Research on Large-scale Cable Intelligent Laying Technology Based on Graph Theory

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Abstract. Power cables, as the most important power transmission medium for indoor substations in urban centres, are important factors that affect the safety, reliability, flexibility and economy of substations. It is important to study the substation cable laying schemes to study the technical and economic schemes of substation construction. Aiming at the goal of achieving the best technical and economical solution for cable laying in substations, by combing the statistics of the total station cable quantity and optimizing the cable laying path in combination with the plane layout, using three-dimensional software, a model for the cable laying of each interval power distribution device was established to complete Three-dimensional visual simulation of cable laying at a station, accurate design of cable laying path, verification of collision, simulation of construction work surface, optimization of cable laying path and facilities, and optimization of cable outbound methods in conjunction with planning requirements. Finally, a cable laying optimization design plan for smooth cable connection, safe construction and operation, convenient expansion, and economical saving can be formed, which can save the cable laying investment in the station.

Keywords: Graph theory, intelligent cable laying, laying technology.

1. Introduction

With the improvement of the performance of computer graphics cards and the advancement of 3D rendering technology in recent years, more and more cable design software provide the 3D display function of cables in order to improve the visualization effect. For units such as hydropower stations or municipal departments, the amount of cable model data may be very large. There are three main reasons: The first is that these units involve massive amounts of cables. For example, in a hydropower station, the number of cables will reach about 15,000. The second is that the attribute parameters of a single cable are large. The path of a single cable starts from the electrical equipment, passes through intermediate facilities such as bridges, cable trenches and buried pipes, and then connects to the electrical equipment. Therefore, the posture of the cable itself is complex and diverse, resulting in a large attribute parameter of each cable. The third and most influential point is that the number of model surfaces of a single cable is large. The existing method for describing the organization of cable 3D modelling data is: first define the sweep path, that is, the centre line of the cable, and then use the
cable cross-section circle to sweep along the centre line of the cable to form a 3D model of the cable. The display data of the three-dimensional cable model is a collection of discrete triangles that sweep the outer surface. The finer the cable display effect, the greater the amount of discrete triangle data.

The existing cable display method is to generate all fine-level triangles of several cables to be displayed, load it into memory at a time, and the graphics card must render all cables every frame. The greater the number of cables, the greater the amount of triangle data. All the display data is in the memory, which will cause a huge demand for memory when displaying a large number of cables. At the same time, each frame of the graphics card is to render all the triangles in the memory, which causes the workload of the graphics card to be always large, and the corresponding view operation is not smooth. Using existing mainstream platform design software, such as Autodesk's AutoCAD and Revit, to draw more than 1,000 cables, the software occupies a huge amount of memory, common view operations will appear stuck, and the user experience is not smooth. Therefore, designing a cable display method with low requirements on memory and graphics card, good display effect, and a smooth display of the entire cable three-dimensional model is an urgent problem for those skilled in the art [1].

2. Introduction to graph theory

As a new intelligent optimization algorithm, graph theory was first proposed in 1997. After more than ten years of research and expansion, graph theory has been successfully applied to travel salesman problems, graph colouring, vehicle scheduling and other problems. It shows good performance in solving optimization problems, especially large-scale combinatorial optimization problems. However, the optimization ability of this algorithm largely depends on the rationality of the neighbourhood construction and the effectiveness of the local search strategy. The problem of cable laying in actual engineering is to connect thousands, even tens of thousands of power cables, control cables, and signal cables from the starting device to the terminal device through a cable channel composed of bridges, cable trenches, and so on. The key to this problem is that under the premise that each channel of the cable has its fixed capacity, which path will be taken by such a large number of cables to make the entire system more stable and economical [2].

Figure G is a laying diagram, abbreviated as \( L = (V, E, d, c, S, F) \). Among them, the vertex pair \( \left( s_1, f_1 \right), ..., \left( s_M, f_M \right) \) consisting of the vertices in the sequence \( S \) and \( F \) represents the path to be laid. In graph \( G \), find a connected path from the start point \( s \) to the end point \( f \) of the path, called the laying of the path, and the edge on which the number of paths laid reaches its maximum capacity is called the full edge. If the shortest total cable laying length is selected as the optimization goal, the cable laying problem considering the channel capacity constraints is equivalent to finding the minimum sum of the laying lengths of all to-be-layer paths in a laying diagram \( L \). The optimization problem can also be expressed as the following mathematical programming model:

\[
Minz = \sum_{i \in K} \sum_{(i,j) \in K} d_{ij} x_{ij} \tag{1}
\]

Where \( x_{ij} \) is the decision variable indicating whether the laying path \( k \) passes from vertex \( i \) to vertex \( j \) through the edge \( (i, j) \), 1 means yes, 0 means no; \( d_{ij} \) is the length of the edge \( (i, j) \), and \( K \) is the path to be laid set. If there is a special path for a special type of cable, for example, a certain cable tray is a power cable tray, and control and signal cables are not allowed to pass, just add the constraint condition (2) to the above model, where \( E_1 \) is the corresponding edge set of the power cable tray, \( K_2 \) and \( K_3 \) are the set of routing paths corresponding to the control and signal cables, respectively. The same applies to other special paths for cables.

\[
x_{ij} = 0, (i, j) \in E_1, k \in K_2 \cup K_3 \tag{2}
\]
The goal of cable laying optimization can also be the most cost-effective cable investment, that is, the total cable cost is the least. Simply multiply the cable lengths of various prices in the optimization target formula (1) by the unit price. Let \( x_1 \) and \( x_2 \) be the two feasible solutions for the cable laying problem. If there are \( k \) routes in \( x_1 \) that are different from \( x_2 \) in routing, and the other \( M-k \) routes are in the same routing, then the distance between solutions \( x_1, x_2 \) is called \( k \), Record as:

\[
\delta(x_1, x_2) = k
\]

(3)

Based on the above definition, this paper defines the neighbourhood structure of the solution according to the distance between different solutions. In other words, the set of solutions with a distance \( k \) from the solution \( x \) is defined as the neighbourhood \( N_k \) of the solution \( x \), i.e:

\[
N_k = \{ x' | \delta(x, x') = k \}, k = 1, 2, ..., M
\]

(4)

For the cable laying problem considering capacity constraints, the benefit of defining the neighbourhood structure in this way is that the search within the neighbourhood and the expansion of the search range can be intuitively performed. When searching in the neighbourhood, another solution \( x' \) in the neighbourhood \( N_k \) can be obtained from the solution \( x \), and it is only necessary to randomly select \( k \) path transformations. When transforming the layout, first delete the layout of the selected path in the layout diagram \( L \), set one of the edges of the original path to be unavailable, and then apply the Dijkstra algorithm to re-lay the path within the available edge range. This not only ensures the obtained solution \( x' \in N_k \), but also takes into account the optimization of understanding.

3. Design process
BRCM software provides the whole process solution from 3D modeling to 2D drawing. Its integrated design process is shown in Figure 1. The process takes the engineering database as the core, stores cable channel path information, starting and ending device location and coding information, combined with cable inventory, and automatically lays a large number of cables in accordance with the set cable laying rules. After laying, all kinds of drawings and reports are extracted based on the database. The whole process realized the high efficiency of the design and the refinement of the results [3].

Figure 1. Cable laying process
3.1. Channel design
When designing cable channels, factors such as engineering conditions, environmental characteristics, quantity and technology are selected, and different laying methods are selected. Generally speaking, power plants usually lay channels with bridges, cable trenches, open pipes, hidden pipes and shafts. BRCM software has different modules to achieve corresponding functions. The BRCM software includes three types of bridges, including trough, ladder and tray, and a variety of accessories. Customize the style and size of the bridge according to the requirements of the construction drawings and add covers. Model creation is quick and easy, and collision check with other professional models is also possible.

The powerful modelling function of the software has the following advantages: parametric drawing of multi-layer bridges, automatic processing of joints, tees and tees and other connections; adopting the two- and three-dimensional integrated design concept, viewing the three-dimensional effect directly when drawing in planes; layering the bridges; Set the laying type of bridges on each floor; set the coding rules of the bridges and automatically batch code; add custom attributes to the bridges and output them in the report.

3.2. Equipment layout
The BRCM software parameterized equipment layout module is powerful and can meet the electrical equipment layout design of the plant. You can create parameterized devices and non-parametric devices, add custom attributes to devices, and output them in reports. When arranging equipment such as cabinets, the size parameters can be modified instantly to define the insertion point and wiring point information. The support and hanger layout module can parameterize the support and hangers, and arrange them in batches along the centre line of the bridge. If you select a multi-layer and multi-row bridge, the software can flexibly implement matrix layout. The software classifies and counts various types of equipment to realize the whole process design from 3D modelling to engineering quantity calculation [4].

3.3. Rule setting
A variety of laying rules are built into the software, including voltage matching, floor area limit, weight analysis, and shortest path principle. For voltage matching, set the cable voltage level (power, control, weak current) that it carries when laying the bridge, and automatically match according to the voltage level when laying; for the volume ratio, the volume ratio allowed by the bridge can be set in batches. If the number of cables is too large and exceeds the limit of the volume ratio, the software will automatically find other paths; for weight analysis, the allowable load value (kg/m) of the bridge can be set in batches. If it exceeds the allowable value during laying, the software will automatically find other paths; The shortest path is the bottom-most laying rule of the software. Under the premise of satisfying the above rules, the shortest route of each cable is calculated according to the search algorithm, and the cable length and the number of the bridge node it passes are calculated. Through the above several laying rules, the software automatically optimizes the laying of a large number of cables, accurately counts the length of the cable, fundamentally eliminates human errors, guarantees the design quality, and improves the design efficiency.

3.4. Two-dimensional plot
The cable laying results are stored in the database. Based on the engineering database, the software can quickly generate all kinds of drawing reports. Use the report generator to quickly generate reports, including cable information and equipment bridge information; the report template style can be customized, and the custom attributes added by the equipment and bridge can be output in the report; the report can also be exported to different format files. The cable tray model after cable laying additionally carries various types of cable laying information, including the cables laid in the cable tray and the occupancy rate of the cable tray volume ratio. The dynamic cross section of the bridge tray is marked on the drawing in the form of a table, as shown in Figure 2. In addition, the software
provides annotation tools for annotating various types of information such as bridge height, bridge encoding, etc. The annotation information is diverse and can meet a variety of needs [5].

4. Design of Intelligent Laying System

4.1. Overall design
The cable laying 3D visual design module uses virtual reality technology to allow cable laying designers to immerse themselves in the virtual environment generated by the computer in real time to design real construction site related construction plans, including virtual scene roaming, laying plan design, laying path optimization, etc. So that designers can complete accurate cable laying scheme design without frequent trips to the real site. At the same time, based on augmented reality technology, the camera on the AR device identifies the corresponding 2D engineering drawings and displays the corresponding 3D cable laying design plan. The construction team can quickly and accurately obtain project-related construction on the AR device. Information to improve the efficiency of project implementation. The system is divided into a background server and a foreground client. The foreground client mainly includes a system management terminal, a VR client, and an AR client.

All data is stored in the background server, as long as the user can log in to the client and use the system as long as there is a network. The system will transfer the required data to the local according to the user rights (system management users can view and modify all data, cable laying design users can view all cable laying plan data and modify their own design plan data, and construction users can view all design plan data) Client. As shown in Figure 3.
4.2. Functional analysis

4.2.1. User information management function. The platform is only open to the relevant staff of Electric Power Design Institute Co., Ltd. Therefore, in order to enhance the work of project information security and confidentiality, it is necessary to design user information management functions for the system. The software sets corresponding use rights for different users, including user identity verification, construction project information management, construction site layout design scheme saving and uploading, etc., so as to realize the confidentiality of the relevant information of the software users, and perfect user information management functions. It is also convenient for software users to monitor and manage construction projects in real time.

4.2.2. Device model information management function. The equipment model in this project is designed by 3DMax, Maya and other three-dimensional modelling software. In order to truly reflect the situation on the construction site, the equipment model is designed with the original size of the real equipment, and the texture map of the model is also captured by a professional photography camera. The obtained information ensures the consistency of the device model and the real device to the greatest extent, thereby enhancing the realism of the virtual scene.

4.2.3. Construction site construction function. In order to truly simulate the construction environment of the cable laying project, the 3D cable laying design platform needs to support the construction site construction function. Through the various editing tools built into the platform system, the construction of the real construction scene can be quickly completed and the construction can be restored in the virtual environment. The situation on the site allows designers to have an intuitive and accurate understanding of the construction site, thereby providing an effective, accurate, and reliable reference for the design of cable laying facilities.

4.2.4. Design function of construction plan. Construction plan design is the core function of the 3D cable laying design platform. In the construction site construction function, the real construction situation of the project is presented. On this basis, the designer simulates the construction process in the virtual scene by calling various types of cables and construction tools, so as to select and formulate the corresponding construction plan.

5. Conclusion

The replacement of traditional CAD drawing methods by 3D cable laying software is an inevitable trend under the influence of modern engineering environment, and with the complexity of engineering and the complexity of equipment, it gradually shows its advantages. Designers need to be gradually familiar with 3D design software, and software manufacturers also need to constantly update and improve the design software to improve their own reliability and operational convenience. The popularization and application of 3D design is the direction of joint efforts of software manufacturers and designers.

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