Substation Secondary Cable Path Optimization Design Based on 3D Simulation and Improved Dijkstra Algorithm

Shengqing Li\textsuperscript{1,2,}\textsuperscript{a}, Yi Zhang\textsuperscript{1,2}\textsuperscript{*}, Zhiyong Ling\textsuperscript{1,3}, Xiaobing Zhang\textsuperscript{3}

\textsuperscript{1} School of Electrical and Information Engineering, Hunan University of Technology, Zhuzhou 412007, China;
\textsuperscript{2} Hunan Engineering Research Center for Intelligent Control Technology of Photovoltaic Microgrid, Zhuzhou 412007, China;
\textsuperscript{3} State Grid ZhuZhou Power Supply Company, Zhuzhou 412000, China.
\textsuperscript{a}zsb@hut.edu.cn
\textsuperscript{*Corresponding author’s e-mail: 1046383423@qq.com

Abstract. In order to accurately predict the length of secondary cable laying in substation construction project and avoid the problem of resource waste in engineering construction, a secondary cable path optimization model based on 3D simulation and Dijkstra algorithm was established. Firstly, through the application of Bentley software, the three-dimensional model of substation is established, and the workflow of BRCM cable laying software is introduced. Secondly, the common and the improved Dijkstra algorithm are used to carry out the path planning on the raster map respectively, and the experimental simulation is carried out. Finally, the simulation results show that the path length of the improved algorithm is 24.32\% and 28.66\% less than that of the traditional Dijkstra. It is 12.34\% less than that of the ant colony algorithm, which provides some useful theoretical references for the secondary cable laying in the future substations.

1. Introduction
Substation secondary cable laying is the first step of the secondary construction, which involves a wide variety of transmission and distribution lines, a large number of workplaces and locations, construction difficulties, and the working environment is more complex and prone to unexpected difficulties\cite{1-2}. Therefore, cable design changes should be minimized during construction. The optimal design and accurate calculation technology of substation secondary cable path based on three-dimensional simulation technology plays a decisive role in the reliability, economy and safety of substation main cable laying\cite{3-5}. Centered on the problem of optimal design of substation secondary cable path with three-dimensional simulation technology, scholars at home and abroad have made thinking and discussion in many aspects, and achieved some stage results. Compared with traditional
2D design, 3D simulation technology has many advantages, and 3D simulation application technology has a very broad prospect[6-7]. An improved visual SLAM optimization algorithm can realize the optimization of arbitrary scene reconstruction, reduce the error of scene reconstruction, and make it more convenient to analyze the actual terrain and build the three-dimensional simulation model of substation[8]. Based on rasterized 3D map, an optimization algorithm combining genetic algorithm and dynamic programming method is proposed to solve the path optimization problem[9]. Based on GIS raster map, the optimal path between two points is solved by dynamic programming method[10]. On the basis of genetic algorithm, the travel salesman (TSP) path optimization method is used to optimize the specific path, which can effectively reduce the distance between lines and solve the problem of urban power grid planning[11]. Based on the coevolutionary algorithm, the improved RRT algorithm is nested to get the best optimal path[12]. Combining genetic algorithm and Dijkstra algorithm, the optimal design of cable laying route is obtained[13]. An improved Dijkstra algorithm for AGV path planning is proposed[14].

The existing literature generally considers the design of cable lines on a two-dimensional plane alone, but this design idea cannot show the mutual constraints between cable laying and surrounding terrain and environment. With the promotion and popularization of 3D simulation technology, the combination of 3D technology and substation engineering construction can be more efficient and intelligent for construction.

Aiming at the problem of optimal design of secondary cable routing in substation, this paper studies and designs a solution algorithm of secondary cable routing in substation based on 3D model. Firstly, Bentley 3D model design software is used to establish the 3D model diagram of the substation. Secondly, the improved Dijkstra algorithm is used to establish the 3D model diagram of the substation. Finally, a practical example is given to verify the reliability and feasibility of the model.

2. Establishment of three-dimensional model of substation

In this paper, Bentley three-dimensional collaborative design platform was used to design substation cable laying, Bentley Raceway and Cable Management, it is a professional cable laying software belonging to the platform, which can assist the electrical professional to complete the three-dimensional laying of substation cables[15-16].

2.1. Bentley 3D modeling process

Firstly, under the Substation system, three-dimensional drawings are established according to the basic design principles of electrical equipment and main wiring. The same electrical equipment can use the same device code in other three-dimensional drawings. Secondly, the main electrical wiring of the equipment is calculated by the software of the short-circuit current set in advance. Finally, according to the three-dimensional model requirements of power facilities and civil engineering, the establishment of all power facilities and reinforced concrete and other equipment. Usually, it is required to create 3D models based on the principles of ease, simplicity and simplicity.

After the 3D model is created, specific parameters should be set for each device according to the actual engineering situation. These parameters must conform to the rated value of electrical equipment, otherwise it will cause the simulated equipment can not be used normally. The corresponding equipment parameters should generally include at least the model of the equipment, production date, rated power supply voltage, rated power, rated
capacity, rated output current, rated frequency, production process manufacturer, etc. In order to facilitate the rapid matching of equipment and adjustment of other engineering applications, it has become necessary to expand the property library of equipment and the model library of electrical facilities. The completed 3D model is shown in Figure 1.

![Three-dimensional diagram of substation](image)

**Figure 1.** Three-dimensional diagram of substation

2.2. **BRCM Software to carry out the work flow of cable laying**
During the cable laying process using BRCM software. First of all, models such as cable trench and buried pipe are built according to the actual situation of the project, and then the cable path and electrical equipment are intelligently numbered and imported into the inventory. After import, it automatically matches the existing model in the laying software, and adopts the "optimal path algorithm" to automatically calculate the optimal path from the starting point to the end point of the cable, and finally generates the cable aggregate diagram. The whole process is completely digital design, which can effectively avoid various collision problems. This method can realize the automatic selection and optimization of cable laying path, and improve the laying quality. The process is shown in Figure 2.

![BRCM cable laying software design process](image)

**Figure 2.** BRCM cable laying software design process
3D cable laying software, with its advantages of simple operation and accurate design, replaces 2D CAD drawing which is tedious and not accurate enough. It is an inevitable trend under the function of modern digitalization.

3. Optimal path algorithm

In this paper, Dijkstra is used to solve the path optimization problem. Dijkstra algorithm solves the shortest path problem in the power graph and is used to calculate the shortest path from one node to the other nodes [17].

3.1. Map rasterization

Divide a map with environmental information into a N×N raster map, with \( C_{ij} \) representing the raster for row \( i \) and column \( j \). The effect is shown in Figure 3.

![Figure 3. Map rasterization](image)

In a raster map, green dots are the starting point of a path and red dots are the end point of a path. The black squares are obstacles in the path of simulated buildings, electrical equipment, etc. The shortest distance of cable laying between two points is found by path optimization algorithm.

3.2. Dijkstra Algorithm principle

Dijkstra algorithm is mainly used to pass it to extend to all other starting, the starting point of the nodes of the shortest path, the main calculation in the original is one of the features of a starting node path as computing center, the short circuit outside deeper radial extension to expanding, until the short circuit outside the radial extension until the final destination. The formula for solving the linear distance between two nodes is as follows:

\[
\text{d}(A, B) = \sqrt{(x_A + x_B)^2 + (y_A + y_B)^2}
\]

The Dijkstra algorithm calculates the shortest path as follows:
Step1. First, we need to specify a starting point \( x \) and an ending point \( y \), and introduce a secondary array (Vector) \( V \), where each element \( V[i] \) represents the length currently found from the starting point \( x \) to each other vertex \( x_i \).

Step2. The initial state of \( V \) is: if there is an arc from \( x \) to \( x_i \), then \( V \) is the weight on the arc, otherwise set \( V[i] \) to infinity.

Repeat steps 1 and 2 to get the shortest path \( \mu \) from \( x \) to \( x_i \). The algorithm overview diagram is shown in Figure 4.

Figure 4. Dijkstra algorithm overview diagram

3.3. Algorithm to improve

Because Dijkstra algorithm has many intermediate variables during path optimization, problems such as long computation time and low storage efficiency will occur in complex ground condition optimization. To solve these problems, the Dijkstra algorithm is improved. The steps of the improved Dijkstra algorithm are as follows:

First, let the starting point of the grid be \( x \) and the end point be \( y \). The number of vertices is \( n, V = \{v1, v2, v3, ..., vn\} \) respectively, \( S_y \) representing the weight of edge \( (vi, vj) \), which satisfies \( (vi, vj) \geq 0 \). Let \( \overrightarrow{VxVy} \) represent the shortest path from the starting point to the selected point.

Step1: Initialize, set \( \overrightarrow{V1} = 0 \), if the straight-line distance \( \overrightarrow{VxVy} \) is equal to \( \overrightarrow{VxVj} \), then this is the shortest path. If there is more than one side chain in the process \( x \rightarrow j \), record the vertex and distance passed by each side chain, and continue Step2.

Step2: Starting from vertex \( x \), find the minimum weight of the edge chain passing through two adjacent vertices. Let the two vertices be \( vi \) and \( vj \), that is:

\[
| (Vx, Vj) | = \min_{j \in n} | (Vx, Vy_j) |
\]
Step3: Repeat Step2 to find the minimum weight of \((v(i+1), v(j+1))\) until the last node is \(y\). At this time, the shortest path is obtained. Similarly, \(x\) and \(y\) are taken as root nodes, and a binary tree is adopted to start from two points. The shortest path can be checked by backward tracking.

4. Simulation and experimental analysis

In order to have a more intuitive observation of the path optimization results, this paper compares the following two aspects: 1) the path optimization results of the traditional Dijkstra algorithm and the improved Dijkstra algorithm are compared; 2) Comparison of path optimization results between improved Dijkstra algorithm and ant colony algorithm.

In this paper, the path optimization experiment computer configuration is as follows:

CPU: Inter(R) Xeon(R) E-2224G 3.50GHz
System: Windows 64-bit operating system

The advantages and disadvantages of the traditional Dijkstra algorithm and the improved algorithm were compared, and the simulation experiment was carried out through MATLAB.

![Comparison diagram of algorithm path optimization](image)

**Figure 5.** Comparison diagram of algorithm path optimization

As shown in Figure 5, the green initial starting point and red target end point of path optimization are artificially defined, and the red line is the obtained path result. (a) Fig. Path optimization diagram of traditional Dijkstra algorithm under simple roadblocks; (b) Figure shows the path optimization diagram of the improved Dijkstra algorithm under simple roadblocks; (c) Path optimization diagram of traditional Dijkstra algorithm under complex roadblocks; (d) Figure shows the path optimization diagram of the improved Dijkstra algorithm under complex roadblocks; (e) Fig. Path optimization diagram of ant colony algorithm. The optimization results are shown in Table 1.
Table 1. Path optimization results of Dijkstra algorithm

|                | (a) | (b) | (c) | (d) | (f) |
|----------------|-----|-----|-----|-----|-----|
| The shortest distance | 37.0 | 28.0 | 123.5 | 88.1 | 100.5 |
| Turning points     | 7   | 7   | 48  | 5   | 35  |

The analysis shows that, compared with the traditional Dijkstra algorithm, the improved Dijkstra algorithm uses polyline path instead of straight path to make the path distance shorter. In the case of simple roadblocks, the shortest path distance obtained by the improved Dijkstra algorithm is reduced by 24.32%, but the turning points of both algorithms are 7. It shows that the improved algorithm is slightly better than the traditional algorithm under the good construction environment.

In the case of complex roadblocks, the shortest path distance obtained by the improved Dijkstra algorithm is reduced by 28.66% compared with the traditional Dijkstra algorithm and 12.34% compared with the ant colony algorithm. And the number of turning points of the improved algorithm is far less than those of the other two. This indicates that the more complex the construction environment, the improved algorithm can reduce the number of cable laying turns, save cable raw materials and improve the construction efficiency.

5. Conclusion

This paper proposes an improved Dijkstra algorithm based on the optimization of secondary cable path of three-dimensional simulated substation to solve the deficiency of traditional Dijkstra algorithm in solving the optimal path. The Matlab simulation results show that compared with the traditional Dijkstra and ant colony algorithm, the path length of the improved Dijkstra algorithm reduces by 24.32% and 28.66% compared with the traditional Dijkstra algorithm, 12.34% less than the ant colony algorithm; Fewer turn points. This algorithm has a more efficient laying result for substation secondary cable path optimization problem and is more suitable for application in practical environment.

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