Design of Distribution Network Pre-planning System Based on GIS

Dawen Huang[1(✉)], Qiugen Pei[2], Yong Xiao[1], and Wensheng Lu[1]

[1] Zhaoqing Power Supply Bureau of Guangdong Power Grid Co., Ltd., Zhaoqing 526000, China
hdwgmy@163.com
[2] Guangdong Power Grid Co., Ltd., Guangzhou 510000, China

Abstract. Aiming at the demand of distribution network pre-planning, this paper analyses the current situation and existing problems of distribution network pre-planning, and proposes a distribution grid pre-planning system based on GIS. Based on the design concept and technical route of the grid planning system in the early stage of distribution network, the functional modules and overall architecture of the system are designed. Developing system design based on GIS, maximizing the integration of grid information, providing more accurate and diversified decision-making basis for distribution network planning business personnel, and improving the quality and accuracy of distribution network pre-planning.

Keywords: GIS · Distribution network · Pre-planning · Grid-based · Micro-services · CIM

1 Introduction

The overall process of power distribution network construction project can be divided into three parts: pre-planning design, distribution network construction, and late completion inspection. Among them, the pre-planning and design work is very important in the process of power distribution network construction. In terms of quality, the pre-planning has a direct impact on the stability and optimization of the distribution network power supply system. In terms of investment, it has an important impact on the number of personnel, equipment and materials inputs, including the overall project cost estimation [1]. The pre-planning design mainly carried out preliminary investigations on urban land use planning and power grid development status, and accurately predicted the load distribution. Based on Pre-planning scheme, the designer will select the optimal location of the substation and select the optimal wiring mode, which will make the cost budget and benefit estimation work more scientific and reasonable. It will greatly improve the effectiveness and feasibility of power distribution network work, in order to provide customers with safer power consumption, and promote the overall power grid construction and optimization [2].

The geographic information system (referred to as GIS) can fully integrate the geographical location and its related attribute data, and integrate the relevant information graphics. It provides users with spatial geographic data query, spatial statistical

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analysis and visual support, analysis, management and decision-making, making the planning process and results more intuitive and interactive. The power network line in GIS has linear geographic features. GIS can succinctly display the equipment load of the distribution network and the distribution of users, automatically generate various relevant statistical analysis charts, and effectively provide scientific and effective data for power system operation management and production decision. Therefore, GIS has become one of the most powerful spatial analysis support technologies in power network planning informatization [3–5].

In order to solve the current problems of distribution network planning, such as reference data cannot be displayed simultaneously, a lack of technological application for spatial data query, spatial statistical analysis, data sharing management and so on, this paper proposes a method of distribution network planning based on multi-source power network business data and spatial data, combined with power network CIM model automatic analysis method, and powerful spatial analysis technology of GIS.

The method can automatically update the geographical position and attribute information of the network frame, combine relevant business data with geospatial data, and assist the network frame planner to scientifically and effectively evaluate the current network frame transfer capability, power supply security level, and power supply reliability. It can simulate the wiring operation in the distribution network frame planning, automatically estimate the line load transfer capability after network frame planning, and realize the intelligent distribution network planning.

The method improves the quality and accuracy of the distribution network planning and ensures the effectiveness and feasibility of the distribution network construction work. The system has been piloted and applied in the distribution network planning business of Zhaoqing Power Supply Bureau of Guangdong Power Grid Co., Ltd.

2 Present Situation and Problems in Distribution Network Pre-planning

The pre-planning method of the distribution network, which strengthens the problem-oriented and precise investment concept, will help promote the scientific development of distribution network construction. It is of great significance for building network frame, clarifying the construction standards, and optimizing the construction plan. With urban power network construction expansion, the phenomenon of network frame information and geospatial information detachment in the early planning process of distribution network is also increasing, which leads to the failure of the traditional distribution network pre-planning method to be applied to the current power distribution network project. The pre-planning method of traditional distribution network has limitations in the current era of intelligent informationization, resulting in distribution network planning within a single region and between regions, and the overall distribution network planning and construction and urban space structure lack coordination [4]. The specific problems in the pre-planning methods of traditional distribution networks are as follows.

2.1 Lack of Integrated Design Concept and Depth Analysis

Distribution network planning requires a large amount of reference data, including municipal planning data, power network status map, power grid structure, attribute data, distribution network equipment operation data, marketing data, etc. These data are scattered in different systems, and data information is difficult to obtain and analyze [6].

Therefore, when formulating the scheme, the analysis indicators are relatively simple and cannot effectively describe the complex distribution network operation environment. Lack of comprehensive depth analysis of multiple influencing factors and quantitative analysis of investment benefits led to the failure to select an optimal planning solution.

2.2 Poor Scalability of the Distribution Network

Part of the planning scheme has poor coordination with the urban spatial structure in the location selection of the network frame equipment. The division of the power supply range of the substation is unreasonable. And there is an uncoordinated distribution network planning within a single area and between the various areas. Some new planning loads have no power supply path, which results in limited expansion capacity of the distribution network and difficulty in expanding the power supply range [7].

2.3 Difficult to Optimize the Network Structure of the Distribution Network

The purpose of network frame planning is to balance the power of each partition and plan the power supply range of each substation to determine the optimal power network frame configuration scheme, while meeting economic and reliability requirements. Therefore, distribution network planning is a complex optimization problem with multiple objectives, uncertainty and nonlinearity [5].

2.4 Lack of Necessary Information Support Means

The data collection and finishing is mainly based on offline reporting. The program planning relies on simple calculation, empirical analysis, lack of information-based means of automatic data acquisition and application of technical means such as spatial data query, spatial statistical analysis, and data sharing management. Quality and accuracy are difficult to guarantee [8, 9].

3 Technical Route

Based on the current pre-planning situation of the distribution network, this paper proposes the design concept and technical route of the pre-grid planning system for distribution network.

3.1 Docking with the Business System

By integrating the three major system data of Distribution Network GIS System, Measurement System and Marketing System, the layout data, user quantity data and load data will be organically combined and assisted in visual analysis. The standardized business process and data format are used to realize the main functions including pre-multi-source survey data integration and sharing, line simulation planning, and planning program feasibility analysis, which will assist the distribution network planner to complete the distribution network planning with high efficiency.

3.2 Adopting Micro-services Architecture

The system needs to integrate confidential data such as control detailed planning data and land use planning data, which requires high security performance. At the same time, according to the planning business needs of the distribution network, the planning scheme involves multi-source data fusion, interactive editing of grid devices, real-time rendering of data analysis, etc., which requires high performance and speed of the computer, so the overall architecture of the system adopts micro-services architecture.

3.3 Formulating and Sharing the Planning Scheme

Before the planning scheme is formulated, the planner obtains the network equipment data, the attribute relationship data, the measurement data, and the marketing data from the server according to the feeder line and the load time. The planner only needs to extract the data involved in the solution-related feeder groups. Therefore, the data for scheme formulate is relatively lightweight. The planning scheme will be saved to the local lightweight database SQLite management call. After the planning scheme is completed, the data will be shared with the server for other business personnel to refer to or review on the Local Area Network.

3.4 Unified Integrating Application Environment

Our system uses a unified distributed spatial database system. The server publishes map browsing, data query, spatial analysis, data management and other services in the form of Web Services. The geographic service adopts the WMS and WFS service interfaces conforming to the OGC standard, which realizes seamless integration with the heterogeneous spatial data map services of other GIS platforms, reduces the network transmission burden, and improves the client access speed. Geographic and business data are transmitted in a specific encrypted form to ensure the security of the transmitted data.

4 System Design

4.1 System Function Design

According to the demand analysis of the pre-planning of the distribution network, business application modules include multi-source data visualization integration,

planning solution management, grid planning, and planning feasibility analysis are designed. The main function design of the system is shown in Fig. 1.

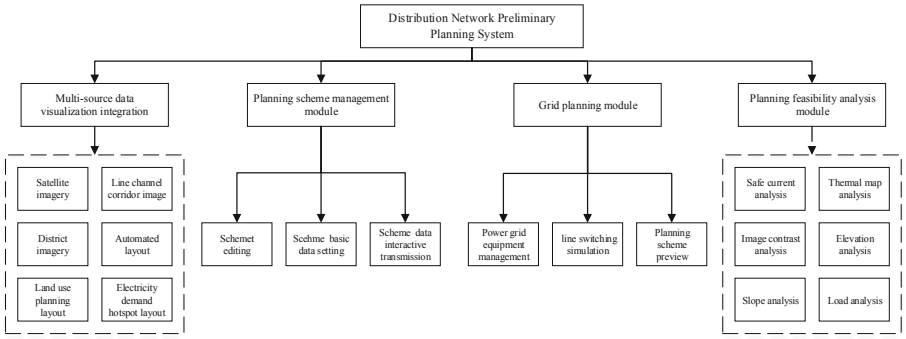

Fig. 1. Main function design of the system

Multi-source Data Visualization Integration. The pre-planning design of the distribution network needs to refer to multi-source data. In addition to the data in the three systems of GIS System, Measurement System, and Marketing System, it is still necessary to consult various forms of data to assist the planning and design, and improve the rationality of the scheme formulation. Multi-source data mainly includes satellite image, line channel corridor image, district image, automated layout map, land use planning layout, power demand hotspot layout and other data. Based on GIS visualization technology, multi-source data integration is displayed on the same map to realize "one map of planning information", which helps to improve the scientific, normative and planning efficiency of grid planning decisions.

Planning Scheme Management Module. The planning scheme management module includes proposal content editing, proposal basic data setting, and proposal data interactive transmission. The storage form of the proposal includes both local and server forms. The planning scheme supports offline editing and also supports sharing of the solution within the LAN. Different operators can provide feedback on the proposed scheme, reducing the situation that the single-person operation leads to insufficient consideration of the program. In addition, according to different privilege levels, users can perform different operations on the server-side proposal data, which is beneficial to proposal data sharing, multi-department collaborative operation, and unified organization and control of scheme data.

Grid Planning Module. Based on the grid the grid composed of feeder groups, the distribution network planning is beneficial to optimize the current complex interlaced network structure and solve the problem of uneven distribution of substation and line load. The traditional distribution network planning method is to collect data from multiple parties, including GIS System, feeder line diagram, metering system data table, Marketing System data table, etc. for manual integration and recalculation. Now users simply select the grid from the business logic or geospatial to display the grid

asset device on the map. The system supports users to create new equipment, transform equipment, split lines, merge lines, set segment points, etc. on the map. And it realizes the balance of the substation and each line load, high reliability or minimum network loss, and can intelligently calculate the planning result according to the adjustment of users. The module mainly includes power grid equipment management, line switching simulation, and planning scheme preview.

(1) *Power Grid Equipment Management.* In the pre-planning process of the distribution network, it is necessary to judge whether it can perform the line switching according to the attribute information of the grid equipment. Different grid devices contain multiple attribute data, and some attribute information will affect the planning scheme feasibility, data statistics, etc., such as wire type, wire diameter, station residual interval, transformer type, and so on. The power grid devices that support users viewing and editing mainly include: lines, automation switches, tie switches, towers, cable distribution boxes, switch boxes, distribution transformers.
(2) *Line Switching Simulation.* The system supports users to simulate line switching operation, splitting and merging feeders in different grids, re-planning the grid structure, and re-calculating the statistical data of feeder load, number of users, transformer capacity, line length, safe current, etc., to generate automation layout. Automation layout is based on substation as the starting point and automation switch as the sectional point. In the form of graphic and text integration, it can display the feeder segment situation intuitively for users, simulate the transfer results of fast feedback lines, and assist users to judge the rationality of the scheme. The scheme meets the technical requirements of distribution network planning, such as no more than 6 loop nodes of medium voltage cable lines, no more than 6 main segments of medium voltage overhead lines, and appropriate allocation of sectional switches in longer branch lines. If the planning scheme cannot meet the transfer demand, the transmission line can be simulated repeatedly until the network frame planning is reasonable.
(3) *Preview Planning Scheme.* After the completion of the scheme, the scheme report can be automatically generated, including the technical parameters of the scheme, the estimated number of planned construction, the automated layout map, the load forecast, etc., which assist users to further check the rationality of the scheme from a macro perspective. At the same time, the scheme report realizes the comparison of technical economy between different planning schemes, objectively reflects the advantages and disadvantages and feasibility of the planning scheme, and provides users with more reasonable and optimized planning schemes to improve the scientific planning.

Planning Feasibility Analysis Module. In the process of formulating the plan, it is necessary to take into account factors such as the actual geographical environment and load line conditions to avoid rework caused by insufficient analysis of multiple influencing factors after the plan is formulated. The planning feasibility module can combine spatial geographic information and load users and other related data on the map to support real-time rendering analysis such as safe current analysis, thermal map analysis, image contrast analysis, elevation analysis, slope analysis, load analysis, etc.

It supports real-time rendering analysis such as safe current analysis, thermal map analysis, image contrast analysis, elevation analysis, slope analysis, load analysis, etc., to assist users in evaluating the reliability, economy and feasibility of the planning solution.

4.2 System Whole Framework Design

Starting from the main function design of the above system, the pre-planning system of the distribution network is established on the basis of the information standardization system, the security protection system framework and the system support platform. The system adopts the loosely coupled design of data layer, service platform layer, business logic layer, and presentation layer architecture, as shown in Fig. 2.

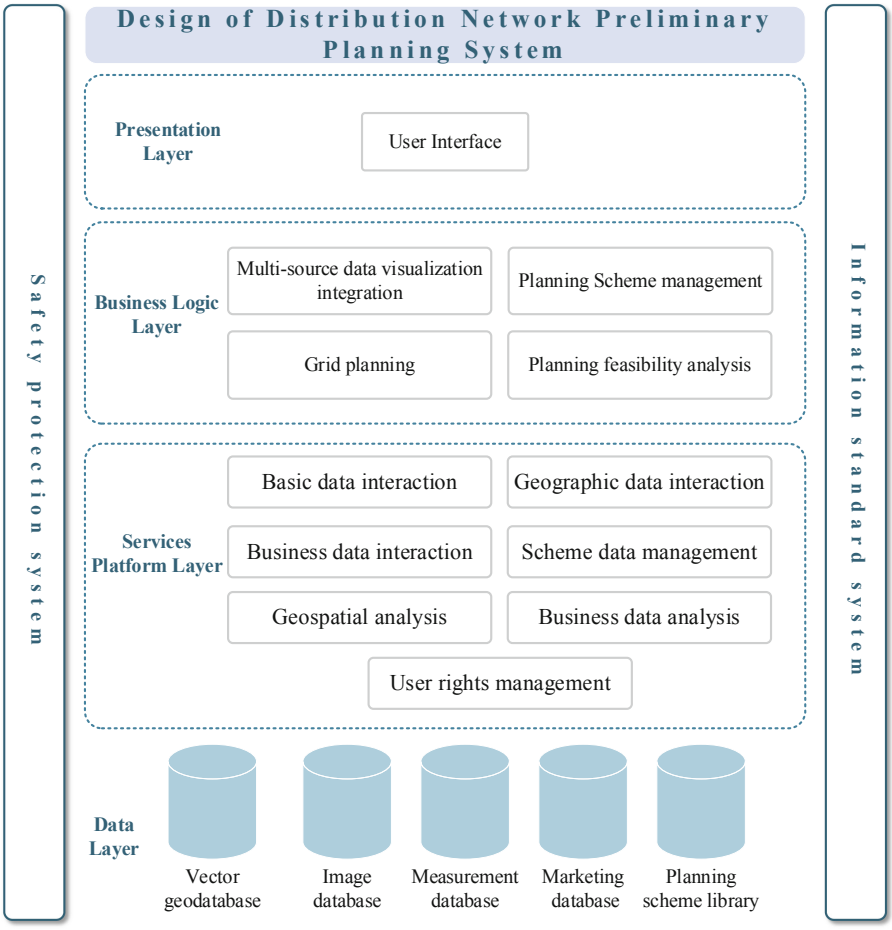

Fig. 2. System whole framework design

Data Layer. Data layer is responsible for integrating GIS System, Measurement System, Marketing System and other pre-planning data to realize automatic update, data storage, data organization, data management and data sharing of multi-source data. It established a unified multi-source data interaction standard specification, realized internal data sharing in the local area network, and provided effective and complete data support guarantee for the formulation of the pre-planning of the distribution network.

Services Platform Layer. The service platform layer is responsible for providing planning service interface services for clients, and implementing interactive operations with geographic data, measurement data, marketing data, and solution data in the data layer through a unified and standardized interface. It plays the role of data organization, scheduling and management. The service platform layer mainly includes services such as data acquisition, data analysis, and data feedback.

Business Logic Layer. The business logic layer is responsible for invoking the service interface provided by the service platform layer, and obtaining the basic data, geographic data, and service data required by the solution, and then performing the simulation operation of the plan. The application layer provides convenient and efficient analysis functions to assist planners in judging the rationality of the solution. The completed planning scheme content and its basic data are fed back to the server through the business service interface to realize data sharing.

Presentation Layer. The presentation layer is responsible for presenting the business data and analysis results in an intuitive visualization. It is the layer at which the user interacts through the client. Users can interact with the functions of the business logic layer in the presentation layer to implement functions such as pre-planning data viewing, element drawing, planning scheme development, and intelligent planning analysis.

5 Major Innovations of the System

5.1 Functional Design Based on Distribution Network Planning "Six Steps"

The main functions of the system are designed based on the six steps of the current distribution network planning business process, including current situation collection, load forecasting, scheme formulating, planning Scheme library, planning project library, and statistical analysis of indicators, as shown in Fig. 3. Through standardizing the business process of distribution network planning in the system, the standardization and unification of the distribution network planning operation process is realized. Users are guided to comprehensively consider various influencing factors to ensure the scientific nature of the planning scheme.

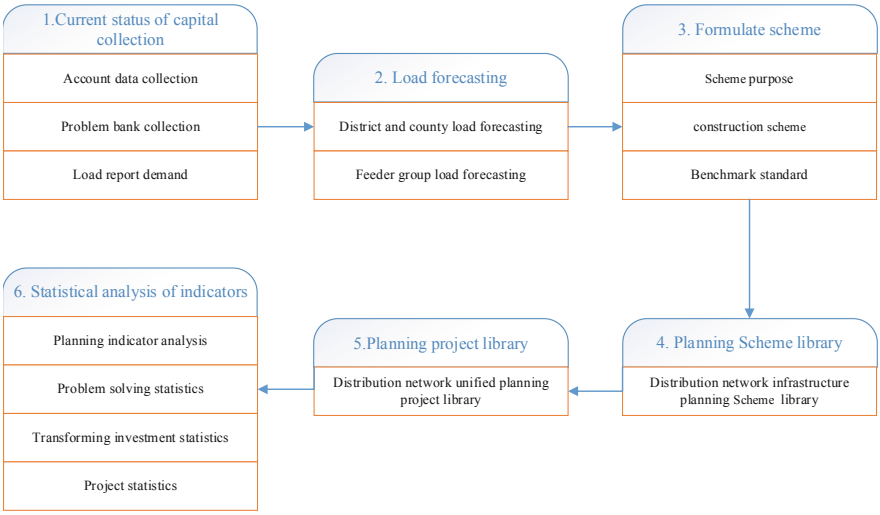

Fig. 3. Six steps of the distribution network planning business process

5.2 CIM Automatically Extracts Network Topology Information

By analyzing the CIM model in the GIS System, the spatial location information and relationship attribute information of the network equipment including the distribution line equipment and the internal equipment of the station can be dynamically obtained, thereby constructing a unique topological relationship data structure. The topology information can effectively describe the context, affiliation, and segmentation information of the device. From the data level, the system reorganizes the decentralized independent equipment reconstruction into a complete and continuous logical structure, which provides a good data foundation for the network pre-planning system of the distribution network. This makes it easy for users to view the information of any segment transformer in the planning process, and quickly count the load and user number data in the segment.

5.3 Automatic Calculation of Segmentation Information and Generation of Automated Layout Maps

With the automatic switch as the segmentation point, the load, number of users and line length of each segment of the feeder are automatically calculated. At the same time, the automatic layout map is automatically generated according to the segmentation information, which assists users in quickly analyzing whether the indicator meets the standard and judges the automatic switch, and the rationality of the installation location, to build a more economical and reasonable network structure, to ensure the implementation of the planning program.

6 Typical Applications of the System

6.1 Intelligent Analysis of Terminal Voltage Quality Problem

The terminal voltage quality problem is one of the important problems in the distribution network, which is mainly caused by long supply radius and heavy load of the line. Through analyzing the grid structure and automatically calculating the power supply radius and line load, the system is able to assist users to judge the case of too long power supply radius, heavy load and overload, as shown in Fig. 4.

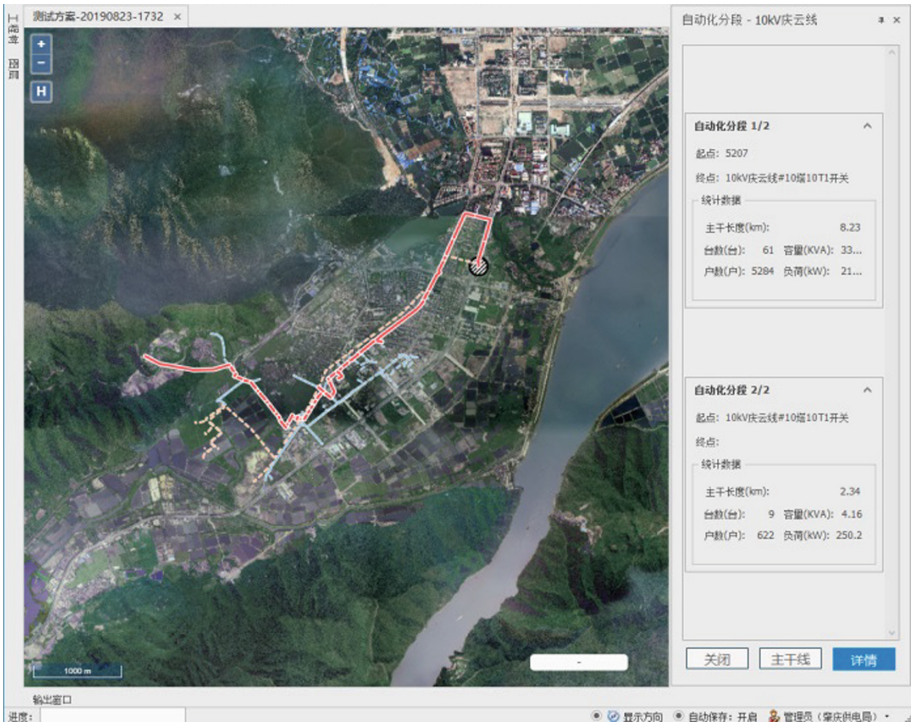

Fig. 4. Intelligent analysis of too long power supply radius and heavy load

6.2 Cutover Load Simulation

In case of heavy load and overload and large branches problems of the lines, where the feeder group cannot meet the requirements of power transfer and supply, it shall be necessary to cutover load. As shown in Fig. 5, part of cutover load from the blue line with heavy load, is transferred to the orange line with light load. After recalculating the segment statistics data, it is able to check whether it fulfills the requirements of the available power transfer and supply.

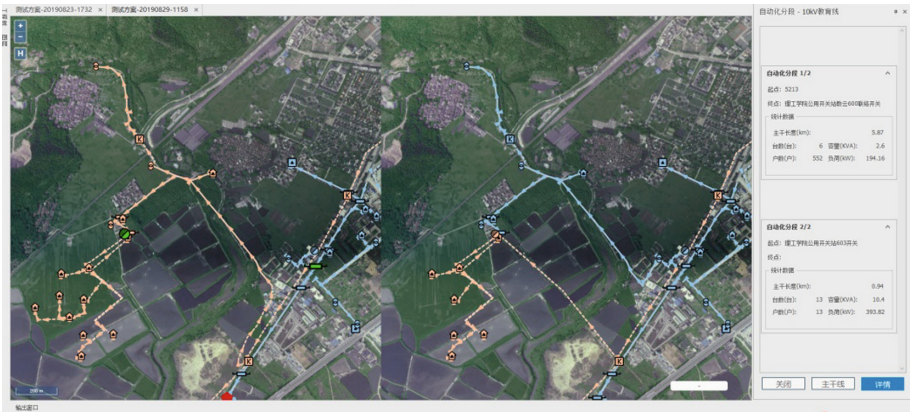

Fig. 5. Cutover load simulation

6.3 Automatic Section Location Optimization Simulation

In case of centralized load distribution and large branches problems, as shown in Fig. 6, the positions of automatic switch and interconnection switch shall be added or

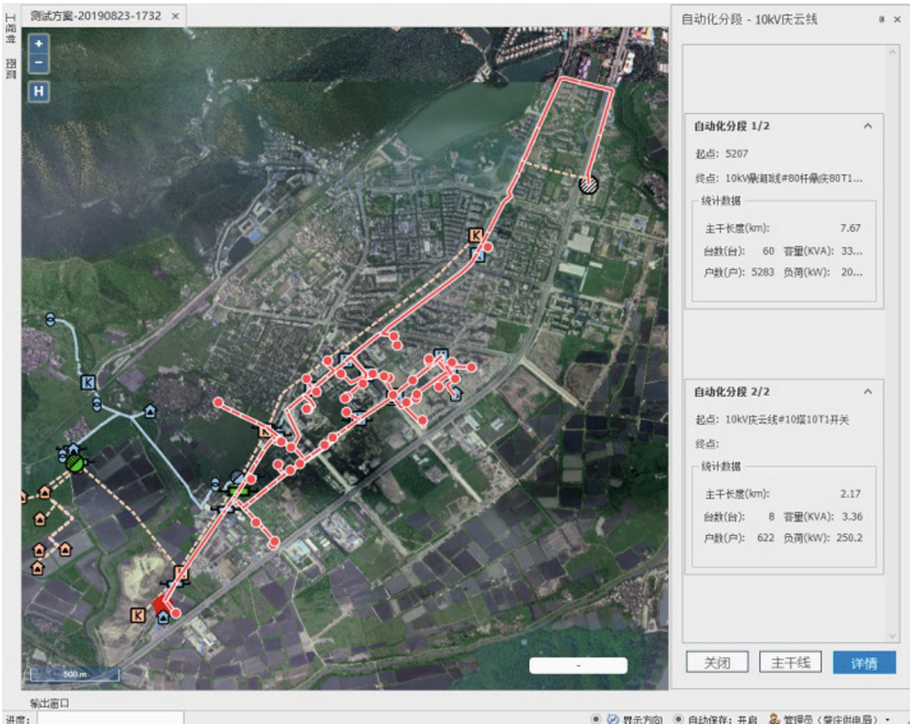

Fig. 6. Before automatic section location optimization

adjusted. The line is divided into automatic sections with the switch on the automatic column as the dividing point. After analyzing the load of each automatic section through the system, users can set automatic switch in the sections with load concentration problems, in order to realize the average number of users in each section and meet the requirement of no more than 3000 users in each section in the technical guidelines for distribution network planning, as shown in Fig. 7.

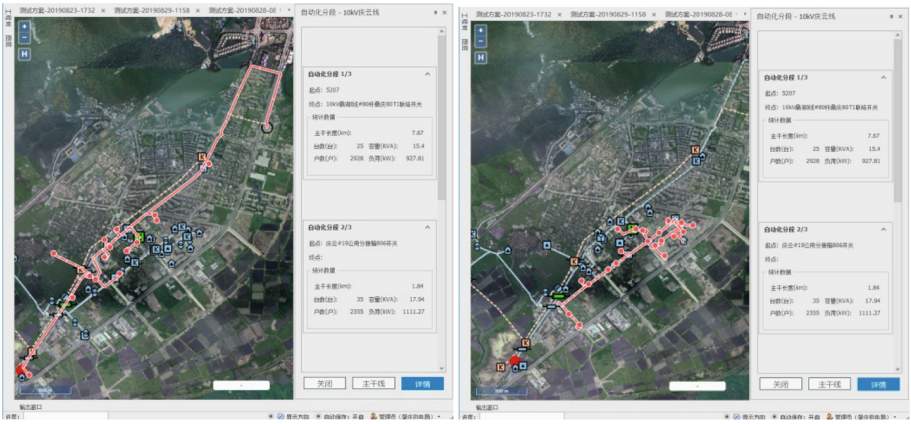

Fig. 7. After automatic section location optimization

7 Conclusion

In summary, GIS can carry out the maximum information integration work. Therefore, GIS is suitable for the design of network pre-planning system for distribution network, providing more accurate and diversified decision basis for distribution network planning business personnel to ensure the safety and reliability of distribution network operation. Through the integration of various professional system information exchange channels related to the distribution network planning, the integration of geographic information, network topology information, equipment operation information and customer marketing information of the distribution network will be realized, so that the distribution network planning reference data can be uniformly displayed and upgraded. It improved the quality and accuracy of the pre-planning of the distribution network. At the same time, through the visual simulation analysis and planning data sharing, the formulation of the distribution network planning and construction plan is more reliable and reasonable. At the same time, the work efficiency of distribution network planning is greatly improved and the planning cost is reduced.

In this paper, based on the network pre-planning system of GIS distribution network, a series of designs are carried out. Based on the design concept and technical route of this system, the main functions and the overall architecture design were carried out. At the same time, it elaborates on the main innovation points and typical

applications of the system, and hopes to provide support for the distribution network planning work, thus helping the national power grid construction and sustainable social and economic development.

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