day, and the altitude angle will reach its maximum value around noon, it can be seen from the data points in Figure that the rate of change of the angle is faster in the morning and afternoon, and the rate of change is more moderate around noon. From Figure 4 and Figure 5, the sun azimuth angle in a day was rising trend, has been increasing, and noon can be seen in the rate of change of the inflection point, that is, the maximum rate of change at noon, the summer solstice sun directly to the Tropic of Cancer, the equator on the autumnal equinox sun directly to the equator, due to the simulation site is located in the northern hemisphere, summer solstice sunshine time is the longest, the altitude angle and the angle of change than the autumn equinox is also more pronounced inflection point, the above data with The above data and change rule is in line with the actual movement of the sun, and can be used as an important data for the future reference of the position of the heliostat.

4. Conclusions

This paper provides a research idea and framework for use in the field of energy structure transformation, which helps to build a new energy modernization. At the same time, the simulation results are obtained by inputting the date, geographic location and other data into the simulation program, and 9:00 to 16:00 in a day as the research cycle to imitate the sun's movement trajectory in a day to get the simulation data, and then the data are integrated and inputted into the matlab simulation to get the change of altitude angle and azimuth angle images in a day. The above data and the rule of change are in line with the actual movement of the sun, and can be used as an important data for the future reference of the position of the heliostat. This paper explores this through wind tunnel wind tunnel tests and numerical simulations. From the above comparative analysis of wind tunnel test and numerical simulation results, it can be seen that the simulation results are in good agreement with the test results, and the reliability of the CFD simulation method used in this paper is fully verified. The feasibility of the method is demonstrated.

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