Optimal Analysis of Transmission Lines Using Ant Colony-Improved Matter-Element Extension Method

Yuntian Liu* and Jingqi Sun
School of Economics & Management, North China Electric Power University, Beijing 102206, China
*Corresponding author e-mail: liuyuntian@ncepu.edu.cn

Abstract. Traditional transmission line design often relies on human experience and is highly subjective. In order to realize intelligent transmission line route optimization, this paper relies on the established geographic information system platform, selects 119°14'50" east longitude to 119°17'56" east longitude, and 31°57'34" north latitude to 31°54'49 north latitude. For the rectangular area of ", first rasterize the area into a 20*20 grid according to the rasterization model, then enter the coordinates of the avoidance area, and optimize the shortest transmission line path according to the ant colony algorithm. Then based on the rasterized matter-element scheme, an improved matter-element extension evaluation method is used to comprehensively evaluate the feasible points around the matter-element node of each path, and the point with the best economic efficiency is selected as the transit point of the transmission line. Optimization of the entire transmission line. The results of the numerical example analysis prove that the method has a better auxiliary decision-making effect on the erection of transmission lines.

Keywords: Transmission Line Path Optimization, Rasterized Model, Ant Colony Algorithm, Improved Matter-Element Extension Evaluation Method

1. Introduction

Transmission line construction is the foundation of power grid engineering, and path selection optimization is the basic work and the most important link, which should be paid attention to. The traditional transmission line design can be divided into three steps: drawing up the route route through drawings, field survey and final route plan determination. Specifically, the designer first draws a number of feasible routes on the map and records their coordinate positions; then conducts a field survey to record important information such as obstacles in the area where the path passes; and finally draws important information such as obstacles on the map. Then, select the line again. Repeat this several times to determine the final path plan [1].

For designers, traditional path design work is extremely intensive, cumbersome, time-consuming, and low in efficiency. In addition, the path plan derived from the traditional design method largely depends on the designers and survey personnel’s own technology, professional quality and experience [2]. The disadvantage is that the map is updated slowly, the amount of basic data is large, and some
data cannot reflect the local area. The actual situation causes the wrong path selection; the high work intensity and long design time affect the progress of path selection, which is laborious and laborious. With the development of information technology, designers began to use modern global positioning technology (GPS) and remote sensing technology (RS) to collect geographic information and generate electronic maps, using automatic computer-aided design software AutoCAD as a display platform and route drawing Platform to assist manual path selection design [3]. Scholars at home and abroad have also done a lot of research on path optimization. For example, literature [4-6] proposes that analytic hierarchy process and fuzzy analytic hierarchy process can be used to consider the differences between many influencing factors, and to add weight coefficients to influencing factors. Alexabdred [7] studied the raster model of the cost surface Find the path with the lowest cumulative cost between the two locations in different path widths. Li Xiaobao [8] uses GIS and fuzzy analytic hierarchy process to transform the terrain, address, icing, pollution, land use type, etc., that affect the transmission line into a grid. The model is evaluated and compared, and the better plan is selected by comparing the two pre-planned route plans. Literature [9] uses the GIS optimal path analysis function and the fuzzy analytic hierarchy process to construct the optimization and optimization of the roads in the goaf. Literature [10] uses GIS and Experts scored to generate terrain undulation and slope raster cost, and based on Dijkstra's algorithm to solve the lowest cost route of the central Yunnan water diversion project. Literature [11] constructed a genetic algorithm-based transmission line optimization model, an overhead transmission line automatic ranking model, and a three-dimensional display model of the transmission line. The 500kV overhead transmission line from Jiantang Substation in Shangri-La County, Yunnan to Tai'an Substation in Lijiang City Taking the planning as an example, the research and verification of the model and the discussion of the results are carried out, and a transmission line route optimization model based on genetic algorithm is established, which realizes the three-dimensional visual display of the optimized overhead line, and meets the decision-making assistance in the room. Through research on path optimization problems by domestic and foreign researchers, it can be found that existing transmission line path optimization methods tend to be more one-sided, fail to take into account the factors that affect the economics of transmission lines, and do not have a complete transmission path planning process. The model needs to be improved urgently.

This paper uses ant colony algorithm and improved matter-element extension model to rasterize the geographic information system, and optimizes the transmission line with the shortest path and the most economical goal. After the verification of examples, the model has a better guidance for the erection of transmission lines.

2. Summary of Key Influencing Factors of Transmission Lines

According to the requirements of power system planning and differentiated planning and design for the development of substation line selection, it is necessary to comprehensively consider factors such as grid structure, line length, topography, town planning, environmental protection, transportation, construction conditions and operation, and carry out multiple plans. Technical and economic comparisons ensure that the lines are safe, reliable, economical and reasonable, high-quality and efficient.

At present, the key influencing factors of substation line selection are also divided into two categories, one is line selection avoidance factors, and the other is technical and economic factors.

Route selection avoidance factors include the following aspects:

1. Natural environment. 1) Avoid mining areas when selecting routes and avoid pressing ore. 2) Hydrometeorology should pay attention to the requirements of flood detention areas, reservoirs, spillways, and waterways. Passing waters near reservoirs, lakes, etc., it is advisable to choose the dominant wind to run on the windy side. A place where the river bank is stable and not subject to flooding and with good geological conditions. 3) Human influences on constructions. When selecting routes, consider facilities such as airports, explosives depots, oil pipes, gas pipes, and water pipes. When the route passes near the airport, the restricted area of obstacles at the airport should be investigated, and the area should be avoided as much as possible. If it is impossible to avoid, the
requirements of the height limit of the airport clear area should be met. 4) Landscape and cultural relic protection areas. Information on the current status and planned ecological red line areas along the route, including nature reserves, scenic spots and conservation areas, should be collected during route surveys. For the first-level control area where all forms of development and construction activities are prohibited, the route should be avoided; when the route does need to pass through other levels of control areas, a written agreement from the relevant management department must be obtained. 5) Poor geology. When selecting the route, pay attention to collecting data on geological and meteorological conditions along the route, and try to avoid areas with high occurrence of natural disasters, poor geological zones, and mining areas.

(2) Policy planning. 1) Proposed electromagnetic buildings. When selecting a route, it is necessary to investigate in advance whether there are plans to build a radio station, television station antenna, and navigation station in the area in advance, and to understand the location, height, purpose, and scale of the proposed construction, and make reasonable evasions. 2) Underground pipeline. It is necessary to investigate the underground distribution of local oil, gas, and water pipes to avoid accidents during construction.

(3) Technical reasons. The line selection should be operated according to the planning requirements of the access system.

Table 1. Transmission line avoidance factor table

| Evasive factor library | Natural environment | Mine |
|-----------------------|---------------------|------|
|                       | Flood detention area, reservoir, etc. | |
|                       | Human influence buildings | |
|                       | Landscape, cultural relics protection area | |
|                       | Bad geology | |
| Policy planning       | Proposed electromagnetic buildings | |
|                       | Underground pipeline distribution | |
| Technical reasons     | Access system planning requirements | |

The technical and economic factors of line selection include the following aspects:

(1) Bad geology. When selecting a route, encountering poor geology such as goafs may increase the workload and difficulty of line laying and increase the cost of route selection.

(2) The impact of traffic and existing routes. 1) The line should be as close as possible to the existing national roads, provincial roads, county roads and rural roads to facilitate the construction and operation of the line. 2) New lines should reduce crossing over existing lines, avoid crossing 220kV and 500kV lines in one gear for 3 times or more. When crossing over, the operation and dispatching departments should be consulted, and the power outage plan should be optimized to shorten the power outage time as much as possible. When a new line crosses an existing line, it is necessary to select the location of the crossing point reasonably, and try to avoid upgrading the existing line. 3) When the transmission line intersects with the main railway and expressway, an independent tensile section shall be adopted, and the crossing angle shall be reasonably determined in accordance with the requirements of the railway design and expressway design specifications. The safety level of the independent strain-resistant section of the high-speed railway transmission line is designed according to the first class.

(3) The difficulty of policy processing. 1) The cable route should be integrated with the overall urban planning, and should be arranged uniformly with various pipelines and other municipal facilities, and should be approved by the urban planning department. 2) Plan compensation. When choosing a route, it is necessary to comprehensively consider compensation costs and civil work, and try to avoid densely populated housing areas, forest areas, and cash crop areas.

(4) Access system planning. It is necessary to fully integrate the outgoing line planning of the substation, rationally arrange the outgoing line intervals and outgoing corridors of the substation to avoid unnecessary crossings; if it is not possible to clearly reserve the outgoing direction of the interval, the current line needs to consider the crossing overs that exist in the long-term outgoing line.
Table 2. Technical and Economic Factors of Transmission Lines

| Economic factor library | Natural environment | Bad geology |
|-------------------------|---------------------|-------------|
|                         | Traffic and existing path impact | Highway convenience |
|                         |                         | Important built transmission lines |
|                         |                         | Across railways and highways |
| Policy reasons          | Policy processing difficulty |
|                         | Settlement expenses    |
|                         | Land acquisition cost  |
| Access system planning  | Access system planning requirements |

3. Two-Stage Transmission Line Optimization Model Based on Rasterized Ant Colony Algorithm and Improved Matter-Element Extension Method

In order to facilitate research, this paper 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 model processing steps are as follows:

3.1. Rasterize Geographic Information and Enter the Avoidance Area

Based on the geographic information map obtained from exploration and surveying in Jiangsu Province, after the planning area is selected, the map is rasterized: assuming that the length of the working environment map is L and the width is B, the environment is divided into $n \times m$ unit grids. The information map $(n \in \mathbb{N}, m \in \mathbb{N})$, the unit grid is a small square with length and width $l$, and satisfies:

$$l = \frac{L}{n} \leq \frac{B}{m}$$

In the formula, $l$ is the determined grid side length, which is called grid granularity.

3.2. The principle of path optimization based on raster map

(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:

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

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

(2) Pheromone update

(2.1) Local pheromone update rules

$$\tau_{ij}(t) \leftarrow (1 - \rho)\times \tau_{ij}(t - 1) + \rho \Delta \tau_{ij}$$

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

(2) Global pheromone update rules

$$\nabla \tau_{ij} = \left( L_{ij} \right) \times \frac{1}{\alpha \Delta \tau_{ij}}$$

where $L_{ij}$ is the global optimal case, $\nabla \tau_{ij} = 0$, other cases
In formula (4), \( \alpha \) is a global volatilization coefficient between 0 and 1, which can enhance the algorithm's ability to explore in space.

(3) Adaptive parameters

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

(6)

In the ant colony algorithm, a heuristic function needs to be set. The heuristic function can guide the ants to plan the 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:

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

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:

\[
p(\omega_k) = \frac{\left[ \tau(\omega_k) \right]^\alpha \left[ \eta(\omega_k) \right]^\beta}{\sum_{\omega_k \in \text{neighbour}} \left[ \tau(\omega_k) \right]^\alpha \left[ \eta(\omega_k) \right]^\beta} \quad \omega_k \in \text{neighbour (} \omega_{k-1} \text{)}
\]

(7)

In the formula, \( \alpha \) and \( \beta \) are the weight indexes of the pheromone and the heuristic function, respectively, and \( Z \) represents the subsequent picture element that can be selected at the \( \omega_k-1 \) picture element.

3.3. Economic Evaluation of Route Selection

The matter-element extension method is used to evaluate the economics of route selection in the designated area.

(1) Read the weights of the various factors influencing line selection obtained by the analytic hierarchy process to obtain the index weight sequence \( \Omega (\omega x1, \omega Y1, \omega Y2, \omega Y3, \omega Y4, \omega W1) \);

(2) After referring to the technical regulations on site selection of power transmission and transformation projects of Jiangsu Power Grid Corporation and the power engineering design manual, the indicators proposed in Chapter 2 are divided into five evaluation levels, which are excellent, good, fair, poor and difference;

(3) Determine the classic domain: According to the evaluation level divided in the previous step, determine the five classic domains of p1-p5, among which: p1 represents "excellent", p2 represents "good", p3 represents "fair", and p4 represents "comparative Poor", p5 represents "bad";

(4) Determine the item element plan to be evaluated, and each grid in the optimal route based on the ant colony algorithm can reach the grid to the next step for trial calculation, that is, use the adjacent 8 cells (in adjacent If the cell exists), the route indicator evaluation and comparison with the current cell will form a total of nine plans;

\[
\text{Figure 1. Raster element scheme}
\]

(5) Standardized processing of classic domains and objects to be evaluated, the processing methods are:

\[
\hat{v}_i = \frac{v_i}{\max v}, i = 1, 2, \cdots, n
\]
6. According to the model given in Section 1, use the programming software to calculate in the
computer to obtain the closeness and evaluation level of the nine objects to be evaluated.
7. Calculate the paste progress of each matter element plan and calculate the evaluation level.
8. Optimize the waypoints based on the closeness and evaluation level.

4. Evaluation Index System Construction
Combining the economic factors of transmission and transformation engineering route selection
analyzed in Section 1, and taking into account actual engineering experience, it is concluded that the
economic factors that affect transmission and transformation engineering route selection mainly
include bad geological treatment costs, traffic planning and policy reasons, and access. The impact
of system planning requirements is shown in Table 4-2. These factors mainly have an impact on the
construction cost of the line selection of the transmission and transformation project. The line
selection of the transmission and transformation project should choose a more economical plan while
meeting these key indicators.

Table 3. Evaluation index system for line selection of power transmission and transformation projects

| Target layer | middle layer | Factor layer |
|--------------|--------------|--------------|
|              | Foundation treatment X | Deep soft soil X1 |
| Technical and |              | River pond X2 |
| Economic Evaluation |              | Sand liquefaction X3 |
| Index System of Early |              | Cave X4 |
| Warning Model for Route Selection of Transmission and Distribution Projects |              | Goaf X5 |
| Planning policy reasons Y |              | Graded roads, rivers Y1 |
|                          |              | Policy processing difficulty coefficient Y2 |
|                          |              | Along the line, crossing Y3 |
|                          |              | Settlement expenses Y4 |
|                          | Technical reasons W | Access system planning requirements W1 |
|                          |              | Across high-speed rail, high-speed, important transmission lines W2 |

(1) Based on the analytical method of analytic hierarchy process, construct the judgment matrix of
each level according to the established index system:
(2) Construct weight vector and consistency check. Through calculation, the eigenvector of each
judgment matrix is obtained, also called the weight vector. The meaning of this vector is the weight of
the influence of each factor of the lower level on a certain factor of the upper level.
(3) Calculate the combined weight vector and consistency check. Using the above method,
calculate the influence weight of all influencing factors in the scheme on the target layer.

5. Example analysis
In order to verify the effectiveness of the model proposed in this paper, a rectangular area from
119°14'50" east longitude to 119°17'56" east longitude and 31°57'34" north latitude to 31°54'49" north
latitude is selected. The area is rasterized into a 20*20 grid, and then the avoidance area is input to
form a grid diagram as shown in the following figure:
Then set the input parameters of the ant colony algorithm:

**Table 4. Evaluation grade of the matter to be tested**

| parameter                        | value   |
|----------------------------------|---------|
| Information heuristic            | 1       |
| Expected heuristics              | 7       |
| Information volatilization factor| 0.3     |
| Pheromone enhancement factor     | 1       |
| Starting point                   | (0,20)  |
| Ending point                     | (20,0)  |
| Number of ants                   | 50      |
| Number of iterations             | 200     |

The optimized transmission line path diagram after operation is as follows:

**Figure 2. Distribution of avoidance factors**

**Figure 3. The result of ant colony optimization**

After obtaining the preliminary planning map, select the planning unit with the larger bend on the map and the closest to the red line area for optimization, that is, use adjacent cells to evaluate and compare the route indicators with the current cell. The maximum number of feasible comparison cells is 8. In this case, the unit on the figure (11, 6) is selected and verified by the matter element extension method.
The input data of the matter element extension model is obtained by collecting the information of each cell area as follows:

**Table 5. Matter-element correlation degree distribution**

| Cell coordinates | (10, 7) | (10, 6) | (10, 5) | (11, 5) | (12, 6) |
|------------------|---------|---------|---------|---------|---------|
| Deep soft soil X1| 20.00   | 22.29   | 27.71   | 10.00   | 17.71   |
| River pond X2    | 0       | 0       | 20      | 7       | 21      |
| Sand liquefaction X3| 20      | 20      | 21      | 5       | 20      |
| Cave X4          | 0       | 0       | 20      | 0       | 0       |
| Goaf X5          | 18      | 19      | 28      | 5       | 16      |
| Graded roads, rivers Y1| 24 | 22.5 | 25 | 7.2 | 13.4 |
| Policy processing difficulty coefficient Y2| 14 | 12 | 14 | 5 | 10 |
| Along the line, crossing Y3| 2.1 | 1 | 3 | 1.6 | 4 |
| Settlement expenses Y4| 13.75 | 23.28 | 23.75 | 14.22 | 14.22 |
| Access system planning requirements W1| 10 | 7 | 16 | 9 | 8.5 |
| Across high-speed rail, high-speed, important transmission lines W2| 0 | 0 | 0 | 0 | 0 |

The obtained matter element extension correlation degree distribution is as follows:

**Table 6. Matter-element correlation degree distribution**

| coordinate | Comprehensive association level |
|------------|-------------------------------|
| (10,7)     | 2                             |
| (10,6)     | 2                             |
| (10,5)     | 4                             |
| (11,5)     | 1                             |
| (12,6)     | 2                             |

Therefore, the point (11, 6) on the optimal path can be obtained by the ant colony algorithm, which can be optimized to the point (11, 5). The same method is used to detect each cell on all paths, and all the optimization of the path can be completed.

6. Conclusions

On the basis of analyzing and summarizing the avoidance factors and technical and economic factors of the transmission line, the gridding ant colony algorithm and the improved matter element evaluation method are used to optimize the path of the transmission line. According to the principles of optimal economic efficiency and shortest path, First, the transmission line planning area is rasterized, and the ant colony optimization algorithm is used to avoid line selection avoidance factors. Then, based on the rasterized matter-element scheme, a comprehensive evaluation of the feasible points around the
matter-element node of each path is performed, and the economy is selected. The optimal point is used as the transit point of the transmission line, and the optimization of the entire transmission line is finally completed.

In the past, manual planning and construction of transmission lines often relied on professionals to finalize the construction plan based on experience, which has strong subjectivity. This article intelligentizes the process of transmission line optimization, using ant colony optimization algorithm and improved matter element extension evaluation method to combine into two The staged transmission line optimization method, through two stages of optimization steps, obtains the final optimized path, which has a better auxiliary decision-making effect on the erection of the transmission line.

References

[1] Ji Wen. Power System Design Manual [M]. Beijing: China Electric Power Press, 1998. (in Chinese).
[2] Feng Qianqian. Research on transmission line path optimization problem based on intelligent optimization algorithm [D]. Jinan: Shandong Normal University, 2016. (in Chinese).
[3] Li Jianwei, Ren Qingchang: Study on Supply Air Temperature Forecast and Changing Machine Dew Point for Variable Air Volume System. Building Energy & Environment 27(4), 29–32 (2008). (in Chinese).
[4] Hosseini M, Bahmani H F. Evaluation and routing of power transmission lines by using AHP method and genetic algorithm[M]. 2011
[5] Eroglu H, Aydin M. Optimization of electrical power transmission lines’ roution using AHP, fuzzy AHP, and GIS [J]. Turkish Journal of Electrical Engineering & Computer Sciences, 2015, 23(5): 1418-1430.
[6] Zhou Pengcheng. Application research of evaluating line transmission path optimization design based on analytic hierarchy process[J]. Electrical Technology and Economy, 2018(05): 50-52. (in Chinese).
[7] GON ALVES A B. An extension of GIS-based least-cost path modelling to the location of wide paths [J]. International Journal of Geographical Information Science, 2010, 24(7): 983-996.
[8] Li Xiaobao, Yang Kuo, Hu Mengjin. Evaluation of transmission line route plan based on GIS and fuzzy analytic hierarchy process[J]. Digest of Electrical Engineering, 2017, 3: 26-29. (in Chinese).
[9] Dong Changsong. Research on optimization of road selection in goaf based on GIS optimal path method[D]. Chang'an University, 2010.
[10] Bao Qian, Ge Ying, Wen Ping, et al. Research on the lowest cost route of the water diversion project in central Yunnan taking into account the terrain[J]. Geographic Information World, 2017, 24(3): 55-59. (in Chinese).
[11] Qin Yuancun. Research on optimization and application of genetic algorithm and GIS in the path of UHV overhead transmission lines[D]. Yunnan University, 2018. (in Chinese).