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# ElectricVIS: visual analysis system for power supply data of smart city

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## Abstract
Smart grids provide a key driver for smart city development. The smart city power supply data visualization can realize the power characteristic information of various attributes and operating states in the online monitoring data of massive power equipments in a graphical and visual presentation, which provides a powerful guarantee for timely and effective monitoring and analysis of equipment operating status. However, with the rapid development of smart cities, the complexity of urban power data and the ever-increasing amount of data hinder the power managers' understanding and analysis of the power supply situation. Based on the smart city power supply data, a novel visual analysis system ElectricVis for urban power supply situation is proposed, which can interactively analyze large-scale urban power supply data. ElectricVis reduces the difficulty of understanding urban power supply situations by adopting novel visual graphic designs and time patterns that display power data in multiple scales. ElectricVis also provides different visual views and interaction methods for interrelated hierarchical data in urban power data, which is critical for detecting the cause of anomalous data. Finally, we evaluated our system through case studies and analysis by power experts.

**Keywords** Smart city · Visual analysis · Urban power supply · Graphic design

## 1 Introduction

Smart cities have fully utilized the new generation of information technology in urban development planning, realizing the in-depth integration of informatization, industrialization and urbanization, and improving the effectiveness of urban management and the quality life of citizens. As an important part of smart cities,

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smart grids mainly solve urban energy problems and the key driving force for the development of smart cities.

The urban power supply network is a particularly important part of the smart grid that the city power supply data contain valuable information such as the power supply security situation of the city and the power development trend. With the development of smart cities, the number and scale of power supply networks in smart grids increased dramatically, and at the same time, massive amounts of complex power data were brought. In response to this change, the effective real-time display and abnormal monitoring of the urban power supply situation have become the primary task of maintaining the safety of the urban power supply system. Effective power supply situation display and anomaly monitoring can help power experts understand the current urban power supply situation and respond to security events, such as regional power outages caused by continuous overload of equipment. At the same time, it can also assist power management personnel to make planning decisions for the future power grid, so that the smart grid can better support the development of smart cities.

Power researchers and practitioners who acknowledged the importance of power data visualization had studied interactive analysis systems for power, such as Ballal et al. [1], Gegner et al. [2], Baba et al. [3]. These systems used traditional power flow diagrams, dorling diagrams, heatmap and bar charts to visualize wide-area power data. However, due to the complexity of urban power supply data, we found that these systems were ineffective for analyzing urban power supply data. More specifically, we needed to consider the following challenges in visualizing urban power supply data:

**Complexity** The smart city power supply data types mainly include substation, substation subordinate power supply lines and power users under the power supply line; each type has multiple power data attributes.

**Applicable graphics** Traditional visualization methods combined with multiple charts can display complex power data, but will increase the user's cognitive burden, and need to design visual graphics suitable for displaying urban power supply data.

**Interaction** Need to provide an effective means of interaction, allowing users to better explore the hierarchical information in the city's power supply data, and to easily explore and analyze the causes of abnormal data.

To address these challenges, we introduced the ElectricVis system, an interactive visual analysis system for smart city power supply data. The main goal of our ElectricVis system was to help power experts effectively observe the city's power supply situation and provide a variety of interactive means to help power experts discover and explore anomalous data in the system. Through close consultation with power experts, we reflected detailed real-world requirements into our design, kept their tasks and concerns in mind. Considering the complexity of urban power supply data, ElectricVis minimizes the barriers to interpretation of urban power supply data by providing a succinct overview of the city's power supply data. We designed visualizations to display and compare time and space information of urban power supply data in a multi-scale manner, which was one of the main needs of power experts. ElectricVis also provides an effective means of interaction so that users can explore different hierarchies of power data and discover the correlations. Finally, we evaluated our system through case studies and scenario analysis by power experts.

In summary, our main contributions include:

- Identify domain requirements for visual urban power supply data analysis and articulating design rationale through a close collaboration with power experts.
- Design a novel graphic suitable for power data visualization to express multi-dimensional power information in power supply systems and combine various visualization methods to display urban power data.
- Develop a set of visual analysis tools and interactive technologies to facilitate power analysts to explore urban power supply situations and trends from different perspectives.

## 2 Related work

In this section, we briefly described two topics related to our system: (1) previous work to support urban power data visualization analysis, and (2) space-time data visualization for power data visual analysis.

### 2.1 Visualization of urban data

Extensive studies were conducted on visual analysis of urban power supply data. In the urban power supply system, the power data are mainly from substation, substation auxiliary lines and users mounted under the line. Ballal et al. [1] used multiple line graphs to show the situation between various types of power data in substation and service transformers for monitoring purposes. Gegner et al. [2] represented traditional systems. For example, some static charts were used to show the power elements, such as pie charts to show the percentage of line load, animated flow arrows to show the direction of power and power flow, the line thickness highlighted the voltage level, and hidden the voltage level required by the power load in the background. Finally, colors were used to show the changes between voltage or frequency, and animation cycles were used to show how the network evolved over time. Baba et al. [3] used multiple line graphs to display abnormal power data detected and analyzed in the system. Cabrera et al. [4] proposed a framework for visualizing the health of power systems, using line graphs, pie charts and thermograms to show power distribution. Li et al. [5] proposed a power data visualization system, which is also used for power data visualization, which was a line chart and a pie chart. Christe et al. proposed a power quality visualization system that provides the ability to query power quality events. Users can filter events based on multiple complex conditions. At the same time, the system uses traditional forms, line graphs, electronic maps and other visualization methods to visualize power data. Fang et al. [6] presented a method of urban network cell to assist urban land use. Yuan et al. [7] proposed a novel method of spatial constraint model-driven clustering to automatically monitor and depict water conservancy data in urban areas. Ye et al. [8]

strengthen urban traffic management that was used in traffic accident data. And the work from Lu et al. [9] can be seen that the reasonable allocation of urban resources is of great significance to urban planning.

However, in terms of visualizing smart city power supply data, these systems had the following limitations: (1) They all used traditional visualization methods that were too singular and inefficient for presenting smart city power data with multiple data types. (2) They rarely visualize smart city power supply data and lack effective interaction means for users to explore data of interest. Compared to existing power visualization systems, ElectricVIS was targeted at city power supply data in smart grid. Based on the clock model, we designed a novel visual graph as a detailed view to show the multi-dimensional power data of the power supply equipment. At the same time, we designed a power hierarchy diagram suitable for demonstrating the overall structural situation of urban power supply data in smart grids. In addition, the existing power data visualization system rarely provides interactive means, so we designed an interactive visual analysis system for the smart city power supply system and provided users with a rich interactive means. At the same time, the hierarchical visualization method is used to visualize complex power data, which greatly reduces the cognitive burden of users, and also facilitates users to explore smart city power supply data according to hierarchical relationships.

## 2.2 Visual analysis of spatiotemporal data

Visual analysis of spatiotemporal data can effectively display the attributes of the data, helping users to visually discover potential information in the data. A survey by Andrienko et al. [10] raised the need of finding effective visualizations of temporal dimension in geospatial data. The existing work could be roughly divided into two categories, namely linked views, where the spatial and temporal aspects of data were displayed in coordinated multiple views, and integrated views, where temporal information was displayed with geospatial visualization in the same view. Linked-view methods had become standard approaches to display temporal and spatial data. Zhang et al. [11] introduced a visual analysis system based on urban public service management as the main task, using thermal maps, line graphs, scatter plots and other synchronized views to visualize urban public service issues. Aman et al. [12] proposed a new visualization method for crisis maps and embedded it into the map to represent the spatial properties of the dataset. Liu et al. [13] proposed an interactive visual analysis system to provide advertising planners with a candidate solution for billboard placement. Zhang et al. [14] proposed a visual analysis situation-aware system based on Weibo data, which supports real-time exploration of microblog data across multiple analysis scales. They also designed a glyph-based visual design overlay on the map to visualize Weibo data. Sun et al. [15] provided a novel visualization technique for path scaling that embeds multi-dimensional data into a map for display. Zhao et al. [16] reflected scenes in the real world by means of fuzzy clustering. Combining the above system and visualization method, we designed a novel visualization graphic to display the smart city power supply data. Considering that the integrated view may cause occlusion problems, we displayed it in a linked view.

## 3 Design process

The goal of the ElectricVis system is to allow power workers to analyze and explore power data for smart cities. In this section, we will detail the design process of our system.

### 3.1 Identifying domain requirements

Through consultation and discussion with power experts, we have the following requirements for the smart city power supply data visualization analysis system:

**R1. Real-time display of power supply situation in a certain region** The data in the smart city power supply system mainly include substation, power supply line and power users, so the data of the entire city power supply system are large and complicated (**Complexity**). To ensure the stability of the city's power supply, it is necessary to display the power supply situation in the area in real time. The power supply situation is divided into the power position distribution situation and the hierarchical structure situation.

**R2. Easy-to-understand display of multi-dimensional smart city power supply data** Substation, power supply lines, and power users in smart city power supply systems had multiple power data to display. These data need to be displayed as easy as possible to understand and observe (**Applicable graphics**), so that users can quickly grasp the power information and find out the abnormal information.

**R3. Can explore different hierarchies of urban power supply data** The urban power supply system is basically divided into three hierarchies: substation, power supply line, and power users. The types of users of electricity use are mainly divided into four levels: general industry, industry and commerce, residents and other electricity consumption. On the basis of being able to observe the overall city power supply situation, it is also necessary to provide certain interactive means (**Interaction**).

### 3.2 Design goals

Based on the three requirements, we set the following design goals for the ElectricVis system:

**DG1: Support for a succinct visual overview from different perspectives and hierarchies** In order to facilitate the user's observation of multi-dimensional power data, we provided real-time power situational distribution views and power supply hierarchy situation maps for city-based power supply data based on electronic maps. In the power situation distribution view, we focused on the main power supply parameters that could reflect the current regional power supply equipment or electricity users. In the urban power supply hierarchy situation map, we focused on the main types of power and electricity that could reflect the overall power supply level and power flow in the current region. By using a succinct visual overview (**R2**), analysts could quickly grasp important information in multi-dimensional power data to understand the current power supply situation (**R1**) in the area.

**DG2. Provide visualization and interaction of different hierarchies of power supply data** Due to the complexity of urban power supply data, direct visualization of all data was inefficient and inconvenient for users to observe. Referred to the design guidelines of "Overview First, Zoom and Filter, Details on Demand" [17], for the power situation distribution view, we first visualize the substation data, and further visualize the subordinate power supply lines for the substation that users were interested in or continue to use the power users mounted under the visual line (**R2**). For the power supply hierarchy situation map, we visualized the structure of its subordinates according to the level selected by the user. The system should provide a smooth context-constant transformation to highlight different scale changes (**R3**).

**DG3. Provide an exploration of the select object of interest** After mastering the overview and providing the means of interaction, the analyst should be able to perform a detailed analysis of the power equipment or power users of interest. The detailed analysis should include detailed power supply information for the select object and detail changes in the power or service load at different time granularities (**R2**).

## 4 Electric design

According to specific requirements and design objectives, we designed ElectricVis system. In this section, we will introduce in detail our system architecture and visualization technology.

### 4.1 System architecture

ElectricVis is developed based on the server–client architecture. The back-end server is developed using Java, and we use MySQL as the back-end database. The front-end interface is purely web-based and is developed based on several javascript libraries including D3.JS [18], Leaflet.JS, Vue.JS and Echarts.JS [19]. Figure 2 shows the system architecture of ElectricVis.

Our system is mainly divided into two modules, situation display module and analysis module. The situation module can help users to obtain the overall situation of urban power supply in the area firstly. The detailed analysis module helps users analyze detailed electrical equipment information and regional power information.

### 4.2 Power supply situation module

According to our design goals, the visualization system of the power supply situation mainly consists of three views (Fig. 1a, b, d), namely the dashboard view, map view and hierarchical view.


**Fig. 1** ElectricVIS system: **a** dashboard view shows current city power situation information and provides some map control, **b** map view provides a visual summary of the geospatial environment, **c** the area overview view gives the load changes over time in the selected area of the user. **d** The hierarchical view shows the hierarchical trend of the power load in the current region. **e** Comparison view gives data comparison between different times

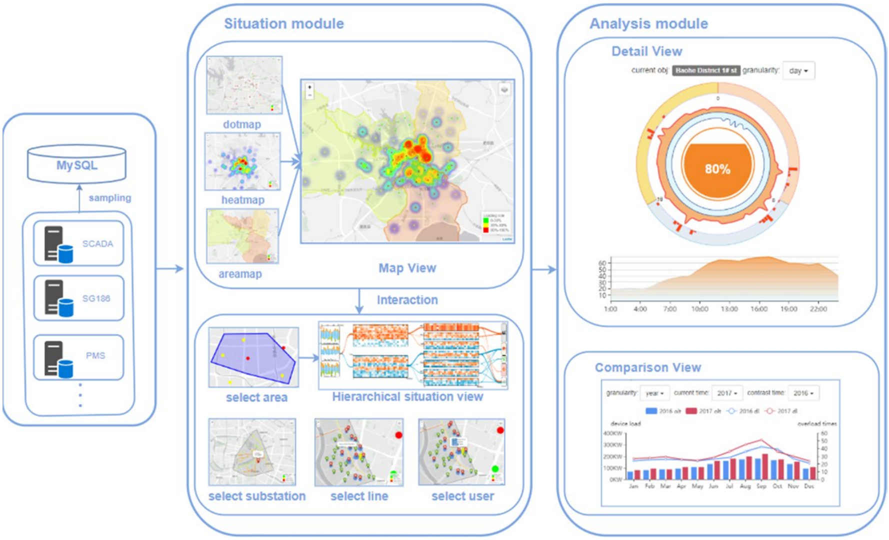


**Fig. 2** System architecture of ElectricVis. Our visualization system is mainly divided into two modules, namely the situation display module and the analysis module

#### 4.2.1 Dashboard view

The dashboard view (Fig. 1a) shows the dataset information for the current urban-powered visualization system. From top to bottom, the view shows the dataset, some statistics of the current dataset and the map control panel which includes the selection of three map layers, custom area drawing, current data time and the system data refresh rate.

#### 4.2.2 Map View

We used the map view to show the power situation distribution. We first used a scalable tile map based on OpenStreetMap to display the current city power supply situation (Fig. 1b). Power analysts told us that they needed to be able to observe the geographical distribution and load information of power equipment and users, so we provided three layers of power supply analysis for analysts: scatter plot, heatmap and district map (Fig. 2).

Each substation was represented by a dot in the scatter plot. The degree of load of the substation was distinguished by different colors (**DG1**). Users could explore related power data information by clicking on a substation which they were interested in. The data included the power supply range of the substation and the subordinate power supply line. Users could further explore the power users under the power supply line by clicking the power supply line (**DG2**). We used a heatmap to show the current city load size distribution. In order to allow power analysts to better observe the power supply situation in the administrative area, we used the administrative map to show the division of the districts and the current load situation. The higher the load, the color was more close to red.

Among them, we used the Graham Scan [20] algorithm to calculate the minimum convex hull of the power users including the substation and represent the power supply range. For the power supply line, we used the line segment to display, in which the color mapping relationship and the substation were the same as the mapping load. For users who were connected to the line, we used the size of the scatter to map the user's power consumption.

#### 4.2.3 Hierarchical view

Power analysts needed to observe the hierarchical structure situation of smart city power supply system more intuitively, so we designed the hierarchical situation view (Fig. 1d) to show the state of the city's power supply hierarchy [21]. That was convenient for electric power analysts to observe the current city's power hierarchy, understand the distribution of urban power flow and master the urban power supply hierarchy. After users selected the data set, that the situation of urban power supply hierarchy will be launched (Fig. 3).

After users selected the data set, the hierarchical situation view would be displayed (Fig. 4). In the view, the hierarchical structure was divided into four parts, which showed: regional load change, high- and low-voltage level load change, substation detail load data and electricity type. The first layer used the rectangular

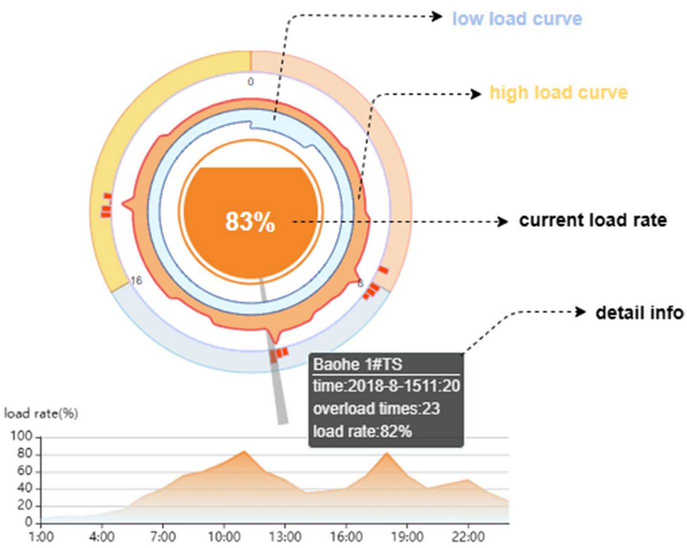


**Fig. 3** Detailed view visualizes the details of the current device. The current visualization indicated that the high load was concentrated in the morning and afternoon on the recent day, and the low load appeared in the early hours of the morning

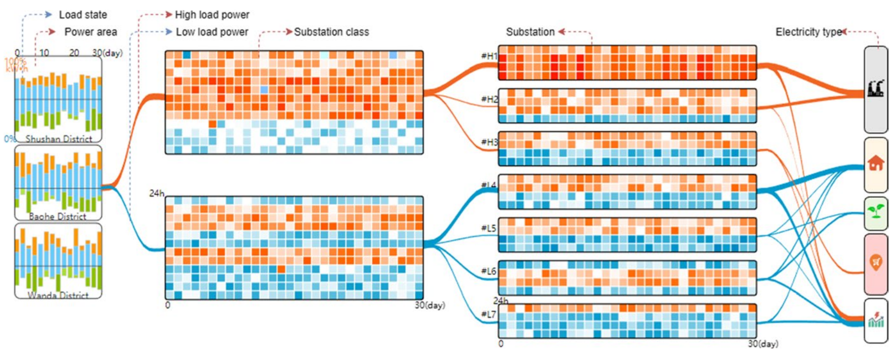


**Fig. 4** Hierarchical situation map: our visualization system was mainly divided into two modules, namely the situation display module and the analysis module

height to represent the power reporting capacity of each administrative district in the urban power supply system. By observing the proportion of height, the proportion of power capacity in a certain area in urban power supply could be obtained. The black horizontal line in the rectangle was the reference line with a load factor of 50%, and the horizontal axis of the histogram in the rectangle represents the time granularity of 1 month. In order to save space, we used 2 days as a time unit, and through the date selection button and the time button to display the nearest power load data. The blue part of the histogram showed the average load fluctuation every 2 days. The highest and lowest points of the histogram represented the highest load and the lowest load, respectively. We used color to fill them to the average load space to represent the unit time and the fluctuations of the highest load and the lowest load.

The orange line between each layers indicated the power flow direction associated with the high voltage, and the blue color indicated the power flow direction associated with the low voltage, while the width of each line segment indicates the level of power consumption.

In order to make it easier for analysts to observe the changes of the load of substation under a certain area with time, we divided the substation into two parts in the high-voltage level and the low-voltage level. Shown in the figure were two large rectangles, where the horizontal axis in the large rectangle represents the time granularity of 1 month, the vertical axis represents the time period in which two hours were a time unit and the small square represents the substation load value of a specific time period. We used orange to indicate that the load was greater than 60% and blue to indicate that the load is below 40%; white indicates that the load was 40–60%, and the depth of the color maps the value.

The second layer provided analysts with coarse-grained high and low-voltage level substation load conditions. In addition, fine-grained substation load changes are also required for analysts. Thus, we designed the third layer, where each large rectangle represents a specific substation. The horizontal axis of the rectangle also represents the time granularity of 1 month, except that the vertical axis was divided into early morning, afternoon and evening. Each small square also represented the load value of a particular substation which represents a particular time period.

After providing the load change under the coarse-grained and fine-grained view of the substation, the analyst needed to judge whether the substation was operating normally according to the type of electricity used. So we designed the fourth layer. Each rectangle represents different types of users, such as general industry users, residential users, agriculture users, industry and commerce users and other electricity users. The size of the rectangle represents the percentage of capacity for different user types. The connection between the third and fourth floors represents the power flow from different substations to specific users. The thickness of the line indicates the size of the electricity used by the user, so that analysts could use it to determine whether the load of the substation was in line with expectations.

### 4.3 Detailed analysis module

According to our design goals, the visualization of the detailed analysis module mainly consists of two views (Fig. 1c, e), detailed view and comparison view.

#### 4.3.1 Detailed view

For the existing substation or power supply line, the number of data fields was large. If the traditional method was used to visualize each power field separately, the final result was a combination of multiple charts to show the possible correlations. Users might experience the burden of context switching [22]. So we gone to design a new visualization that was suitable for city-powered data. Since the substation and the power supply line were similar in the visual field, we used the same graphic for display. After discussions with our local power sector analysts, we identified key information that should be visually encoded, namely real-time load, load change over time, frequency of overload and time. These data allowed users to quickly grasp the power supply information of the device.

In summary, we designed a new glyph as a detailed view (Fig. 1c) which combines multiple power data in one view for demonstration (**DG3**). Considered that overlaying graphics directly on the map can cause occlusion and visual clutter, we used a linked view to place the graphics in a separate window.

When users clicked on the substation or power line in the map view, a detailed view was obtained. In the detailed view (Fig. 5), the daily load change of the device was divided into units of 10 min, and the load change of the device was represented by a time series view surrounding the water polo map [23]. The load with different time granularities was analyzed, so that the analysis results could be more accurately applied to the power industry. In order to facilitate users to select the appropriate time granularity to investigate the required power load information, each detailed view corresponds to the load for a specific time. In addition to 1 day, we provided granularity for 1 month and 1 year, and the time selector was above the detailed view. In order to allow analysts to easily observe high and low load changes, we used two circular area maps to represent high and low load curves, respectively. The outward circular area diagram represents a high-load curve, indicated in orange, and inwardly represents a low load curve, indicated in light blue, in order to make the graphics more convenient to observe and highlight the key points (**DG1**). Since the load of 20–80% was in the normal state in the line load, it would not have a significant impact on the economy and the line. In order to reduce the visual error caused by the load information to the user when analyzed the view that we used a smooth curve for loads with loads between 40 and 60%, for loads above or below this interval, the high-load curve and the low-load curve were, respectively, described. The middle water polo map represents the real-time load of the current device,

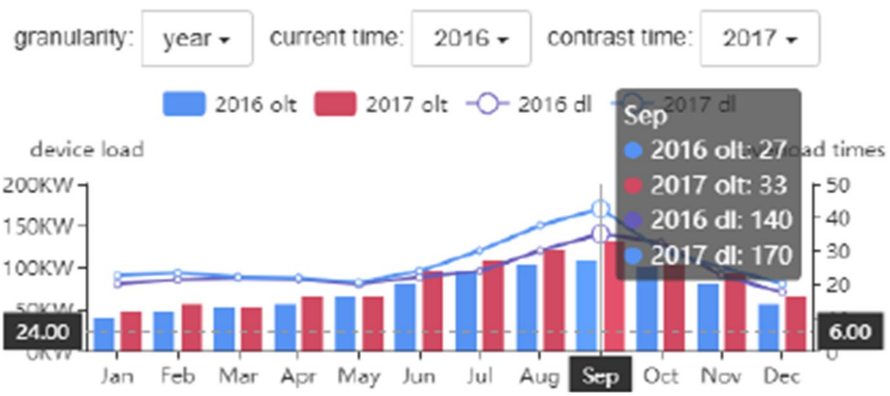


**Fig. 5** Comparison view. Analysts can choose different time granularities and times to compare the current device power data

color mapping real-time load for that the real-time monitoring of substation load information.

The frequency of heavy load was an important data reflecting the quality of power network lines. In order to show the frequency of overload of the device during a certain period of time, we added a ring of mapping time outside the load curve with a histogram embedded in the ring to indicate the frequency of device overload in the current time period (the number of times the load was higher than 80%). The ring presented different parts according to the selected time granularity. If it was 1 day, it would be divided into three parts, which means morning, noon and evening, respectively. If it was a year, it would be divided into four parts, which represented four quarters, respectively. Different colors indicated different parts. Users could hover the mouse over the histogram to see details such as the time period in which the histogram was located and the specific number of overloads.

In order to allow users to further observe the details of the load curve, we in the detailed view below showed the current detailed load curve of the equipment. We used color to map load values. The higher the load, the closer the color was to orange, vice versa.

#### 4.3.2 Comparison view

The detailed view showed the data of the current power supply equipment, which allowed users to quickly obtain the overall information of the power supply equipment. However, for power analysis, it was also necessary to compare the power supply information of the equipment at different times (**DG3**). To meet the requirement, we provided a comparison view (Fig. 1e) for further detailed analysis by the user.

The comparison view was divided into two parts, the upper button group provided time granularity and date selection, while the lower graph used a combination of a histogram and a line chart. We used a histogram to represent the frequency of overload of the device and a line chart to represent the load change of the device. By comparing the power supply conditions at different times in the same time granularity, the load change trend of the current power supply equipment could be obtained. As shown in (Fig. 4), we compared device power supply data in two different years.

## 5 System evaluation

In this section, through the communication with the power personnel and our guidance, we had analyzed and explored the local power cases. This chapter was mainly about our case analysis.

### 5.1 Our data

The data we study came from the power data stored by the local power supply company in the Mysql database; their data mainly come from supervisory control and data acquisition (SCADA), marketing SG186 systems and power production management system (PMS). The data include more than 70 substations in Hefei and more than 30,000 power users. The data are sampled every 5 min so that our system is also refreshed every 5 min by default. Users can also set the refresh time by themselves. Since the power data are confidential, the data presented in this paper are based on the simulation of existing fields of power data. After consulting the analysts in the local power sector in detail, we understand the common fluctuation range of each field of power data and we try to be as consistent as possible with the real data in terms of data volume and data authenticity. Common power data include data of substations, lines and users; the detailed data are as follows:

The substation data include substation name, longitude and latitude coordinates of substation, rated capacity of substation, current load of substation and current time of sampling data.

The line data include the line name, the line longitude and latitude coordinates, the line rated current, the current of the line and the current time of the sampled data.

The user data include the user name, the user latitude and longitude coordinates, the user level, the user capacity and the type of electricity consumption.

## 5.2 Case study

### 5.2.1 Situation analysis

We provided power analysts ElectricVis system to explore urban power supply. First, by observing the dashboard view (Fig. 6f), the power analysts probably learned about the number of major power equipment and users in Hefei. At the same time, power type view showed that the main power supply type in Hefei was general


**Fig. 6** The situation module shows the current power supply situation in Hefei

industrial electricity. Then, through the three layers provider by map view (Fig. 6d), the power analysts observed that the current load distribution was concentrated and high in the Baohe District, so they decided to explore the power supply situation in Baohe District. After clicked on the red dot representing the No. 1 substation in Baohe District, the map showed the power supply line attached to the substation and the approximate power supply range (Fig. 6a).

After clicked on the Baohe No. 2 line with high load, the subordinate users of the line were drawn on the map (Fig. 6b). The red label represents the important user. The green label represents the non-important user. And the blue circle below the label represents the user's reported capacity. The figure showed that the current line contains multiple important users with large reported capacity, which meant that they had greater demand for electricity. Once analysts clicked on a user with a large reported capacity, the map showed the user's detailed information (Fig. 5c). It could be seen from the observation that users had a large reported capacity, and the type of electricity used large industrial power, which might be an important cause of high load on the line.

Analysts used the hierarchical situation view (Fig. 6e) to analyze the power hierarchy situation in Hefei. Firstly, we choose 1 month as the time granularity and the date. Power analysts could observe that the power capacity of the Shushan District was the largest in the whole city. Then, they could observe the histogram to find that the average load in the area is relatively stable, in line with expectations. Analysts continue to observe the Baohe area and learn that the average load fluctuation range of Baohe District was relatively concentrated and most of them are above 50%, and the overall load was in a high state. So analysts wanted to explore the detailed load information and moved the mouse to the Baohe District, and then, the second layer showed the load information of the substation high and low-voltage level in the area. Analysts observed the information for 1 month that the high-load state of the substation at the high-voltage level was concentrated after eight o'clock. The substation load of the low-voltage level rises after 8 o'clock, the load decreases after 12 o'clock, and rises to 4 o'clock in the evening to decrease after 10 o'clock in the evening that the overall load change state was normal. Analysts observed the line width and color between the second and third floors. It could be seen that the three large rectangles on the third layer belong to the substation of the high-voltage level, and the following four substations belong to the substation of the low-voltage level. Among them, #1 substation and #4 substation had a large capacity. Observed the substations of the third floor in detail. It was known that the high-load durations of #1 and #2 of the high-voltage cascade substation were more frequent. The high-low load change time of the low-voltage substation was concentrated at noon and night. This information was consistent with the second-layer observation. At the same time, analysts speculated that high-voltage substations were in high-load state for a long time because their power supply types were usually general industry and commerce. The power demand of such users was usually large, and the load changes of low-voltage substations were in line with the daily life of residents. Analysts speculated that this might be due to the type of electricity used by low-voltage substation users, typically residential users and agricultural electricity. Analysts continued to observe the connection between the third and fourth floors to learn that the high-voltage substation power supply users are general industrial, industrial and commercial and other electricity. The power supply users of low-voltage substations were residential electricity, agricultural electricity, industrial and commercial electricity and other electricity. Most of these observations were in line with the analyst's speculation. Subsequently, it was observed that the general industrial users in the fourth layer account for a large proportion of the electricity consumption in Baohe District, which should be the cause of the overall high load in Baohe District.

### 5.2.2 Detailed analysis

By clicking on the Baohe District No. 1 substation in the map view, analysts got a detailed view (Fig. 7). Analysts selected day and year as the time

granularity. The water polo map in the center of the detailed view showed that the current substation's real-time load rate was 78%, which was close to the high-load state. Figure 7a shows the data of the No. 1 substation in Baohe District on August 15, 2018. There was a low load in the early morning. The high-load curve lasted from morning to around 6 pm, and the load reached its maximum at around 11 noon. The column chart representing the frequency of overload was also concentrated in the morning, at noon and at night. Figure 7b shows the data for the year of the No. 1 substation in Baohe District in 2017. The load curve and the column chart indicate that the high-load period was concentrated in summer and winter, while the load level in spring and autumn was relatively stable. By observing the changes in the substation load curve at different time granularities, the analysts roughly concluded that the main power supply type of the No. 1 substation in Baohe District should be general commercial power.

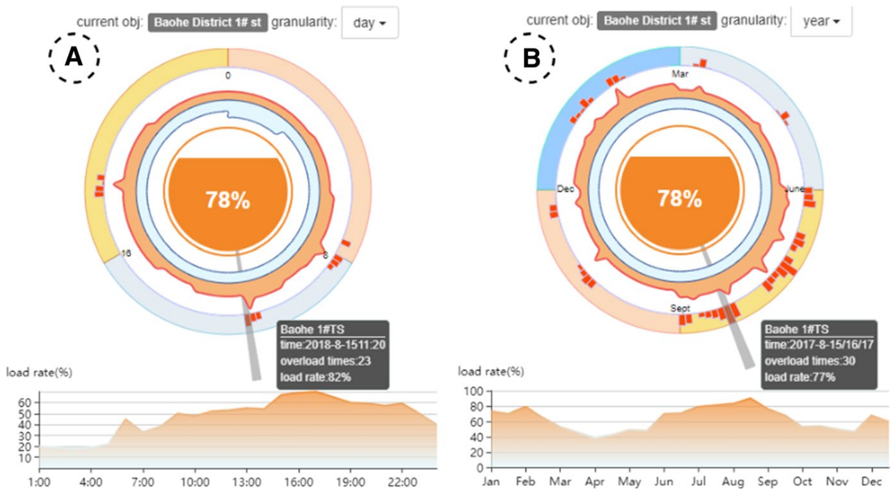


**Fig. 7** Detailed analysis module. The power supply data of the No. 1 substation in Baohe District on August 15, 2018, and 2017 displayed, respectively

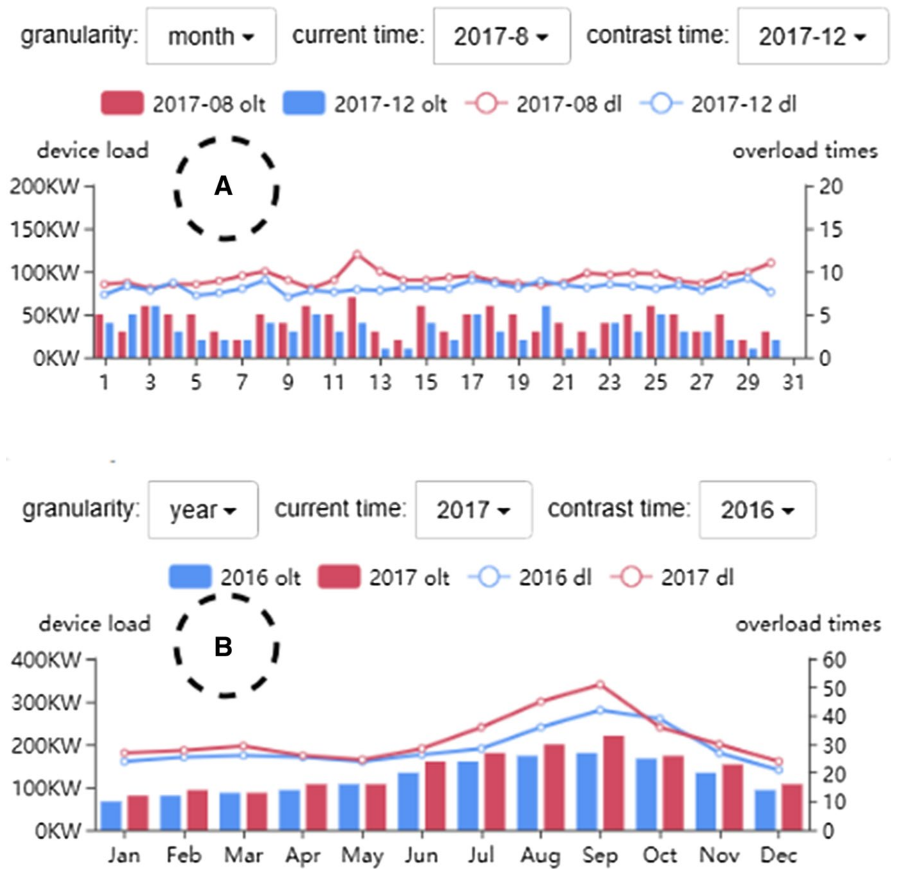


**Fig. 8** The comparison view compares the load conditions of different months and years of No. 1 substation in Baohe District

The analysts used the comparison view (Fig. 8) to select the time granularity of the month and year to observe the trend of the comparison substation data. Compared August 2017 with December (Fig. 8a), the overall load and the frequency of overload in August were slightly higher than those in December while both of them decreased in non-working days in both of 2 months. Due to the hot weather in mid-August, the load was higher than that of December of the same day. Compared with 2016 (Fig. 8b), the overall load increased in 2017, especially in the summer, and analysts realize that it might be necessary to prepare a capacity expansion plan for the substation in the future.

# 6 User evaluation

## 6.1 User research: glyph design for detailed views and hierarchical situation views

The key visualization components of our system were detailed views and hierarchical situational views. In our research, we had studied our two new glyph designs and traditional multi-views which could more effectively visualize multi-dimensional electrical equipment information. We used the power visualization system in [2] as a comparison object, and view the system as a representative of the traditional power visualization view.

### 6.1.1 Experiment

We recruited 20 students from different disciplines and 5 Engineers of State Grid Hefei Power Supply Company to conduct research. We introduced the visualization of the multi-view used in the traditional power data visualization system, as well as the detailed view based on the clock glyph design and the visualization of the hierarchical view based on the Snakey Diagram design. There were 10 tasks for each visualization. We have provided the visual view in this article as well as the view in the traditional power visualization system. The task was generally divided into three types: (1) find the load information of the substation in the same area as much as possible, (2) indicate the approximate power supply range of the substation based on the power equipment in the view and (3) explore the causes of high loads on lines or substations.

### 6.1.2 Experiment result

Figure 9 shows the number of completions and completion time. The view of our system for task 1 can show the geographical location information of the substation, the reported capacity, the number of reloads, multiple substation data such as real-time load and average substation load over time. But the traditional view can only display geographic location information, rated capacity and real-time load. For task 2, our system can map out the approximate power supply range of the substation, while the traditional view usually does not show. For task 3, our system provides a view of the power hierarchy and a visualization technique based on electronic map hierarchy and users can easily observe the connection between substation, line and electricity users. So users can explore the cause of the abnormal information. The traditional view only shows the fuzzy relationship between the substation and the power supply line, and it is difficult to explore deeper information. In summary, we can see that the glyph view based on our design is superior to the traditional view in task completion rate.

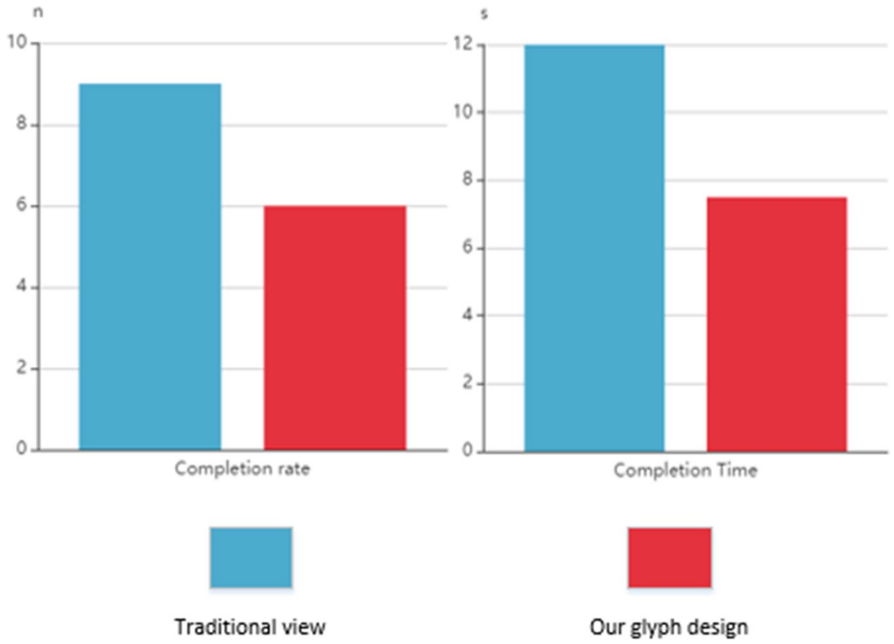


**Fig. 9** The evaluation results of glyph design

## 6.2 User research: hierarchical visualization interactive technology

Our system provided a wealth of interactive means compared to the traditional power visualization system with little interaction. In our research, we examined whether the interactions provided by our system allowed users to learn more about power data and whether users could interact to explore the causes of abnormal data.

### 6.2.1 Survey

As we had some knowledge about the power profession, we had invited 20 students from the power-related majors to conduct research. Each participant spent an average of 10-min experimenting. We used the 5-level Likert scale for evaluation. Users were asked to rate 4 questions on the questionnaire using 1–5 points. Of these, 5 points were very satisfactory, 4 points were satisfactory, 3 points were neutral, 2 points were dissatisfied, and 1 point was very dissatisfied.

The problem is described as follows:

Q1: How is the system interoperability?
Q2: How is the view level representation information clarity?
Q3: How is the need for daily interaction of the system?
Q4: How helpful is the view?

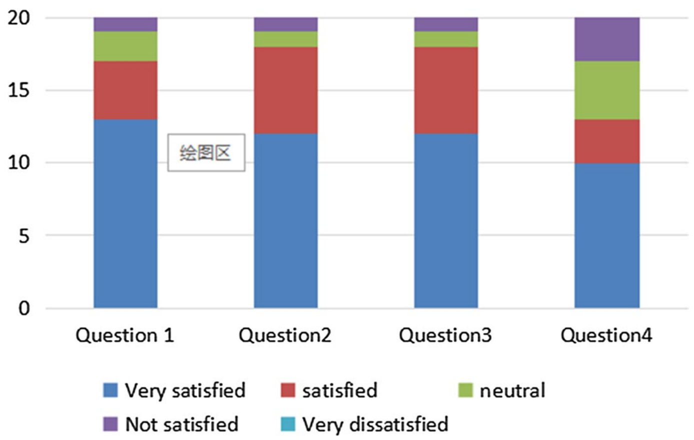


**Fig. 10** The evaluation results of system interaction

Figure 10 shows the results of the questionnaire. The overall user is satisfied with the interactive means provided by the system.

## 7 Conclusion and future work

In this study, we present an interactive system for visualizing urban data. In order to reflect the detailed power supply information, we design a visual graph suitable for displaying multi-dimensional city power supply data. We also integrate various visual analysis methods and interactive techniques to analyze the city's power supply situation. In addition, our system is affirmed by the State Grid Hefei Power Supply Company, which helps managers make informed decisions through our visualization system. In the future, we will continue to work on other factors that may be related to the city's power supply situation, such as distributed power.

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