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Research on heliostat field design based on mesh search optimization algorithm

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Abstract. Nowadays, heliostat field has been gradually put into practical production, how to design heliostat field to make the highest efficiency of light energy utilization is an important problem. By establishing the adjustment model of heliostat, the design problem of heliostat field is studied by using the mesh search optimization algorithm. First, the position of the absorption tower is determined, so that the heliostat is closely arranged, and then the annual average output thermal power per unit mirror area is as large as possible as the objective function. The optimization model is established for the size requirements, installation height and center distance of the heliostat as the constraint conditions, and then the grid search algorithm is used to solve the problem and remove the heliostat with low output thermal power. Until the selected 60MW rated average annual thermal output power is reached, the result is that the average annual thermal output power per unit area of the mirror is 0.6011kw/m2 under the same heliostat size and the average annual thermal output power per unit area of the mirror is 0.6138kw/m2 under different heliostat sizes. The feasibility and accuracy of the model are verified by a concrete example, which lays a foundation for the design of defining the mirror field.

Keywords: Heliostat adjustment model; Average annual thermal power output; Grid search optimization algorithm.

1. Introduction

The accurate prediction of power load is of great significance for the electric power production and the safe operation of the power grid and the national economy [1]. Short term load forecasting is an important part of energy management system. The prediction error directly affects the analysis results of subsequent safety check of power grid, which is of great significance for dynamic state estimation, load scheduling and cost reduction [2-4]. Traditional prediction methods are based on linear regression, such as time series method, analysis method and pattern recognition method has defects of respectively [5].

Heliostat field is one of the most important subsystems in tower photothermal power station [6]. Tower solar solar thermal power generation technology with its unique advantages, such as large concentration ratio, high system efficiency and good power quality, quickly emerged, showing broad prospects for development[7]. In the early stage of the construction of solar thermal power station, optimizing the heliostatic field arrangement is one of the important keys to be solved.

In the design process, it is very important to select the appropriate connection positioning size.In this way, the optical performance can be improved as much as possible under the premise of meeting the light concentration. Because the construction cost of Dinggri mirror field in tower solar thermal power station accounts for a considerable proportion of the total investment of the whole power station (about 30%~50%), how to arrange the high-efficiency and low-cost Dinggri mirror field has become a research hotspot.

As the energy input unit of the whole system, the concentrating efficiency of the heliostat field directly affects the power generation of the whole solar thermal power station. Therefore, the arrangement of heliostat is very important in the mirror field. In order to design a more reasonable arrangement of the heliostatic field, some scholars combined the optimization of the heliostatic field arrangement problem with intelligent optimization algorithm, and put forward a variety of flexible and efficient arrangement methods.

In a tower photothermal power station, the heliostat field is usually composed of multi-sided heliostat installed around the endothermic tower according to certain arrangement rules, which is determined according to the design requirements of the power station. Its main function is to reflect the sun's rays to the top of the heat-absorbing tower on the heat absorber, to collect solar radiation energy, and through the heat exchange medium to drive the generator (usually use the steam turbine) for power generation.

Therefore, the arrangement scheme of the fixed sun mirror field has an important influence on the performance and economic benefit of the photothermal power station. By fully considering the optimization of the layout and the use of intelligent optimization algorithm, the high efficiency and low cost of the heliostatic mirror field can be realized, so as to improve the power generation capacity and sustainable development level of the whole tower solar thermal power station.

2. Materials and methods

2.1. Data acquisition and preprocessing

According to the plan, a circular heliostatic field is planned to be built at the central position of 98.5° east longitude and 39.4° North latitude at an altitude of 3000m. The site will be used to install a heat collector with a diameter of 350m, that is, a cylindrical external light collector with a height of 8m and a diameter of 7m. The height of the absorption tower is planned to be 80m, and a factory building within 100m of it will be used to install equipment such as power generation, energy storage and control. No heliostat will be installed within this range.

The heliostatic mirror will have a mirror side length between 2m and 8m and will be mounted at a height between 2m and 6m to ensure that it does not touch the ground when rotating horizontally. In order to facilitate routine maintenance, repair, cleaning and replacement of parts, the distance between the center of the adjacent heliostat base should be at least 5m more than the width of the mirror.

Based on the rated annual average output thermal power of 60MW, the scheme of different heliostat sizes and mounting heights is discussed to meet the following design requirements: By changing the position coordinate of the absorption tower, the size of the heliostat, the installation height, the number of heliostat and the installation position, under the condition of meeting the rated power, the average annual output thermal power per unit mirror area of the heliostat field is made as large as possible and the specific results are obtained.

2.2. Method introduction

Grid search algorithm is a simple and widely used hyperparameter search algorithm[8]. It divides the parameters to be selected into a grid, and then selects the best combination of parameters by traversing all the parameter combinations [9]in the grid, without favoring any particular parameter.

The simplicity of the algorithm makes it easy to understand and implement. By trying each parameter combination exhaustively, grid search is able to find the hyperparameter combination that performs best on a given data set. This comprehensive search method ensures that the combination of parameters found by the algorithm is the optimal solution in the given hyperparameter space, thus improving the performance and accuracy of the model.

The grid search algorithm performs more evenly in terms of performance, memory overhead, and accuracy[10]. It guarantees a comprehensive consideration of performance, memory overhead and accuracy by traversing all possible parameter combinations, independent of any particular parameter setting preferences. Although this method may increase the computational cost, it ensures that the combination of parameters found is optimal, thus achieving better performance in all aspects.

To sum up, the grid search algorithm is a simple and effective hyperparameter search method, which searches the parameter space comprehensively to find the best parameter combination, thus achieving a more balanced performance in terms of performance, memory overhead and accuracy.

3. Model building and solving

3.1. Determination of the position of endothermic tower

Change the position of the heat-absorbing tower, it is found that when the heat-absorbing tower deviates from the center position, its annual average output thermal power decreases, so the heat-absorbing tower is placed in the center of the circular area is the most appropriate. This has the following advantages: Maximize

the focus of light: Placing the tower in the center of the mirror field can maximize the focus of the sun's light, so that it can concentrate as much as possible to the collector at the top of the tower.

Balance light distribution: Placing the tower in the center position can balance the distribution of light and avoid the uneven focus of light or the loss of certain light focusing ability due to the deviation from the center position.

3.2. Determination of heliostat position

First of all, the heliostat row is covered in the area where the heliostat can be arranged (the arrangement should be carried out according to the constraint conditions), and the distance between the adjacent heliostat is greater than or equal to the width of the heliostat plus 5m. Arrange the heliostats from the innermost ring first, and then arrange the second circle. When the second circle is arranged, the center of the heliostats is arranged along the angular bisector line between the two heliostats arranged center and the center of the endothermic tower adjacent to the first circle, as shown in Figure 1.

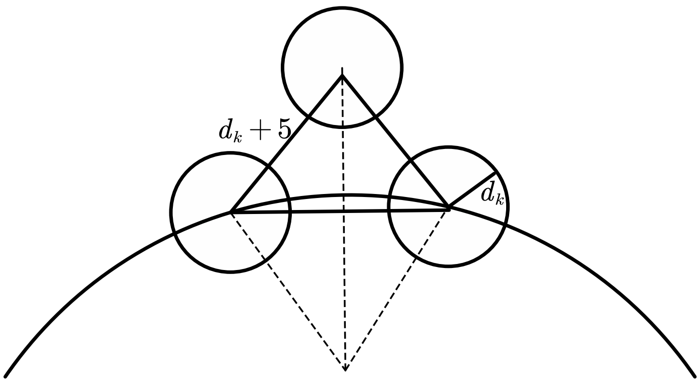

Figure 1. Schematic diagram of heliostat arrangement

When the compact arrangement is completed, the average annual thermal output is calculated with the thermal output of each heliostat. Those with low thermal output are deleted so that the average annual output power of the heliostat field is rated at 60MW.

3.3. Establishment of heliostat model of the same size

3.3.1. Establishment of objective function.

$$p_{Unit\ area} = \frac{DNI \sum_{j}^{60} \sum_{i}^{N} A_{ij} \eta_{ij}}{N h_a h_k} \tag{1}$$

As can be seen from equation (1), the objective function is the average annual output thermal power per unit mirror area, and DNI represents the irradiance of normal direct radiation, which is calculated as follows

$$\mathrm{DNI} = G_0\left[a + be^{\left(-\frac{c}{\sin\alpha_s}\right)}\right] \tag{2}$$

$$\begin{cases} a = 0.4237 - 0.00821(6 - H)^2 \\ b = 0.5055 + 0.00595(6.5 - H)^2 \\ c = 0.2711 + 0.01858(2.5 - H)^2 \end{cases} \tag{3}$$

Where, H represents the local altitude, the unit is km, G_0 is the solar constant, and its value is taken as 1.366 kW/m^2.

3.3.2. Establishment of constraint conditions.

The installation height must ensure that the mirror will not touch the ground when rotating around the horizontal axis, that is, the installation height should be greater than half the height of the helioscope, h_g is the installation height of the helioscope, h_a is the height of the helioscope.

$$h_g > \frac{1}{2}h_a \tag{4}$$

The distance between the center of the adjacent heliostat base is more than 5m more than the width of the mirror, wherein. $i = 1, 2, 3, ..., N-1$ .N represents the number of heliostat, O_i represents the center coordinate (x_i, y_i, z_i) of the i heliostat, and h_k represents the mirror width.

$$|O_{i+1} - O_i| - h_k > 5 \tag{5}$$

The average rated annual output thermal power of the heliostat field is 60MW, where i=1,2,3... ,N; J = 1, 2, 3... ,60. A_{ij} Represents the lighting area of the i heliostat at time j; η_{ij} Represents the optical efficiency of the heliostat on side i at moment j.

$$E_{field\,rated} = DNI\sum_j^{60}\sum_i^N A_{ij}\eta_{ij} = 60000 \tag{6}$$

No heliostat is installed within 100m around the absorber, where O_t is the coordinate (x_t, y_t, z_t) of the center of the absorber, and O_i is the central coordinate (x_i, y_i, z_i) of the i th heliostat.

$$|O_t - O_i| \geq 100 \text{ (i = 1,2,3 ..., N)} \tag{7}$$

The side length of the mirror is between 2m and 8m and the width of the mirror is not less than the height of the mirror, namely

$$\begin{cases} 2 \leq h_a \leq 8 \\ 2 \leq h_k \leq 8 \\ h_a \leq h_k \end{cases} \tag{8}$$

The installation height of the heliostat h_g is between 2m and 6m, that is

$$2 \leq h_g \leq 6 \tag{9}$$

By integrating the above conditions, the final optimization model can be established as follows:

$$\max\ p_{Unit\ area} = \frac{DNI \sum_j^{60} \sum_i^N A_{ij}\eta_{ij}}{N h_a h_k} \tag{10}$$

$$\begin{cases} h_g > \frac{1}{2} h_a \\ |O_{i+1} - O_i| - h_k > 5 \\ E_{field\ rated} = DNI \sum_j^{60} \sum_i^N A_{ij}\eta_{ij} = 60000 \\ |O_t - O_i| \geq 100\ (\mathrm{i} = 1,2,3 \dots, \mathrm{N}) \\ 2 \leq h_a \leq 8 \\ 2 \leq h_k \leq 8 \\ h_a \leq h_k \\ 2 \leq h_g \leq 6 \end{cases} \tag{11}$$

3.4. Establishment of heliostat models of different sizes

3.4.1. Establishment of objective function.

Compared with the objective function of heliostats of the same size, the denominator becomes the sum of the areas of each heliostat individually, i.e. :

$$p_{Unit\ area} = \frac{DNI \sum_j^{60} \sum_i^N A_{ij}\eta_{ij}}{\sum_i^N h_{ai} h_{ki}} \tag{12}$$

3.4.2. Determination of constraints.

The constraints of heliostats of different sizes and endothermic towers are the same as those of heliostats of the same size, which will not be repeated here.

In summary, the optimization model of heliostat of different sizes can be determined as follows:

$$\max\ p_{Unit\ area} = \frac{DNI \sum_j^{60} \sum_i^N A_{ij}\eta_{ij}}{\sum_i^N h_{ai} h_{ki}} \tag{13}$$

$$\begin{cases} h_g > \frac{1}{2} h_a \\ |O_{i+1} - O_i| - h_k > 5 \\ E_{field\ rated\{\square} = DNI \sum_j^{60} \sum_i^N A_{ij}\eta_{ij} = 60000 \\ |O_t - O_i| \geq 100\ (\mathrm{i} = 1,2,3 \dots, \mathrm{N}) \\ 2 \leq h_a \leq 8 \\ 2 \leq h_k \leq 8 \\ h_a \leq h_k \\ 2 \leq h_g \leq 6 \end{cases} \tag{14}$$

3.5. Solution of the model

3.5.1. Solving the heliostat model of the same size.

In the design and research of heliostat field, it is solved by grid search optimization algorithm. Grid search is a method to optimize the model performance by traversing a given combination of parameters. In practice, when trying to determine the best parameters (otherwise known as hyperparameters) for a model, a common approach is to try all possible combinations and choose the one that performs best. The goal is to find the best number and size in the solar reflector array to maximize the average annual thermal output per mirror area and to ensure that the total average annual thermal output is at least 60MW. To achieve this goal, use a grid search to explore the various possible combinations of heliostat number and size.

The solution steps are as follows:

Step1: Set the value range of the parameter: Number of heliostats: from 500 to 3000, increase by 50 each time. Heliostat size: from 2 to 7.

Step2: Go through all possible parameter combinations: For each heliostat number and each heliostat size, calculate the corresponding annual average thermal output power.

Step3: Evaluate the performance of the model: use the 'calc_results' function, which is based on the sun's altitude Angle, azimuth Angle and other factors, as well as the position of the mirror to calculate the related efficiency and thermal power.

Step4: Record the qualified results: If the annual average output thermal power of a certain parameter combination is more than or equal to 60, then record this combination and the corresponding thermal power.

Step5: Output results: All the parameter combinations that meet the conditions and the corresponding results are stored in a data frame.

In short, by using the grid search method to find the best configuration of the solar mirror array, in order to obtain the maximum annual average output thermal power per unit mirror area, while ensuring that the overall annual average output thermal power reaches the preset threshold.

3.5.2. Solving heliostat models of different sizes.

In this design study, the solution is carried out by multi-parameter mesh search optimization algorithm, whose goal is to automatically find the optimal neural network structure. While traditional deep learning methods require researchers to select or design network structures based on experience or literature, NAS aims to automate this process to find more efficient or precise networks for specific tasks. The algorithm works as follows: First, the search space is defined and possible network structures and configurations are determined. Then, you choose a search strategy and decide how to traverse the search space, such as using random search, genetic algorithms, or reinforcement learning. The architecture is then evaluated, evaluating its performance for each selected network architecture, usually based on the accuracy of the verification set. Finally, the best architecture is selected, and at the end of the search, the network architecture with the best performance is selected and fully trained.

The solution steps are as follows:

Step1: Through calculation, simulate the relative position of the sun and the earth in different months and times.

Step2: According to the position of the sun, calculate the radiation intensity of the sun.

Step3: Through optimization, find the optimal position and size of the heliostat, so that they can reflect sunlight to the collector to the maximum.

Step4: Considering the cosine loss of light, atmospheric transmittance, shadow loss and truncation efficiency and other factors, optimize the helioscope layout.

Step5: Find the combination of parameters that maximizes the thermal power of the system by trying different heliostat numbers, initial sizes and size increments.

4. Discussion

As can be seen from Figure 2, the distribution of heliostats is symmetrical up and down and asymmetrical left and right. The reason for this is that each heliostat is installed at the same height and size. The sun's irradiation on the heliostat field is southward, and the southern heliostat causes a larger shade to block each other, so the arrangement of the heliostat on this side is relatively

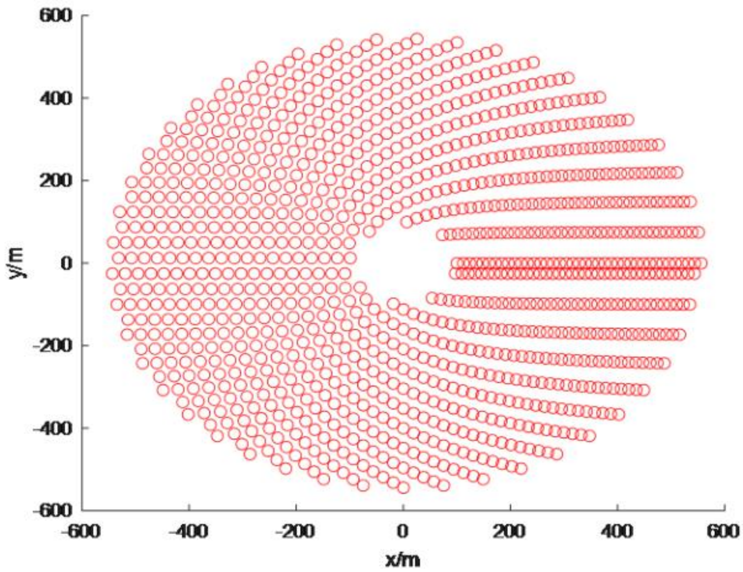

Figure 2. Field distribution of heliostats of the same size

As shown in Figure 3, compared with the field distribution diagram of heliostat of the same size, the arrangement of heliostat of different sizes is more compact, resulting in higher space utilization, because each individual heliostat can have a different size.

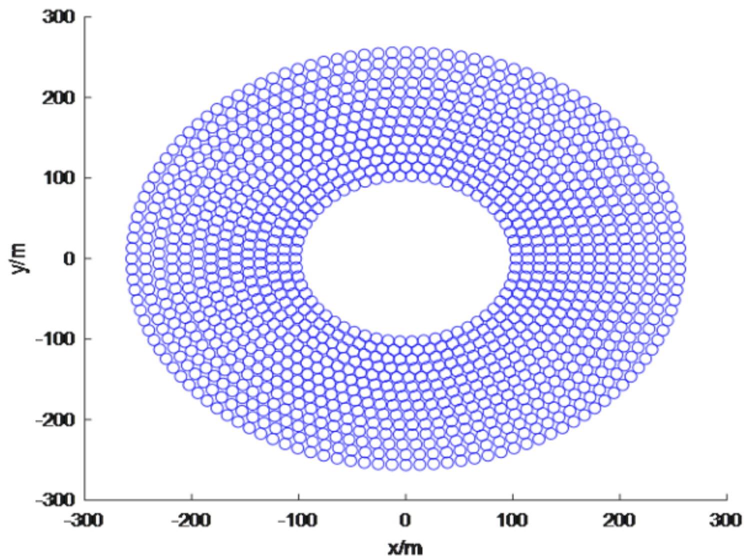

Figure 3. Field distribution diagram of heliostats of different sizes

5. Conclusion

By establishing the heliostat field optimization design model, the method of solving the average annual output thermal power per unit area under the same and different heliostat sizes is analyzed. Under the condition that each constraint condition is satisfied, the heliostatic field is traversed by the grid search optimization algorithm. Finally, according to the optimization model, the average annual output thermal power per unit area of the mirror is 0.6011kw/m2 under the same heliostat size and 0.6138kw/m2 under different heliostat size, which is not enough to verify the feasibility and accuracy of the model.

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