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Multi-Objective Optimization of Smart Grid Based on Ant Colony Algorithm

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ABSTRACT

The study focuses on the route design of the transmission line and has an important influence on the comprehensive benefit of the transmission line. This study proposes the research of multi-objective optimization of power grid based on ant colony algorithm to optimize transmission lines. Firstly, the basic principle of the ant colony algorithm is introduced, and the mathematical model of the ant colony algorithm is presented. Secondly, the ant colony algorithm is applied to multi-objective optimization of transmission line path. The results show that the corresponding shortest path length after the test is 11 734. The multi-objective ant colony algorithm can optimize the transmission line path well, speed up the search speed, and improve the quality of the solution. The method proposed in this study has certain reliability and validity.

***Index Terms*—**Ant colony algorithm, multi-objective optimization; path optimization, smart grid, transmission line

I. INTRODUCTION

The transmission line is the main structure of the power grid, and it undertakes the task of long-distance large-capacity power transmission [1]. As an important part of the transmission line design, the path design of the transmission line is the premise of the follow-up work, and it has an important influence on the comprehensive benefit of the transmission line [2]. The main content of transmission line path design is between two given points. Considering various practical limiting factors, we can find an economical and safe route scheme [3]. Traditional transmission line design can be divided into three steps: drawing up the line route with indoor drawings, field investigation, and final route scheme determination [4]. Specifically, the designer first draws several feasible route paths on the map, records their coordinate positions, and then performs an on-the-spot investigation and recording of important information such as obstacles in the area where the route passes. Finally, they draw important information such as obstacles on the map and then re-route. This was repeated several times to determine the final path scheme [5]. For designers, traditional path design is extremely intensive, tedious, time-consuming, and inefficient [6,7]. Moreover, the path scheme obtained by the traditional design method largely depends on the technology, professional quality, and experience of the designers and surveyors, and has certain limitations. The factors affecting the design of transmission lines are shown in Fig. 1.

II. LITERATURE REVIEW

To solve this research problem, Xiao et al. put forward that AHP and fuzzy AHP could be used to consider the differences among many influencing factors, and an additional weight coefficient can be added for influencing factors [8]. Lu et al. discussed the grid data structure of GIS in detail. The data structure represented points, lines, and areas in grid form, thus describing the objective attributes of spatial entities. The grid structure could be used to simulate the spatial environment information and then the optimal path solution could be realized conveniently by combining intelligent algorithms or graph theory-related algorithms [9]. Li, et al. took the line path as the central axis, generated a parallel strip at a certain distance from the central axis, and used the strip pattern and obstacles in the path to judge whether there was an overlap for judging

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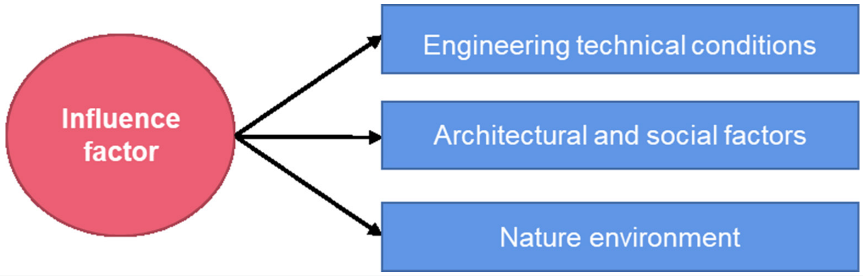

Fig. 1. Main factors affecting the transmission line design.

the safe distance from important facilities to correct the transmission line path [10]. Liu et al. defined the weight of nodes as the distance between nodes by establishing a grid map, thus realizing the shortest path planning of robots. According to actual needs, the goal of the shortest path length in the shortest path in the algorithm can be transformed into the goal with the least cost and the shortest time, thereby realizing various dynamic planning objectives [11]. Yu and others fully analyzed the spatial distribution characteristics of Djkstra shortest path algorithm and GIS, optimized and improved the search technology and data structure, and emphasized the importance of the combination of GIS and Djkstra algorithm in operation efficiency, and the improved algorithm was more suitable for searching the shortest path of two specific points [12]. Sathyanarayana found that the prerequisite for the realization of the algorithm was to select the grid model to divide the cells of the map and build the "environment" [13]. Li et al. expressed intersections and roads in traffic roads as nodes and tie lines in graph theory. On this basis, the genetic algorithm is used to solve the dynamic path planning problem in urban traffic [14]. Yasuaki and others combined the ant colony algorithm with a genetic algorithm, first using ant colony algorithm to generate initial solution and then using genetic algorithm to perform crossover and mutation operation, in which the ant colony algorithm was integrated to accelerate the convergence speed of the algorithm. The mutation operation process is shown in Fig. 2. By mixing these two algorithms, the advantages of each algorithm are absorbed, which speeds up the search and improves the quality of the solution. The flow of the hybrid genetic-ant colony algorithm is shown in Fig. 3 [15]. Dehghanpur used multi-objective ant colony optimization (ACO) algorithm to solve the double-objective shortest path problem and achieved good results [16]. Crisostomi improved Multi-Objective Ant Colony Optimization (MOACO) by using adaptive operators and proposed that the algorithm is divided into two stages. In the early stage, a higher probability is used to search the solution space to collect useful global information. In the later stage, the adaptive operator is used to reduce the search space, thus accelerating the convergence [17,18].

III. METHOD

A. The Basic Principle of Ant Colony Algorithm

Ant colony optimization is a swarm intelligence multi-objective optimization algorithm inspired by the foraging behavior of real ant colonies in nature. It is found that although a single ant does not have much intelligence and cannot grasp the nearby and global geographic information, the whole ant colony can find the shortest route from the nest to the food source. It has been found that ants can leave a pheromone on the path they pass by [19,20].

B. Mathematical Model of Basic Ant Colony Algorithm

In order to better understand the basic principle of the ant colony algorithm, the classical symmetric traveling salesman problem (TSP) is usually used to describe the ant colony algorithm. The simple image description of TSP is as follows: given *n* cities, a travel agent starts from a certain city and finds out the shortest path to visit each city once and only once and finally, returns to the original departure city [21].

This is expressed in mathematical language as follows:

$C=\{c1,c2,...,cn\}$ is a collection of *n* cities; $L=\{1_{ij}\,|c_i,c_j\subset C\}$ is a set of pairwise connections of cities in set *C*. $d_{ij}\left(i,j=1,2,...,n\right)$ is the distance of 1_{ij}, namely:

$$d_{ij}=\sqrt{\left(x_i-x_j\right)^2+\left(y_i-y_j\right)^2} \tag{1}$$

$G=(C,L)$ is a directed graph, and the purpose of TSP is to find the Hamilton cycle with the shortest length, that is, a pair, from the directed graph $G.C=\{c1,c2,...,cn\}$. The shortest close route visited by *n* cities only once.

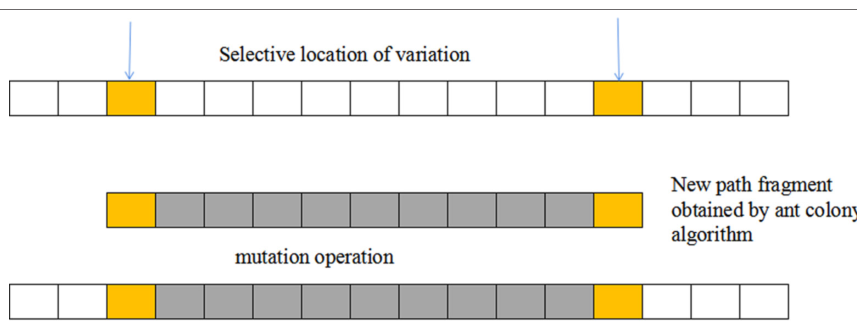

Fig. 2. Diagram of variation operation.

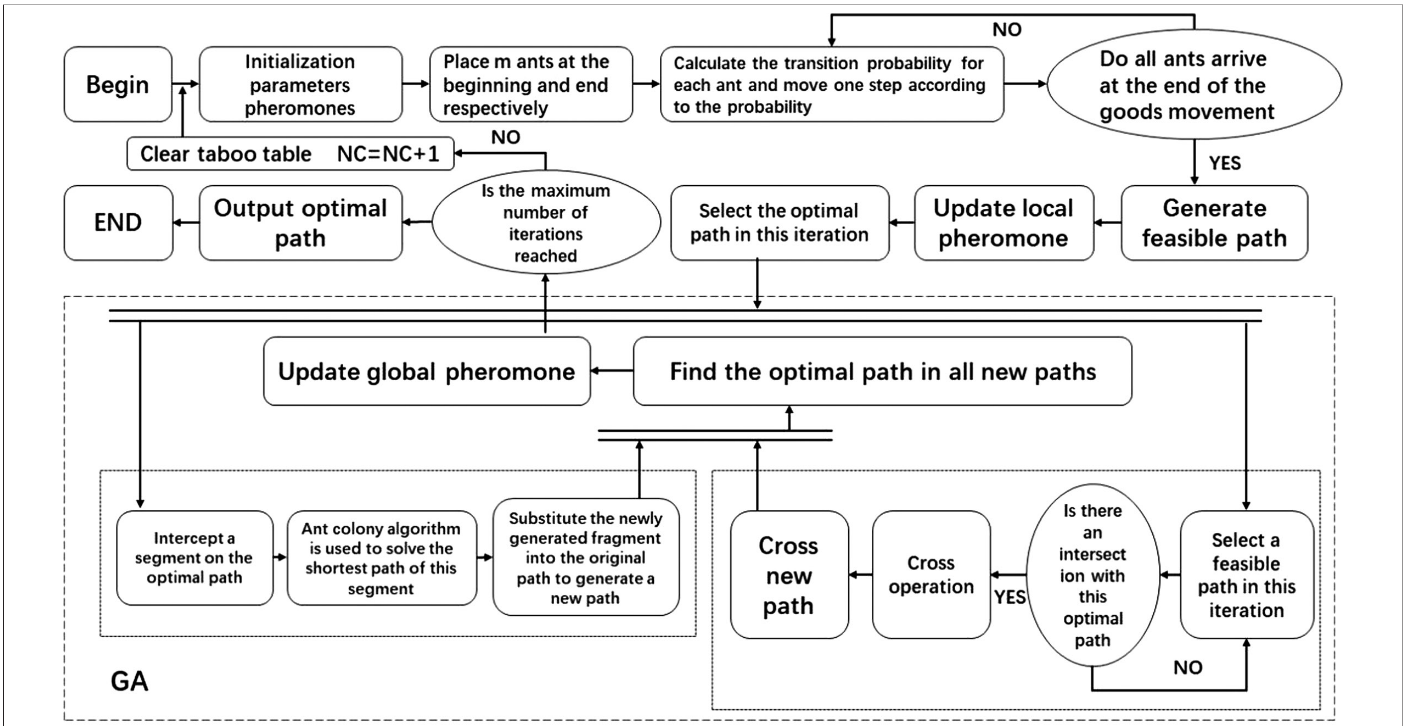

Fig. 3. Flowchart of hybrid genetic-ant colony algorithm.

At first, m ants are randomly placed in *n* cities and then each ant chooses the city to go next. The ants will choose the next target city according to the information on each path and the heuristic information of the path. At time *t*, for the k_{th} ant, it is in city *i*, and the probability of choosing city *j* is as follows:

$$P_{ij}^{k}(t)=\begin{cases}\dfrac{\left[\tau_{ij}(t)\right]^{\alpha}\times\left[\eta_{ik}\right]^{\beta}}{\Sigma_{s\in allowed_k}\left[\tau_{is}(t)\right]^{\alpha}\times\left[\eta_{is}\right]^{\beta}}, if, j\in allowed_k \\ 0, otherwise\end{cases} \quad (2)$$

Each symbol is represented as follows:

$\tau_{ij}(t)$ is the pheromone concentration of the sideline between city *i* and city *j* at time *t*;

α is an information heuristic factor, which indicates the existing pheromone. $\tau_{ij}(t)$ is the parameters of importance. Here, if larger the value of α, larger is the value of pheromone concentration which is used by ants to choose path and also show the self-organization ability of the ant colony.

β is the expected heuristic factor, indicating visibility. η_{ij} is the importance parameter and reflects the importance of heuristic information in the process of ants' path selection. The larger the value, the closer the ants' choice is to the greedy rule.

η_{ij} is for visibility, and it means the visibility from city *j* to city *i*, which is usually expressed by the inverse function of the distance between city *j* and city *i*:

$$\eta_{ij}=\frac{1}{d_{ij}} \quad (3)$$

The smaller is the d_{ij}, the larger are the η_{ij} and $P_{ij}^{k}(t)$. The intuitive representation means that ants are more inclined to choose a relatively short path in their own field of vision. Obviously, this heuristic function indicates the expected degree of the transition from city *i* to city *j*. It is a collection of cities that ant *k* has not visited yet, which can ensure that all cities can be visited only once at most [22].

At *t*+*n* time, the ants arrive at all cities once and only once and complete a traversal, which is called experiencing a cycle. Therefore, after completing a traversal, time *t*+*n* is in the path.

Adjusted according to the following rules:

$$\tau_{ij}(t+n)=(1-\rho)\times\tau_{ij}(t)+\Delta\tau_{ij} \quad (4)$$

$$\Delta\tau_{ij}=\sum_{k=1}^{m}\Delta\tau_{ij}^{k} \quad (5)$$

$$\Delta\tau_{ij}^{k}=\begin{cases}\dfrac{Q}{L_k}, \text{If the k ant passes through the path } (i,j) \text{ in this cycle;} \\ 0, otherwise\end{cases} \quad (6)$$

The symbols in (4), (5), and (6) are explained as follows:

ρ is the information volatilization coefficient. Then, $1-\rho$ indicates the pheromone residual coefficient. In order to prevent the infinite accumulation of information, ρ, the value range of ρ is (0,1);

$\Delta\tau_{ij}$ is the path in this cycle. Initial time $X\tau_{ij} = 0$;

$\Delta\tau_{ij}^{k}$ is the path of the *k* ant in this cycle. (*i,j*) is the pheromone increment;

L_k is the total length of the path taken by the *k* ant in this cycle. In the initial state, the pheromones on all connections are set to equal a small constant [23].

C. Ant Colony Algorithm Is Applied to Multi-objective Optimization of Transmission Line Path

In the multi-objective optimization of power system path based on ant colony algorithm, the planning area is a two-dimensional space, and the area is gridded and shared. When obtaining terrain data, this study uses the data of a certain point in the center of the cell. Assuming that the terrain around each point is not much different from this point, for convenience, the selected point in each cell can be used to represent the terrain of this cell.

There are certain technical requirements in transmission line design, for example, the gradient of power lines should not exceed 30%, and it is better to be below 15%. Therefore, it is necessary to process the plane coordinates and altitude obtained from Google Earth. When dividing cells, equal lines are used, so the orthographic projection of each cell is exactly the same. That is, the length, width, and area are the same. Let the projection of the cell be a small square with side length A [24].

(1) The next feasible point set:

Each cell can directly reach the eight adjacent cells, and the coordinates are shown in Fig. 4.

For location (*i,j*), the ant can only move forward in one of the eight directions shown in Fig. 4, assuming that the coordinates of the next point that can be reached are (*g,h*), then

$$\begin{cases} g = i + di[v] \\ h = i + dj[v] \end{cases} v = 0,1,\ldots,7 \tag{7}$$

Among them, *di* and *dj* are two one-dimensional arrays with values of $di = \{-1,-1,0,1,1,1,0,-1\}$, $di = \{-1,-1,0,1,1,1,0,-1\}$.

(2) Selection strategy of ants:

Only the next feasible point set can reach the intermediate point (*i,j*). For points (*i,j*) and *k*, next feasible point (*g,h*) can be selected according to the probability obtained by Equation (8). The greater the probability, the greater the chance of being selected.

$$P_{ij\to gh}^{k} = \begin{cases} \dfrac{\tau_{gh}^{\alpha}}{\sum\limits_{(x,y)\in allowed_k} \tau_{xy}^{\alpha}}, if\,(g,h) \in allowed_k \\ 0, otherwise \end{cases} \tag{8}$$

Each symbol is represented as follows:

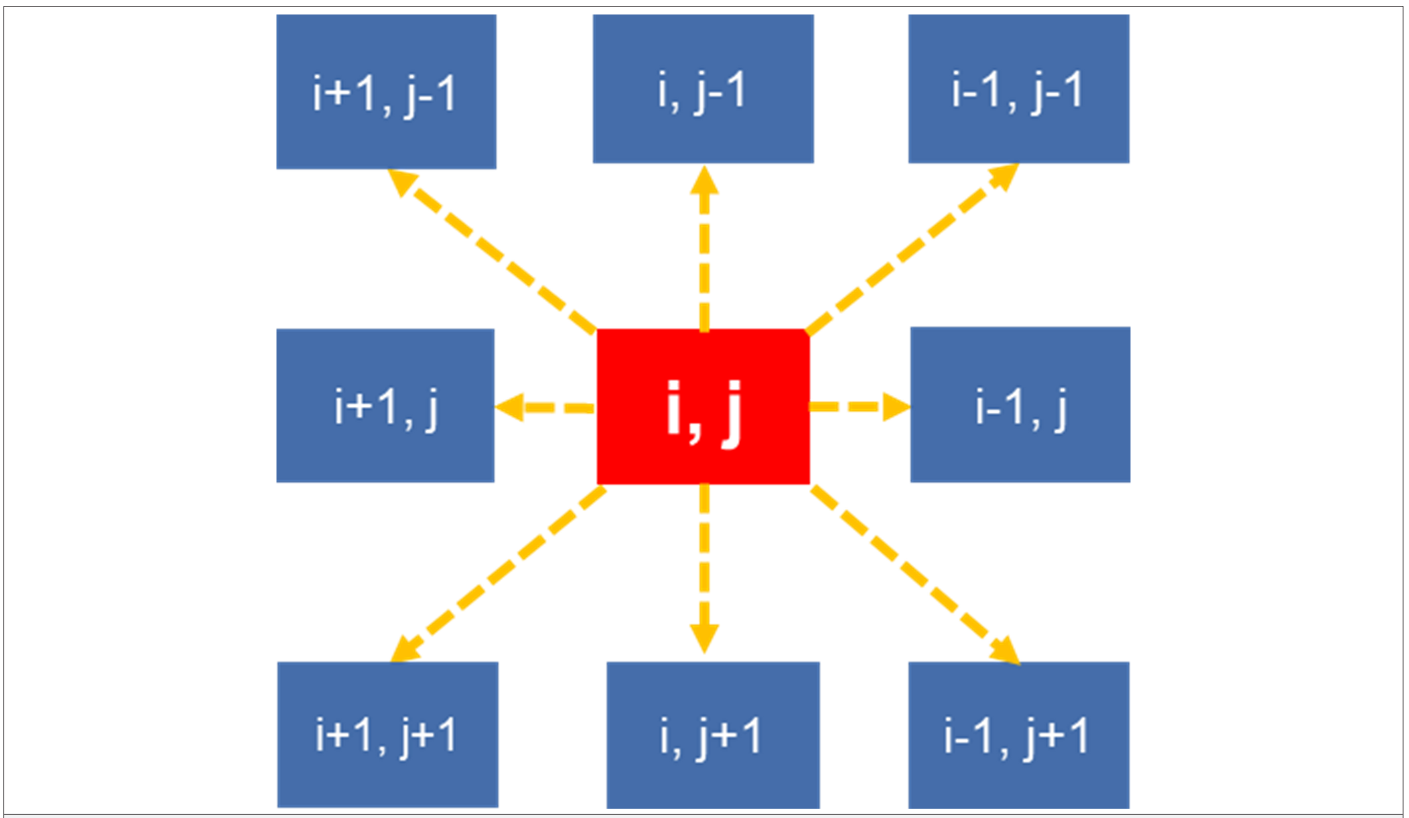

Fig. 4. Coordinate representation of adjacent cells reachable by ants.

$allowed_k$ is the point set that ant k can currently reach. Except for the points that ant k has already passed, the remaining elements are composed of $allowed_k$;

τ_{gh} is to remain at a point (g,h). Generally, the initial value of pheromone concentration is set to a smaller constant, which will be updated continuously with the running of the algorithm.

α indicates the importance of pheromones. Usually, when the ant colony algorithm is used, pheromones will remain on the path that ants have traveled. In this study, the updating rules of pheromones are improved appropriately. After ants complete a cycle, pheromones remain in the passing cells [25].

IV. RESULTS AND ANALYSES

A. Example Application Platform

Multi-objective optimization of transmission line path on the computer can only be completed by using multiple software in cooperation with each other due to current conditions. The system should have the following functions:

(1) Three-dimensional geographic coordinates acquisition: the geographic information of the area to be studied, including plane coordinates and terrain information, can be acquired and the data can be stored;
(2) Coordinate conversion processing: processing the obtained initial geographic information data, that is, converting the obtained latitude and longitude coordinates into plane coordinates, so as to facilitate calculation;
(3) Terrain reproduction: using the extracted geographic information data to visually reproduce the terrain in the system;
(4) Multi-objective optimization and display of line: multi-objective optimization of line path under constraint conditions and display on the reproduced terrain;
(5) Information return: the generated route is returned to the actual position displayed on the map. Therefore, to realize these functions, the following tools or platform environments are needed, such as those given in Table I.

B. The Realization Process of Path Multi-objective Optimization

The realization of multi-objective optimization of transmission line path on the computer can be done as follows, firstly, install Google Earth on the computer, configure Alan, Charles, Ian's System (ACIS)/HOOPS environment platform, select the study area and the starting point of the line through the interface application Google Earth (GE) developed by Google Earth Application Programmable Interface, (API), extract geodetic coordinates, obtain the actual latitude, longitude and altitude data, and then convert the data into a rectangular coordinate system. Considering the practical constraints in multi-objective optimization of transmission line path, the data are further processed and then the corresponding C++ program is written according to the algorithm of the system designed in this experiment, and the optimal line between two target points is solved by the intelligent multi-objective optimization algorithm so that the line can be displayed on the topographic map constructed by Computer Aided Design (CAD) simulation. We can also reverse the coordinate points of the route into latitude and longitude data in real space and then generate Keyhole Markup Language (KML) files, which can be displayed on Google Earth [26].

TABLE I. TOOLS OR PLATFORM ENVIRONMENT REQUIRED FOR SYSTEM FUNCTION REALIZATION

Resource	Specific Name
Hardware	Computer
Operating system	Windows 7
Development platform	Microsoft Visual Studio 2003
Development language	C++
Software	HOOPS 12.0, Spatial ACIS R15, Google Earth

C. Data Acquisition and Conversion Processing

Obtaining actual data is the first step in path of multi-objective optimization, and it is also a very important step [27]. Elevation data extracted from Google Earth can be accessed in the Google Earth Common Component Application Programmable Interface (COMAPI) class library through various functions. Firstly, locate the area to be studied and display it on the screen. The research area is rasterized, and the ground is divided into several small squares. When extracting coordinates, select only one point in a small square and use this point to represent the cell in which it is located [28]. When extracting data, because the number of points that can be extracted at one time is limited, it should not exceed 5000, otherwise, the computer will run extremely slow. At the same time, in order to ensure the accuracy of obtaining topographic information, it is necessary to extract enough points of data. Therefore, we can divide the area under study, extract the data in blocks, and then, integrate the data into a large area [29]. Here, the ground information should be considered. In the process of route multi-objective optimization, the avoidance area can be treated as described above, and the elevation data of the avoidance area can be modified and set to a larger constant in calculation. Google has opened the Google Earth COMAPI (the common component interface of Google Earth), so that users can call various functions of Google Earth in other applications as long as they access this interface [30]. Three main library IApplication, ICameraInfoGE, and IPointOnTerraGE are used to achieve the extraction of geographic data. IApplicationGE class library is the most important class library because it provides an interface for external programs to access Google Earth [31,32]. The data used in this study contain digital elevation information, which can be obtained through the digital elevation model. Digital elevation model (is a raster digital representation of terrain information. The main content is the plane position. Data and elevation data, terrain information such as slope, and aspect can be derived from this. When extracting data, we need to use the functions contained in various categories. The functions and their functions are shown in Table II.

D. Multi-objective Optimization of Transmission Line Path

According to the above contents, multi-objective optimization of the transmission line path is carried out, and the initialization calculation parameters are shown in Table III [33,34]. In each iteration, record the total length of the shortest path in this iteration. The curve with the number of iterations is shown in Fig. 5.

It can be seen from Fig. 5 that this method can reflect the influence of the line slope on the path design of the transmission line and at the same time, realize the function of avoiding the non-traversable

TABLE II. FUNCTIONS REQUIRED TO EXTRACT DATA AND THEIR FUNCTIONS ARE INTRODUCED

Function	Description
Get Point on Terrain From Screen CoordsO	Obtaining the actual coordinates by the pixel coordinates
gePoint. get_ LongitudeO	Acquiring longitude coordinates corresponding to screen coordinates
gePoint. get LatitudeO	Acquiring latitude coordinates corresponding to screen coordinates
gePoint. get_ AltitudeO	Get the altitude corresponding to the screen coordinates.

TABLE III. VALUES OF CALCULATION PARAMETERS

Parameter	Parameter Value
Height difference coefficient	3
Initial grid pheromone concentration	1
Starting point	1
Destination	2000
Maximum number of iterations	400
Number of ants in a single iteration	20
Information cable factor	1
Heuristic function factor	5
Pheromone volatilization factor	0.1
Information cable constant	10 000

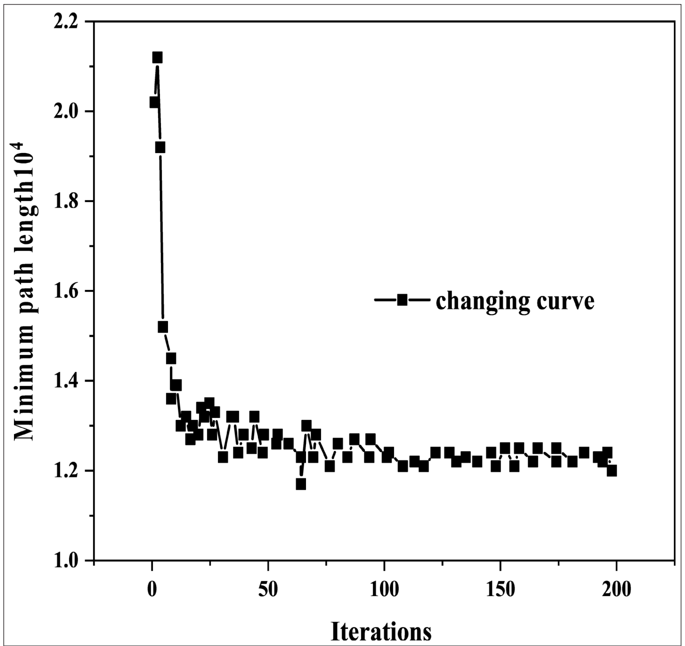

Fig. 5. Variation curve of total length of shortest path.

area. The optimization results obtained by this method provide better assistance for the path design of the transmission line. The basis for decision-making has certain validity and rationality.

V. CONCLUSION

In this study, the multi-objective optimization of smart grid based on ant colony algorithm is proposed, and the multi-objective optimization of the transmission line path by ant colony algorithm is mainly discussed. According to the next feasible point set of ant colony algorithm and the selection strategy of ants, the multi-objective optimization of transmission line path is carried out. The experimental results show that the ant colony algorithm can see that the multi-objective optimization result obtained by this method provides a better decision-making basis for transmission line path design and has certain validity and rationality. Although the multi-objective ant colony optimization algorithm has been used to solve many multi-objective optimization problems in life, there are still some defects. Multi-objective ant colony optimization algorithm has a lot of research on convergence analysis but few on convergence analysis of multi-objective, so these will be the areas to be improved and further research is needed.

Although the algorithm proposed in this study can improve the quality of the solution to a certain extent, the complexity of solving the problem has increased a lot, and the efficiency is low, time-consuming, and takes up large storage space. In the future, further research can be done on improving the hybrid algorithm. Transmission line path optimization, as a very complex engineering problem, has many factors to be considered. Although this study reduces the difficulty of calculation by simplifying the model and obtains a satisfactory solution, it also ignores some factors due to the simplification. In the future, we can consider adding more constraints to make the final solution more in line with the actual needs.

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