Journal of Computing and Electronic Information Management
ISSN: 2413-1660 | Vol. 11, No. 2, 2023

Design of Heliostat Field Based on Genetic Optimization Algorithm

Yunfei Zhang [1,*], Zhengzhi Kuang [1], Haoran Liu [2]

[1] School of Information Science & Engineering, Yunnan University, Kunming, China
[2] National Pilot School of Software, Yunnan University, Kunming, China
[*] **Corresponding author**: Yunfei Zhang (Email: 1095724527@qq.com)

Abstract: This paper mainly focuses on the in-depth study of the application of tower solar photovoltaic power generation technology in low carbon and environmental protection. The optimal design of the heliostat mirror field is carried out by using the ray tracing method and the genetic optimization algorithm. Firstly, the coordinate transformation of the reflective points of the heliostat mirror was realized by establishing the light cone coordinate system, mirror coordinate system and ground coordinate system, and the related annual average optical efficiency and thermal power were calculated; secondly, under the satisfaction of several constraints, the genetic algorithm was applied to optimize the parameters of the heliostat mirror field in order to maximize the annual average output thermal power per unit of mirror area. Finally, a comparison with the existing mainstream schemes proves the effectiveness and rationality of the model.

Keywords: Tower solar; Photovoltaic power generation; Ray tracing method; Genetic algorithm.

1. Introduction

In the face of global climate change and the challenge of sustainable development, China has actively implemented the "carbon peak" and "carbon neutral" strategies, in which tower solar thermal power generation has received increasing attention as a clean and low-carbon new energy solution. The technology effectively collects and converts solar energy through a large array of heliostats [1]. However, in real-world applications, how to maximize the thermal power output and efficiency of this system under multiple constraints is an urgent problem. Therefore, this study aims to address two key issues: first, to calculate the optical efficiency and thermal power output of the heliostat field at the annual average level based on the given absorber tower and heliostat parameters; and second, to optimize the various design parameters of the heliostat field to maximize the annual average thermal power output per unit mirror area, while satisfying the rated annual average thermal power output (60 MW) [2]. These studies will provide strong theoretical support for improving the overall performance of tower solar thermal power generation systems.

2. Principles of the model

2.1. Annual Optical Efficiency and Thermal Power Assessment

This section aims to accurately estimate the annual average optical efficiency, the annual average output thermal power, and the annual average output thermal power per unit mirror area for a given fixed-day mirror field through a multifactor analysis. First, the model considers several key efficiency parameters including, but not limited to, shadow shading efficiency, cosine efficiency, atmospheric transmittance, collector cutoff efficiency, and specular reflectance. Of these, the specular reflectance is set to a fixed constant value (0.92), while the other efficiency parameters need to be solved through mathematical modeling. The modeling further involved performing optical efficiency calculations on specific dates (21st of each month) and at specific points in time (five predetermined calculation time points). These optical efficiency data are then used to estimate the average efficiency for the day, from which the annual average optical efficiency is derived. After solving for the optical efficiency of a single heliostat mirror, the model introduces the normal direct radiant irradiance (DNI) as well as the mirror area as additional parameters to facilitate the calculation of the thermal power output of the entire heliostat field at a specific point in time. These thermal power data are further used to solve for the annual average thermal power output per unit mirror area. Through this series of calculation and solution steps, this study provides a comprehensive theoretical framework for the performance evaluation and optimization of a heliostat mirror field. In particular, the model gives an exhaustive performance assessment at the annual average level.

2.2. Multi-parameter optimization design of heliostat mirror field

The aim of this section is to further enhance the annual average thermal power output per unit mirror area of the heliostat field through comprehensive parameter optimization, while achieving the base constraint of 60 MW annual average thermal power output [3]. The model firstly establishes an objective function based on this baseline thermal power requirement, and then sets up constraints based on this objective function in combination with other factors such as mirror size and mounting height. To solve this complex optimization problem efficiently, an adaptive genetic algorithm is used as the main solution tool. The algorithm adopts a uniform coding strategy to reduce the computational burden, and specifically selects a specific period (e.g., 10.5 or 13.5 o'clock) on a typical day, such as the vernal or autumnal equinox, as the benchmark for model validation. The genetic algorithm implements dynamic parameter adjustments and strategy updates during the optimization process to gradually approximate the target annual average output thermal power. Through multiple rounds of iteration and screening, the model can effectively eliminate inefficient heliostat layouts, thus achieving the predefined optimization goal. In summary, the model provides an efficient and feasible methodology for comprehensive performance improvement of the heliostat field while meeting the basic capacity demand.

3. Modeling

3.1. Optical Efficiency and Thermal Power Evaluation Model

3.1.1. Establishment of the coordinate system

In solving problems involving complex spatial geometric relationships, this study establishes three key coordinate systems: the ground coordinate system, the mirror coordinate system, and the light-cone coordinate system. The ground coordinate system takes the position of the absorber tower as the origin, the due east direction as the x-axis, the due north direction as the y-axis, and the vertical upward as the z-axis. This setup facilitates the accurate calculation of solar azimuth. The mirror coordinate system, on the other hand, is based on a particular mirror with its center as the origin and the plane and normal directions as the coordinate axes. Finally, the light-cone coordinate system is based on the terrestrial coordinate system and is mainly used to describe the direction and distribution of the conical beam. Together, these three coordinate systems simplify the model solving process and provide an accurate spatial reference frame. The three coordinate systems are shown in Figures 1 - 3.

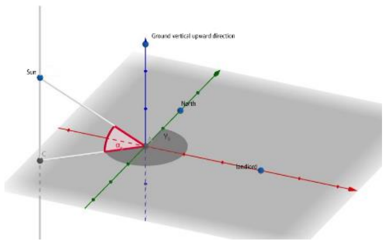

Figure 1. Ground coordinate system

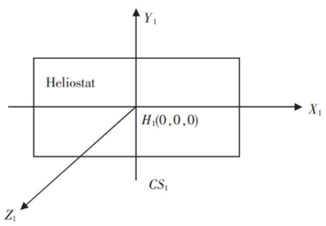

Figure 2. Mirror coordinate system

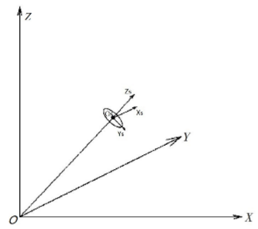

Figure 3. Light cone coordinate system

3.1.2. Modeling of Shading Occlusion Efficiency

In order to accurately quantify the shadow blocking efficiency losses in the heliostat field, this study develops a comprehensive model that includes three main aspects of losses: the shadow losses from the rear heliostat mirrors blocked by the front heliostat mirrors, the light-blocking losses from the rear heliostat mirrors blocked by the front heliostat mirrors when reflecting sunlight, and the shadow losses by the tower to the entire mirror field. The model uses Monte Carlo simulation with discretization for each mirror. The model is schematically shown in Figure 4, Figure 5.

First, the model calculates the shadow loss produced by the tower and identifies the affected reflection points by determining the edge coordinates of the tower's shadow range. These points will be excluded in subsequent calculations of shadow and light blocking losses. Next, the selected mirrors are discretely segmented, with each parcel corresponding to a discrete reflection point.

For each reflection point, the model computes the direction vectors of the incident and reflected rays generated by the sun. Through coordinate transformations and equation couplings, it is possible to determine the intersection of these rays with the mirror surface in front of them, and to determine whether the reflection point is affected by shadowing or light-blocking losses. Typically, the model prioritizes the calculation of shadow loss to avoid unnecessary double counting. Ultimately, the model can accurately determine the number of damaged reflection points and the corresponding efficiency loss.

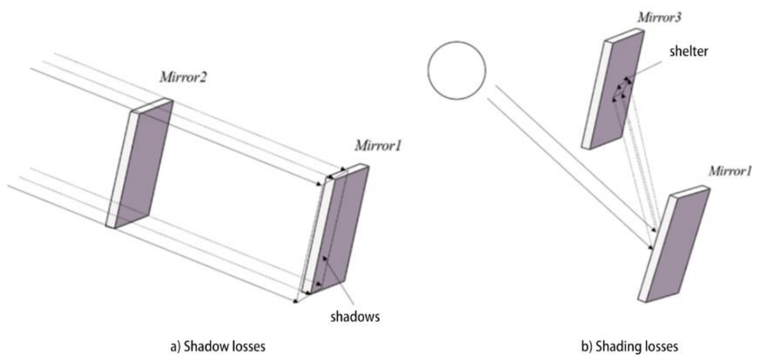

Figure 4. Two effects of the front heliostat on the current heliostat

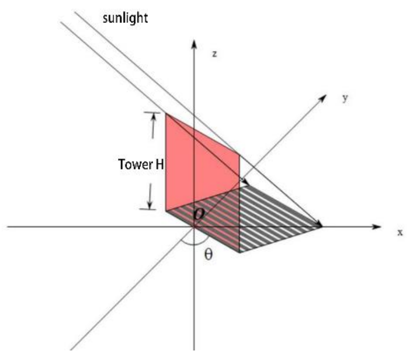

Figure 5. Shadow loss

3.1.3. Modeling of truncation efficiency

Cut-off loss is also called overflow loss When the light spot reflected from the mirror field falls into the receiving surface of the heat absorber, due to the characteristics of the light spot and the precision of the heliostat mirror or shaking may cause the light spot to be shifted or overflowed, resulting in part of the light irradiated outside of the absorber, and this part of the overflowed light spot is formed into the overflow loss. The Schematic of spillage losses is shown in Figure 6.

The incident light from the sun is a conical ray with a half-angle spread of 4.65 mrad. According to the principle of reflection, the light reflected to the absorber is also in the form of a diffuse cone. The farther the distance between the target point and the reflector, the larger the cross-section of the light cone, and part of the reflected light cone cannot fall into the heat absorber, resulting in losses.

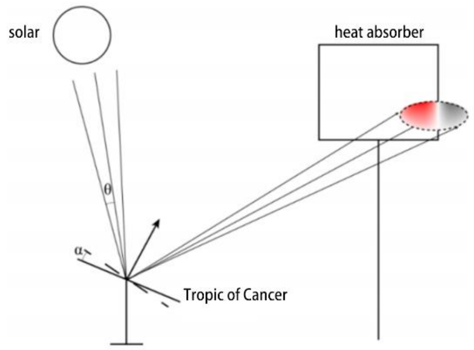

Figure 6. Schematic of spillage losses

To solve for the proportion of this loss, the theoretical modeling is usually done using the ray tracing method: tracing the position of any ray of a beam of sunlight falling into the heat absorber after reflection from a heliostat. Can still use Monte Carlo simulation, the beam in the light cone coordinate system for discrete, the previous calculation of each reflection point is actually the main optical axis of the incident and outgoing, a main optical axis corresponds to a cone of light, discrete sampling after the number of rays is limited, only need to use the program to calculate each beam of each light cone in each ray whether to fall into the heat absorber, to obtain the proportion of the light falling into the heat absorber, when the sampling value is large enough , one can consider this proportion as the truncation efficiency.

3.2. Multi-parameter optimization model for a fixed-sun mirror field

To achieve an average annual thermal power output of 60 MW from the heliostat field, the model aims to optimize the location of the absorber tower, heliostat dimensions, mounting height and number. Based on the output thermal power requirement of the heliostat field, the objective function and constraints are constructed explicitly. Genetic algorithms are used for model solving, and adaptive genetic algorithms are especially employed considering the complexity. The fixed-sun mirrors are encoded during the computation to adapt the algorithm and reduce the computational effort. Also, specific moments of a typical day were used to evaluate the thermal output of the system to save computational time. After several rounds of iterations, the annual average output thermal power per unit mirror area was optimized.

The objective function in this question is to maximize the average annual thermal power output per unit of mirror area:

$$max \frac{E_{f_{total}}}{A_{total}} \tag{1}$$

The constraints are as follows:

$$s.t.\begin{cases} 5+b \le \sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2} \\ 5+b \le \sqrt{(x_n - x_{n-1})^2} \\ 5+b \le \sqrt{(y_n - y_{n-1})^2} \\ 5 \le a < b \le 8 \\ 2 \le h_1 \le 6 \\ 4 \le h_2 \le 76 \\ P \ge 60MW \\ 100 \le \sqrt{x_n^{\ 2} + y_n^{\ 2}} \le 350 \\ a_1 = a_2 = \cdots = a_3 \\ b_1 = b_2 = \cdots = b_3 \\ h_{1,1} = h_{1,2} = \cdots = h_{1,i} \end{cases} \tag{2}$$

Where a single fixed-sun mirror length ai, width bi, number n, position (xn, yn); mounting height h1, i, due to this question all the mounting height is the same, this question is uniformly omitted as h1; collector center height h2.

Currently, there are three main forms that are more common: circular scattering (CRS), square scattering (SQS), and square wye (SQC), and all three forms of heliostat field arrangement place the absorber tower at the center of the heliostat field.

Due to the use of adaptive genetic algorithm, there is no need to carry out the layout division of the three types of heliostats as above to solve the optimal heliostat layout position, in order to reasonably simplify the model, we fix the absorber tower at the center of the heliostat field, i.e., its bottom coordinates (0, 0, 0), and consider the EB layout.

EB Layout:

Considering each heliostat as a particle, define the characteristic length of heliostat as DM, the orientation of each region as Az, i, the azimuthal spacing of the first ring of heliostats in each region as Azi, 1, and the number of heliostats in each ring as Nhel, i, and the calculation formulas are as follows, respectively:

$$D_M = \sqrt{W_s^{\ 2} + H_s^{\ 2}} \tag{3}$$

$$\Delta A_{zi,1} = (0.6396\theta_L + 1.791) \cdot W_s + \frac{0.02873}{\theta_L - 0.04902} \tag{4}$$

$$\Delta \alpha_{z,i} = \arcsin\left(\frac{\Delta A_{zi,l}}{R_{i,l}}\right) \tag{5}$$

$$N_{hel,i} = \frac{2\pi}{\Delta \alpha_{zi}} \tag{6}$$

The formula for calculating the azimuthal spacing of the first ring of heliostats in each region of the heliostat field is as follows:

$$\Delta A_{z1,1} = \Delta A_{z2,1} = \cdots = \Delta A_{zi,1} = A_{sf} \cdot W_s \tag{7}$$

Where Asf is the azimuthal spacing factor, its value is related to the tower height, due to the title of the tower height is fixed to 80m, here take the usual value of 2. In addition to the first ring in each region, the rest of the ring fixing heliostat azimuthal spacing through the region fixing heliostat azimuthal angle is derived from the calculation formula is as follows:

$$\Delta A_{zi,j} = 2R_{i,j} \cdot \sin(\frac{\Delta\alpha_{z,j}}{2}) \tag{8}$$

where ΔAzi, j is the azimuthal spacing of the jth ring of heliostats in region i of the heliostat field:

The azimuthal angle of the heliostat in the ith static field region is calculated as follows:

$$\Delta\alpha_{z,i} = 2\arcsin(\frac{\Delta A_z}{2R_{i,1}}) \tag{9}$$

The constant radial spacing of the heliostats at the junction of neighboring mirror field regions is set to ΔR = DM. $\Delta R_{1,1}$ is the radial spacing between the first and second rings of the first region of the mirror field and is calculated as follows:

$$\Delta R_{1,1} = \sqrt{D_M{}^2 - (\frac{\Delta A_{z1,1}}{2})^2} \tag{10}$$

The radial spacing between the heliostats of neighboring rings in the same region is always set to ΔR1,1. When the radius of the mirror field increases to a certain extent, there will be a shadow masking between the corresponding ring heliostats, resulting in a part of the shadow masking loss, and thereafter the new radial spacing will be re-determined by the geometrical mapping method, as shown in the equation below:

$$L_1 = \sqrt{D_M{}^2 - (\frac{\Delta A_{z1,1}}{2})^2} \tag{11}$$

$$\alpha_1 = \arcsin(\frac{R_{i,j}}{L_1}) \tag{12}$$

$$\alpha_2 = \arcsin(\frac{R_0}{L_1}) \tag{13}$$

$$L_3 = \tan\gamma \cdot (H_t - Z_0), \gamma = \alpha_1 + \alpha_2 \tag{14}$$

$$\Delta R_{i,j} = 2L_2 = 2(L_3 - R_{i,j}) \tag{15}$$

In the above formula, Ht is the optical height of the absorption tower; L is the height of the collector; L1 is the length of a straight line from the center of the collector to the center of the front fixed-sun mirror mirror; L2 is the horizontal distance from the center of the front and back fixed-sun mirror edge point to the center of the front fixed-sun mirror, which determines whether or not the light of the rear fixed-sun mirror is blocked by the front fixed-sun mirror; L3 is the horizontal distance from the center of the former fixed-sun mirror to the heat-absorption tower; α1 is the angle between the center of the former fixed-sun mirror and α1 is the angle between the line from the center of the former solar mirror to the center of the heat-absorbing tower and the vertical axis of the heat-absorbing tower; α2 is the angle between the line from the center of the former solar mirror to the center of the heat-absorbing tower and the angle between the reflected light from the edge of the posterior solar mirror and the line to the center of the heat-absorbing tower; Z0 is the height of the center of the solar mirror from the ground; R0 is the radius of the solar mirror ring; Ri, j is the radius of the jth solar mirror circle in the ith region in the field of the fixed solar mirror; α3 is the angle between the reflected light from the edge of the posterior solar mirror and the axis of the heat-absorbing tower α3 is the angle between the reflected light at the edge of the rear mirror and the axis of the heat absorption tower, which is used to determine whether the light is blocked by the front mirror.

4. Model solving

4.1. Optical efficiency and thermal power solving

4.1.1. Solving the Shading Occlusion Efficiency Model

The solution of the shadow shading efficiency model starts with the input of the month (date), the local moments (here the five time points required in the question are the 21st day of the month at 9:00, 10:30, 12:00, 13:30, and 15:00 local time), and solves for the corresponding solar altitude angle α_S and solar azimuth angle γ_S.

According to the definition of solar altitude angle, draw a ray connecting the center of the Sun to a point on the Earth's surface. The angle between this ray and its projection on the horizontal plane is called the solar altitude angle. The provided formula for calculating it is:

$$\sin\alpha_s = \cos\delta\cos\varphi\cos\omega + \sin\delta\sin\varphi \tag{16}$$

The solar azimuth angle is the angle of the Sun in the azimuth direction. It is typically defined as the angle measured clockwise from the north along the horizon. The solar altitude angle and solar azimuth angle are illustrated in Figure 1. The provided formula for calculating the solar azimuth angle is:

$$\cos\gamma_s = \frac{\sin\delta - \sin\alpha_s\sin\phi}{cps\alpha_s\cos\phi} \tag{17}$$

where is the local latitude and north is positive, it is important to note here that since the azimuth cosine is calculated, the azimuth will not be greater than π ;

ω is the solar time angle and its formula is given in the title?

$$\omega = \frac{\pi}{12}(ST - 12) \tag{18}$$

ST is the local time, expressed using decimals, e.g., 9.5 for ST at 9:30 p.m., and is the angle of solar declination, which is calculated as follows:

$$\sin\delta = \sin\frac{2\pi D}{365}\sin(\frac{2\pi}{360}\cdot 23.45) \tag{19}$$

δ is the number of days from the vernal equinox as day 0. If D is after March 21, calculate the time directly, and if D is before March 21, add 365 as a modulus to do the calculation.

Through the above formula for the sun's altitude angle and solar azimuth, we can get the direction of solar incidence vector, the vector to do the reverse processing, pointing to the center of the sun for the direction of the positive, to facilitate the back of the practice of vector arithmetic, that is:

$$\overrightarrow{v_{\text{sun}}} = (\cos\alpha_s\sin\gamma_s, \cos\alpha_s\cos\gamma_s, \sin\alpha_s) \tag{20}$$

From the question the reflected light for the center of the heliostat and the center of the center of the collector line, so the reflected unit vector $\overrightarrow{v_{ref}}$ can be obtained by the center of the collector coordinates minus the center of the centers of the heliostat coordinates for the unit vector.

Therefore, traversing each mirror in the mirror field, the normal vector of mirror i is found through the incoming direction vector of the sun and the given outgoing vector as:

$$\vec{n_l} = \frac{\overrightarrow{v_{\text{sun}}} + \overrightarrow{v_{ref}}}{\left|\overrightarrow{v_{\text{sun}}} + \overrightarrow{v_{ref}}\right|} \tag{21}$$

From this normal direction vector, the attitude of the heliostat is known, which is uniquely determined by the angle of rotation of the two axes, through which the equations of the transformation between the ground coordinate system and the mirror coordinate system are obtained.

The extent to which the shadow of the tower falls on the ground is calculated from the solar altitude angle and solar azimuth angle and the cross section of the tower: $[x_{t_1}, x_{t_2}]$, $[y_{t_1}, y_{t_2}]$.

Now use MATLAB to discretize the mirror i. Equal cuts are made along the x and y axes of the mirror coordinate system, followed by a loop that traverses each chunk. The coordinates of the chunks are expressed in terms of the mirror coordinate system, and a chunk corresponds to a reflection point (approximated as the center of this chunk), assuming that any reflection point $H_k(x_k, y_k, z_k)$, performs the following step-by-step judgment:

1) First, determine whether xk, yk belongs to $[x_{t_1}, x_{t_2}]$, $[y_{t_1}, y_{t_2}]$, if yes, it means that this one reflection point is in the shadow of the tower, counted in the loss of reflection points, do not need to proceed to the next step of the calculation, if not, go to the next step of the calculation.

2) The center point of the mirror is $C_i(x_i, y_i, z_i)$, and a transformation matrix T is obtained from the normal vector to transform this reflection point from the mirror coordinate system to the ground coordinate system:

$$H_{kf} = T \cdot H + C_i \tag{22}$$

To accurately calculate the shadow loss and light blocking loss, the model first calculates the distance between the center of the current mirror and the center of each of the other mirrors in the mirror field and selects the six nearest mirrors for analysis. The equations of the incoming and outgoing straight lines are determined from the direction vectors and the coordinates of the mirrors themselves. These straight lines were coupled with the plane equations of the nearby mirror j to find the intersection points of incidence and reflection. By determining whether these intersection points lie within the edges of the mirror j, the model can decide whether that reflection point is affected by shadowing or light-blocking losses and count it as a loss point accordingly. This process helps to assess the optical efficiency of the mirror field more accurately. After the traversal, knowing that the number of mirrors in the mirror field is m discretized in two directions number n on each mirror, the shadow blocking efficiency is calculated as, if the number of reflection points counted as losses is p:

$$\eta_{sb} = 1 - \frac{p}{n^2 \times m} \tag{23}$$

4.1.2. Solving the Truncated Efficiency Model

The solution of the truncation efficiency model is calculated based on the shading loss model, because the solar energy already lost by shadowing or light blocking, attenuation, etc. is removed. On the basis of the previous specular discretization, only the reflection points that have not been counted as losses are calculated for their reflected light cones, traversing these effective reflection points, using their ground coordinates Hkf, and since the half-angle spread of the light cones is 4.65 mrad, the discretization is divided both in the half-angle spread direction and in the axial direction as shown in the figure, which allows to obtain the discretized light direction vectors (light cone coordinate system)：

$$\vec{S_\imath} = (\sin\sigma\cos\tau, \sin\sigma\sin\tau, \cos\sigma) \tag{24}$$

Because after the discretization, the attitude of the small mirror where the small reflection point is located is still the same, so the sunlight shines over, the reflected light, i.e., the main optical axis, i.e., the z-axis of the light cone is the same as the direction vector of the reflected light from the center point, and the transformation matrix $T^{'}$ can be obtained, so that we can get the light vector in the ground coordinate system:

$$\vec{V_s} = T' \cdot \vec{S_l} + O_s \tag{25}$$

Find the equation of the line from this direction vector and the effective reflection point:

$$l_i : H_{kf} + c\vec{V_s} \tag{26}$$

Cylindrical heat absorber equation representation:

$$\begin{cases} x^2 + y^2 = R^2 \\ z \in \left[H - \frac{h}{2}, H + \frac{h}{2}\right] \end{cases} \tag{27}$$

The coordinates of the intersection point of the discrete rays with the heat absorber are solved by association, and it is determined whether the rays fall on the cross section of the heat absorber, if so, they are counted as effective rays, if not, they are counted as ineffective rays. Total discrete rays q, effective rays r, then the stage efficiency:

$$\eta_{\text{trunc}} = \frac{r}{q} \tag{28}$$

The table of efficiencies tested after bringing in the data is shown below:

Table 1. Average optical efficiency and output power table

Average annual optical efficiency	Average annual cosine efficiency	Average annual shadow shading efficiency	Average annual cut-off efficiency	Average annual thermal power output (MW)	Average annual thermal power output per unit area of mirror (kW/m2)
0.699381	0.854880	0.987586	0.900796	49.864757	0.793772

4.2. Multi-parameter optimization solution for fixed-sun mirror fields

4.2.1. Algorithm design

Since the optimal design requires solving many complex spatial relations for the xyz coordinates of the heliograph, and eight nonlinear and linear constraints are known to be considered, an algorithm adapted to the solution of high-dimensional, large-scale problems must be found [4].

For the nonlinear constraints in the model, firstly, based on the idea of Lagrange multiplier method, a multiplier λ is introduced to transform the equation nonlinear constraints into a part of the objective function. Then, the solution is carried out under consideration of each inequality constraint, and when the result violates the inequality constraints, it is transformed into the equational constraints and solved again until the optimal solution that does not violate the inequality constraints is obtained. In practice, this model calculates a set of parameters when the rated output thermal power is maximized, and then deletes some fixed-day mirrors with the lowest efficiency until the rated power requirement is met. Therefore, this model uses an adaptive genetic algorithm to realize this multi-constraint three-dimensional convergence problem.

4.2.2. Analysis of the optimal layout of the half-surface

Since the mirror field layout in the problem is known to be symmetric, the overall mirror field layout of this problem can be transformed into the analysis of the optimal layout of the half plane, based on adaptive genetic algorithm, programmed in MATLAB for the solution, giving the optimal layout of the half plane of the solved diagrams, such as Figure 7, Figure 8 shown.

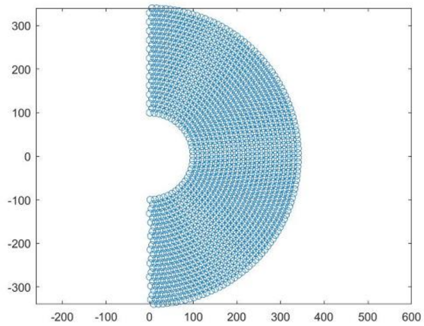

Figure 7. Optimal Layout of Half Surface

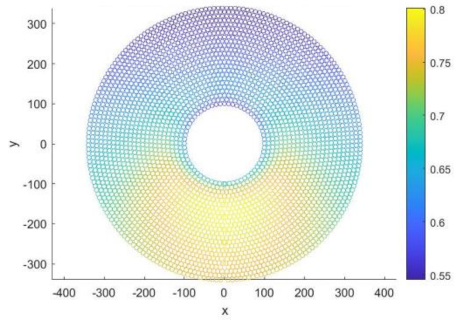

Figure 8. Distribution

From known studies [5], the overall optical efficiency of the heliostat field in the form of a circular scattering is the highest, in line with the simulation results, at which point the design parameters are as follows:

Table 2. Average optical efficiency and output power table

Average annual optical efficiency	Average annual cosine efficiency	Average annual shadow shading efficiency	Average annual cut-off efficiency	Average annual thermal power output (MW)	Average annual thermal power output per unit area of mirror (kW/m2)
0.688936	0.854880	0.988892	0.923250	52.375233	0.833735

Table 3. Table of optimal design parameters

Absorption tower coordinate position	Sunset mirror size (W × H)	Installation height of heliostat (m)	Total number of heliostats	Total area of fixation mirrors (m2)
0, 0	7x7	4	1050	51450

5. Conclusions

This study focuses on optimizing the fixed-sun mirror field in tower solar photovoltaic power generation. Firstly, the spatial geometric operations are facilitated by constructing three coordinate systems: ground, mirror, and light cone. Second, the ray tracing method is applied to accurately calculate various annual average performance metrics, including optical efficiency and output thermal power. Under the premise of satisfying a series of constraints (e.g., mirror position, number, and size), the genetic algorithm was used to further enhance the annual average output thermal power per unit mirror area and successfully optimize the key design parameters. The study also accurately evaluated the shadowing and light-blocking losses through Monte Carlo simulation and direction vector analysis, thus providing a more comprehensive understanding of the performance of the mirror field. The comprehensive results are not only consistent with existing literature data, but also provide useful optimization directions for future solar thermal power generation technologies.

References

[1] Cheng Qiyun, Sun Caixin, Zhang Xiaoxing, et al. Short-Term load forecasting model and method for power system based on complementation of neural network and fuzzy logic [J]. Transactions of China Electrotechnical Society, 2004, 19(10): 53-58.

[2] Fangfang. Research on power load forecasting based on Improved BP neural network [D]. Harbin Institute of Technology, 2011.

[3] Amjady N. Short-term hourly load forecasting using time series modeling with peak load estimation capability [J]. IEEE Transactions on Power Systems, 2001, 16(4): 798-805.

[4] SHI Biao, LI Yu Xia, YU Xhua, YAN Wang. Short-term load forecasting based on modified particle swarm optimizer and fuzzy neural network model [J]. Systems Engineering-Theory and Practice, 2010, 30(1): 158-160.

[5] Ma Kunlong. Short term distributed load forecasting method based on big data [D]. Changsha: Hunan University, 2014.