Optimization of Transmission Lines in Substations Using Ant Colony Optimization Algorithm

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Abstract. In the design process of the transmission line of the traditional substation system, the plans and decisions often made by people, resulting in unsatisfactory line design results, which are not the most economical optimal results, and they are not even considered in the preliminary planning. Going to areas where lines cannot be erected has caused slow progress and poor accuracy in the feasibility study stage. This paper combines the ant colony intelligent algorithm with the geographic information system, and proposes a substation transmission line optimization model, which outputs the optimal path by inputting geographic information data. This model analyzes the entire process of the transmission line design stage and realizes the intelligent line selection. The analysis of the example in the article proves that the model has a better auxiliary function for the work of the substation line planning stage.

Keywords: Ant Colony Intelligent Algorithm, Geographic Information System, Substation Transmission Line Optimization Model

1. Introduction

The substation is an important part of the power system, which acts as an intermediate link between the user and the power plant. Transmission line planning in substations is an important part of substation design, which affects the safety, economy, and efficiency of substation operation. The optimal design of transmission lines requires comprehensive consideration of technical, economic and environmental factors, based on the core point, and seeking the optimal line layout plan.

At present, there has been a set of mature methods in the field of transmission line path optimization. However, with the continuous advancement of computer technology, the use of path optimization algorithms provides new technical means for transmission line optimization. Literature [1]-[3] uses particle swarm optimization for path optimization. Aiming at the disadvantages of traditional particle swarm optimization (PSO), such as low optimization efficiency, easy to fall into local optima, and strong randomness of calculation results, an improved particle swarm optimization is proposed. By introducing the cluster optimization strategy, the dispersion of the particle optimization is expanded, so that the variables can find the overall optimal solution. The simulation and example
results show that compared with the traditional particle swarm algorithm and other improved particle
swarm algorithms, the proposed improved particle swarm algorithm has stronger global search ability
and more reliable optimization calculation results in the process of transmission line path planning.
Literature [4] established a transmission line path optimization model based on genetic algorithm.
According to the theoretical model of genetic algorithm, a plane linear model suitable for transmission
line route optimization is designed, and a transmission line route optimization model based on genetic
algorithm is constructed. Literature [5]-[6] explored the application of genetic algorithm in intelligent
robot automatic path finding and electric vehicle automatic path finding. Literature [7] uses the
membrane calculation method to optimize the transmission line optimization. Literature [8]-[11]
verified the application of Dijkstra algorithm in various fields of path optimization, analyzed and
classified the environmental factors affecting the path of transmission lines, established a hierarchical
model of environmental factors, and calculated it through the interval analytic method. The weight of
each environmental factor in the selection of the transmission line path; establish the cell directed
network of the GIS map; on this basis, comprehensively consider the environmental factors, line
length, line corners, and establish the minimum cost model of the line path as a The weight of the path
is finally generated by Dijkstra algorithm. Literature [12] considers the environmental factors that
affect the selection of the transmission line path, establishes a taboo algorithm process, determines the
weight of each environmental factor in the selection of the transmission line path through
environmental factor analysis and scientific basis, establishes a life cycle cost cell, and applies
simulation software Matlab compiles tabu search algorithm to generate the optimal path. Through
studying the relevant literature, it can be found that the existing research lacks a summary of the red
line area of the route planning and the research of the whole process analysis of the route design.

In order to assist the decision-making of the transmission line erection in the feasibility study stage,
this paper combines the ant colony algorithm optimization method with the geographic information
system to explore the optimal selection path of the substation transmission line, build a reliable
substation transmission line selection optimization system, and input geographic information Data to
output the optimal path. The model analyzes the entire process of the transmission line design stage
and realizes the intelligentization of line selection. The analysis of the calculation examples in the
article also proves the scientificity and effectiveness of the model.

2. Line Optimization Basis
There are many factors that affect the cost of a transmission line project, and the path selection plan
has an important impact on the line cost, including the following factors:

1. The transmission line path plan should be operationally safe, economical, and reasonable,
combined with the overall planning of the local government, plan the transmission line corridor,
optimize the line direction, and provide the corridor utilization rate.

2. Route selection should avoid important facilities such as military facilities, large industrial and
mining enterprises, prohibited development zones and restricted development zones, national or
provincial nature reserves and scenic spots, etc. The route selection should avoid bad geological zones,
heavy ice zones, areas prone to dancing, micro-climate, micro-topography zones and other areas that
affect safe operation. When it is impossible to avoid avoidance, full demonstration and necessary
measures should be taken.

3. A comprehensive technical and economic comparison should be made for the route plan of the
transmission line to facilitate operation and maintenance. The path selection of transmission lines
should focus on solving the feasibility of the line path to avoid disruptive factors. Each line should
choose two to three feasible line path plans. The following table shows the areas where transmission
lines cannot be erected after field investigation:

| Target layer | Intermediate layer | Classification layer | Factor layer |
|--------------|--------------------|----------------------|-------------|
|              | Ore suppression    | Ore suppression      |             |
| Natural environmental factors | Hydrological and meteorological aspects | flood detention areas, reservoirs, spillway, waterway requirements, water source protection areas, etc. |
|-------------------------------|----------------------------------------|-----------------------------------------------------------------------------------------------|
| Human-influenced structures   | airports, explosive depots, oil pipes, gas pipes, water pipes, etc. |
| Cultural relic conservation area, scenic spot | Cultural relic conservation area, scenic spot |
| Poor geology                  | heavy ice areas, vibrating areas, micro-weather, high-prone areas of natural disasters, micro-topography areas, goaf areas, landslide areas, seismic fault zones |
| Environmentally sensitive area-ecological red line | ecological red line |
| Planning policy factors       | Proposed electromagnetic structures | Proposed radio and television antennas (location, height, purpose), navigation station |
| Government local planning requirements | Basic farmland |
| Waterway requirements         | Reservoir, power station and other water conservancy facilities, river hydrological data |
| Technical factors             | Access system planning requirements | Access system planning requirements |
| "Three-span"                 | high-speed rail and river |

### 3. Route Optimization Model Based On Ant Colony Algorithm

#### 3.1. Principles of Ant Colony Algorithm

Ant Colony Algorithm (AG) is a simulation optimization algorithm that uses robotic ants to simulate group behaviors such as ant colony movement in real natural environments. AG was first proposed by Italian scholar Dorigo M and others in 1991, and it was the first Try to solve the traveling salesman problem (TSP). Later, some scholars systematically studied the basic principles and mathematical models of ant colony algorithm. The basic idea of the ant colony algorithm is derived from the principle of the shortest path for ants in nature. According to the observation of insect scientists, it is found that although the vision of natural ants is not developed, they can find the shortest path from food source to nest without any hint. After the surrounding environment changes, adaptively search for the new best path.

The basic principles of ant colony algorithm:

1) The ants release pheromone on the path.
2) When you come across an intersection that you haven't walked through, choose a random path. At the same time, pheromone related to path length is released.
3) The pheromone concentration is inversely proportional to the path length. Later, when the ants encountered the intersection again, they chose the path with higher pheromone concentration.
4) The concentration of pheromone on the optimal path is increasing.
5) Finally, the ant colony finds the optimal foraging path.

References are cited in the text just by square brackets [1]. Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under heading references, see our example below.

3.2. Principle of Path Optimization Based On Raster Map

3.2.1 State transition. In order to avoid excessive residual pheromone and overwhelming heuristic information, after each ant completes a step or traverses all \( n \) cities (that is, the end of a cycle), the residual information must be updated. Therefore, the amount of information on the path \((i, j)\) at time \(t+n\) can be adjusted according to the following rules:

\[
\tau_{ij}(t+n) = (1 - \rho) \cdot \tau_{ij}(t) + \Delta \tau_{ij}(t)
\]

\[
\Delta \tau_{ij}(t) = \sum_{k=1}^{m} \Delta \tau_{ij}^k(t)
\]

3.2.2 Pheromone update.

a) Local pheromone update rules

A single worker ant takes one step forward and updates the local pheromone:

\[
\tau_{ij}(t) \leftarrow \tau_{ij}(t-1) + \rho \Delta \tau_{ij}
\]

In formula (2), \( \rho \) is a quantity between 0 and 1, called the volatility coefficient, which can reduce the speed of local optimization and avoid falling into a local solution prematurely.

Global pheromone update rules

b) Global pheromone update rules

\[
\tau_{ij}(t) \leftarrow (1 - \alpha) \tau_{ij}(t-1) + \alpha \Delta \tau_{ij}
\]

\[
\nabla \tau_{ij} = \begin{cases} (L_{gb})^{-1}, & i, j \text{ are the global best ones} \\ 0, & \text{others} \end{cases}
\]

In formula (3), \( \alpha \) is the global volatilization coefficient between 0 and 1, which can enhance the algorithm's ability to explore in space.

3.2.3 Adaptive parameters. In the ant colony algorithm, a heuristic function needs to be set. The heuristic function can guide the ants to plan a path to the target with higher efficiency and greater probability. The heuristic function of the model in the transmission line planning problem is as follows:

\[
\tau(\omega_k) = \frac{t}{d(\omega_k)}
\]

In the above formula, \( d(\omega_k) \) represents the distance between the graphic element where the artificial ant is located and the end cell of the plan, \( t \) is a constant, and the value \( t \) in this paper is 28.3.

In this way, the closer the primitive is to the end point, the larger the heuristic function. At the same time, the probability judgment formula of the forward direction of the primitive becomes:
In the formula, $\alpha$ and $\beta$ are the weight indexes of the pheromone and heuristic function respectively, and $|Z|$ represents the subsequent primitives that can be selected at the $\omega_{k-1}$ primitive.

3.3. GIS-based Ant Colony Optimization Algorithm Steps

In order to facilitate the study, this article mainly considers the influence of the length of the transmission line on the design cost of the transmission line, and considers the geographic dimension as two-dimensional. The steps of this model mainly include:

**Step1.** Input the GIS data of the route planning area, establish a rasterized data structure, embed the rasterized model in the GIS, and avoid the red line area of the route planning summarized in the previous article.

**Step2.** Initialize the calculation parameters of the ant colony algorithm, the initial grid pheromone concentration, start point, end point, maximum iteration number, number of ants in a single iteration, pheromone factor, heuristic function factor, pheromone volatilization factor and pheromone constant.

**Step3.** Place $m$ ants at the starting point, start the $k$-round ant foraging activity, and start iteration.

**Step4.** Determine whether there is a feasible point set, if so, move the forward point and go to step 5, otherwise go to step 6.

**Step5.** Judge whether the ant has moved to the end point, if yes, go to step 6, otherwise, go to step 4

**Step6.** Determine whether to traverse all ants, if yes, go to step 7, otherwise return to step 3.

**Step7.** Determine whether the maximum number of iterations is met, if yes, go to step 10, otherwise return to step 3.

4. Case Study

This paper selects a rectangular area from 118°20’ east longitude to 118°21’ east longitude and 32°42’ to 32°41’ north latitude as an example to verify the effectiveness of the proposed algorithm. Using the rasterization algorithm described above, this rectangular area is divided into 20*20 grids, and the cells are numbered from 1 to 400 in the order from left to right and top to bottom. According to the red line area of the route plan summarized in Chapter 2, input the GIS data into the model and get the rasterized route plan original map as shown in the figure below after rasterization.

![Figure 1. Rasterized route planning original map](image-url)
According to the ant colony optimization model described in Chapter 3, optimize the transmission line and assign parameters:

**Table 2. Parameter value**

| Parameter                      | Parameter value |
|--------------------------------|-----------------|
| Information heuristic factor   | 1               |
| Expected heuristic factor      | 7               |
| Information volatilization factor | 0.3           |
| Pheromone enhancement factor   | 1               |
| Starting point                 | (0,20)          |
| End                            | (20,0)          |
| Number of ants                 | 50              |
| Number of iterations           | 100             |

Each iteration process will produce a shortest path $L$, the following figure is the change curve of $L$ with the number of iterations during the algorithm operation:

**Figure 2. Change curve of shortest path - $L$**

The final optimization result is shown in the figure below, the shortest path length is 31.2 (grid unit). According to the optimization results, it can be found that the model has a good reference and auxiliary early warning function for the scheme design of substation transmission lines.
5. Conclusion

This paper takes the geographic data in the geographic information system as the research object, and proposes a substation line optimization design model based on GIS and ant colony optimization algorithm by combining GIS and ant colony intelligent algorithm. This algorithm realizes the avoidance of areas where lines cannot be erected in GIS, and takes the line cost into consideration, and realizes the path optimization under the minimum cost design requirements. Through the calculation of examples, the scientificity and validity of the model are proved.

References

[1] WANG Qingbin SHI Liangyuan HUANG Hui YANG Yun LIU Ping'an LIU Junting. Research on Power Transmission Line Path Planning Based on Improved Particle Swarm Optimization Algorithm[J]. Guangdong Electric Power, 2018, 31(09):135-141. (in Chinese)

[2] ZHOU De-yun, LI Xiao-yang, ZHANG Kun, PAN Qian. Multiple routes planning based on Particle swarm algorithm and hierarchical clustering[A]. Control Theory Professional Committee of Chinese Society of Automation. Proceedings of the 34th China Control Conference (Volume A)[C]. Control Theory Professional Committee of Chinese Society of Automation: Control Theory Professional Committee of Chinese Society of Automation, 2015:5. (in Chinese)

[3] Jian Shen, Jingyuan Zhang, Heng Li. Department of Weaponry Engineering, Naval University of Engineering, Wuhan, 430033, China. Route Planning for Underwater Terrain Matching Trial based on Particle Swarm Optimization[A]. International Science and Engineering Center (ISEC), Hong Kong, Huazhong Normal University, China. Proceedings of 2010 Second International Conference on Computational Intelligence and Natural Computing (CINC 2010) Volume 1[C]. International Science and Engineering Center (ISEC), Hong Kong, Huazhong Normal University, China: Intelligent Information Technology Application Society, 2010:4. (in Chinese)

[4] Yuancun Tan.. Research on Optimization and Application of GA and GIS in EHV/UHV Overhead Transmission Line Path[D]. Yunnan University, 2018. (in Chinese)

[5] Yong Zhou, Jia Kuan Gao, Yubo Zhang, Hao Wu. The Route Planning for AMR Based on Combined Ant Colony and Genetic Algorithm[A]. Northeastern University, China Institute
of Automation, Cyber Physics System Control and Decision Professional Committee. Proceedings of the 31st China Control and Decision Conference(4)[C].Northeastern University, Chinese Society of Automation, Cyber-Physics System Control and Decision Professional Committee: Editorial Department of "Control and Decision",2019:6.(in Chinese)

[6] Guo Zhenfeng,Li Yang,Jiang Xiaodan,Gao Sheng. The Electric Vehicle Routing Problem with Time Windows Using Genetic Algorithm[A]. IEEE Beijing Section,Global Union Academy of Science and Technology,Chongqing Global Union Academy of Science and Technology, Chongqing Geeks Education Technology Co., Ltd.Proceedings of 2017 IEEE 2nd Advanced Information Technology,Electronic and Automation Control Conference (IAEAC 2017)[C].IEEE Beijing Section,Global Union Academy of Science and Technology, Chongqing Global Union Academy of Science and Technology, Chongqing Geeks Education Technology Co., Ltd:IEEE BEIJING SECTION(Transnational Institute of Electrical and Electronics Engineers Beijing Branch),2017:5.

[7] Shuo Ren.Research and Application of Optimal Transmission Line Path Based on Membrane Calculation[D].Shandong Normal University,2015.(in Chinese)

[8] Yu Wang. Research on Optimal Design Algorithm of Transmission Line Path Based on GIS[D].North China Electric Power University,2015.(in Chinese)

[9] Xiaochuan Min,Fanchao Meng,Dianhui Chu,Lei Wang. Modeling and Solution Algorithm for Fourth-Party Logistics Routing Problem Based on Service Composition[A]. Asia Pacific Institute of Science and Engineering.Proceedings of 4th International Conference on Data Mining, Communications and Information Technology (DMCIT 2020)[C].Asia Pacific Institute of Science and Engineering:Chengdu Sherlock Education Consulting Co., Ltd,2020:8.(in Chinese)

[10] Yong Huang. Research on the Improvement of Dijkstra Algorithm in the Shortest Path Calculation[A]. Institute of Management Science and Industrial Engineering.Proceedings of 2017 4th International Conference on Machinery,Materials and Computer(MACMC 2017)[C].Institute of Management Science and Industrial Engineering:Computer Science and Electronic Technology International Society,2017:5.

[11] Ji-sheng CUI,Yun-xin WU,Hong GANG,Tao WANG,Peng QIU,Bin XU,Bo-wen ZHOU. Research and Application of the Optimal Repair Path Based on BP-Dijkstra in the Distribution Network[A]. Science and Engineering Research Center.Proceedings of 2017 2nd International Conference on Applied Mechanics, Electronics and Mechatronics Engineering(AMEME 2017)[C].Science and Engineering Research Center:Science and Engineering Research Center,2017:9.

[12] Qiang Zhang,Huang Huang,Yuezhe Chen.Research on Transmission Line Path Based on Optimal Algorithm[J].Northeast Electric Power Technology,2020,41(01):38-41.(in Chinese)