Equipment Operation Analysis and Application Research Based on Big Data Electric Power Distribution Network

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Abstract. With the rapid development of the current power supply enterprise, it is necessary to process the distribution network business according to the actual business requirements, and easily collect and transfer the archiving and operation data in four distribution network equipment types from the source business system to explore the potential correlation of power big data indicators. This paper proposes one method of constructing the distribution network operation monitoring index system based on two aspects of operation efficiency and power supply capacity, and proposes a corresponding data analysis model for detailed analysis, and finally carries out the model verification. The experimental tests of four types of equipment operation analysis in the internal big data distribution network show that, the proposed methods could locate the distribution network operation quickly and accurately.

1. Introduction

Data has become the core resource of power companies [1]. The power supply enterprise equipment generates massive operation data every day, and the power data shows an exponential growth overall, which puts forward new requirements for data processing capabilities. How to process these massive data becomes the core problem of enterprises. The distribution network equipment is of various types and large numbers [2], but it is mainly composed of high-voltage distribution lines, substations, medium-voltage distribution lines, main transformers, distribution transformers, etc. This paper conducts operational evaluation for four types of equipment (high-voltage distribution lines, main transformers, medium-voltage distribution lines, and distribution transformers), which can best reflect the operating status of the distribution network. This paper will be researched based on these four types and their operation efficiency coordination degree and power supply capacity coordination index. And the construct and implement relevant indexes of operation efficiency balance degree and coordination degree with power supply capability margin balance degree and coordination degree will be explored and carry out application.

Recently, some countries have begun to study the application of power big data. For example, Australia uses data mining to predict the average value of electricity prices; Germany uses electricity data to predict customers' electricity consumption habits and infer the amount of electricity required by the entire grid for a certain period of time in the future. Denmark uses the meteorological data of Vestas wind system to optimize and analyse the placement of electrical generators. The application of China's power big data is still in its infancy. At present, it has actively carried out the big data analysis of distribution networks in Chinese grid companies and headquarters, but there are still many deficiencies. Electricity is a basic energy related to the people's livelihood. The processing and
application of big data for electricity also face new challenges and also bring new opportunities [3-4]. Strengthening the application of big data in power systems and in-depth mining and analysis of the value of power data will help companies to dig deeper into the value of analysis data, provide quantitative decision support for grid investment and give efficient and scientific guidance for operation and maintenance [5-6].

The structure of this paper is as follows: first introduce the operation-related evaluation model, then present the big data analysis on four types, and experimental verification results are given in the section 4, finally is the summarized and prospected contexts.

2. Operation-Related Evaluation Model

2.1. Operational Efficiency Evaluation Model

The operation efficiency model is mainly divided into five levels: the operation efficiency of the single equipment, the overall operation efficiency of the equipment of the same layer, the overall operation efficiency of the power grid system, the balance of the operation efficiency of the same layer, the coordination degree of the system operation efficiency. Based on the operational efficiency of a single device, an operational efficiency evaluation model of the equipment at the same level, the entire grid system is established to form a complete evaluation index system for the operational efficiency of the grid system [7-8]. The operation efficiency model of the single equipment is constructed based on the equipment continuous curve. The construction principle is as shown in figure 1. Based on this principle, the operation efficiency evaluation model is equation (1):

$$EER = \left( \frac{S_{E1}}{S_1} \right) \cdot \rho_1 + \left( \frac{S_{E2}}{S_2} \right) \cdot \rho_2 + \left( \frac{S_{E3}}{S_3} \right) \cdot \rho_3$$  

(1)

where, EER is the actual power supply of the equipment running in the j-th stage, $S = S_1 + S_2 + S_3$ is the actual power supply of the equipment, and $S_{Ej}$ is the maximum power supply that can be delivered under the premise that the equipment in the jth stage meets the safe operating limits, $S_E = S_{E1} + S_{E2} + S_{E3}$ is the maximum amount of power that the equipment can meet the safe operating limit, $\rho_j$ is the weight value of the operating efficiency of the equipment running in the j-th stage, and T is the overall equipment operation evaluation period.

The operation efficiency of the equipment at the same layer is based on the operation efficiency of the single equipment, and the equipment value is used as the weight to calculate the operation efficiency of a certain level of the power grid, such as each voltage level (110 kV and below), and the overall equipment type. The calculation formula is as Eq.2:

$$SER_i = \sum_{j=1}^{M_i} \theta_i EER_{ij}$$  

(2)

where, $M_i$ is the total number of category i-th equipment, the value of i is 1/2/3/4, 1 represents high-voltage distribution line equipment, 2 represents the main transformer equipment, 3 represents
medium-voltage distribution line equipment, and 4 represents power distribution Transformer; $\theta_i$ is the value weight, which is the ratio of the value of a single device to the total asset value of this type of equipment; $EER_i$ is the operating efficiency value of the j-th type i-th equipment, that is, the operating efficiency value of the single equipment.

The operating efficiency of the power grid system is based on the original value of the equipment, and iterates layer by layer to calculate the power supply efficiency $(A+E)$ and the operating efficiency value of the power grid in the administrative area $110 \text{kV}$, which is shown in equation (3):

$$\text{SER} = \sum_{i=1}^{N} \omega_i \text{SER}_i$$  

where, $N$ is the number of equipment levels in the system, $\omega_i$ is the ratio of the asset value of a certain level of equipment to the total asset value of the system, and $\text{SER}_i$ is the system operating efficiency of i-th level of equipment based on economic operation.

The operation efficiency balance of equipment at the same layer is used to measure the relative balance of operation efficiency between equipment at the same layer. In order to eliminate errors caused by different dimensions, self-variation or large differences in values, the construction principles of margin and balance indicators are exhausted May make the data value fall between 0–1, as shown in the following equation (4).

$$B_{EER} = e^{-\sqrt{\frac{\sum_{i=1}^{N} (EER_i - \text{EER})^2}{N}}}$$

where, the numerator of the index part is the standard deviation of the operating efficiency of the equipment at the same layer, and the denominator is the average value of the operating efficiency of the equipment at the same layer.

The equation (5) represents the operation efficiency of different levels of the power grid system, which implies the system operation efficiency coordination degree forms the operation efficiency coordination degree between the system levels by performing variance calculation and natural index.

$$B_{SER} = e^{-\sqrt{\frac{\sum_{i=1}^{N} (SER_i - \text{SER})^2}{N}}}$$

2.2. Evaluation Model of Power Supply Capacity

In this paper, the supply capacity evaluation model is N-1 security standard. The margin balance and coordination indication are designed by the definition of these indicators mentioned in [9-12]. The power supply capacity margin of single equipment is defined by the ratio of supply capacity reserve (SCR) to maximum supply capacity (SC).

$$SCM = \frac{\text{SCR}}{\text{SC}}$$

where, SC is the maximum power supply capacity by $\text{SC} = k \times P_u$, the k is the overload coefficient; And $\text{SCR} = \text{SC} - P_{\text{max}}$, $P_{\text{max}}$ is the maximum load.

The capacity margin of the same layer is the evaluation of the capacity margin and is reduced by the ratio of the total power capacity reserve with the same voltage level.

$$GSCM_i = \frac{GSCR_i}{GSC} = \frac{\sum_{j=1}^{M_i} \text{SCR}_j}{\sum_{j=1}^{M_i} \text{SC}_j}$$

where, $i$ is its value in the operating efficiency and $M_i$ is the total number of devices.

The balance of the supply capacity in the same layer is an evaluation of the balance between similar equipment under the same voltage level. It is calculated by Eq.8:

$$B_{SCM_i} = e^{-\sqrt{\frac{\sum_{j=1}^{M_i} (\text{SCM}_j - \text{SCM})^2}{N}}}$$
where, SCM<sub>ij</sub> is the power supply capacity margin value of the jth device of category i

The calculation method of the power supply capacity margin coordination between the devices at each layer is:

\[
C_{GSCM} = e^{-\sqrt{\frac{\sum_{i=1}^{N} (GSCM_i - GSCM)^2}{N}}} \tag{9}
\]

where, the value of i is the same as the value of i in the operating efficiency and GSCM<sub>i</sub> is the power supply capacity margin value of the i-th device.

3. Big Data Analysis on Four Types

By using big data technology to analyse the operation of the four types of equipment in the distribution network, it will achieve the goal that collecting the operation of the power grid based on the main equipment file information and operation data, locate the existing problems of the power grid, and promote the coordinated development of the power grid and economic operation [13-15]. Big data analysis ideas and processes mainly include four parts: demand analysis, data tracing, data cleaning, model construction and evaluation, as shown in figure 2.

![Figure 2. The general idea and process of big data analysis.](image)

According to our big data analysis ideas and processes, the verification results of this analysis are:

1. Collect sample company data based on data needs. Collected the main equipment files and operation data of the distribution network of nine cities’ companies;

2. Detailed and integrate the access data according to the established detailed rules to prepare for the calculation of indicators;

3. Calculate the index, execute the calculation procedure according to the definition of each index value, and obtain the calculation results of equipment operating efficiency and power supply capacity in the pilot area;

4. Verify the availability and effectiveness of the model based on the calculation result indicators, continuously tune the business model and data model.

4. Experimental Verification Results

The data from 9 cities data were collected. There are 364 high-voltage lines, 712 main transformers, 2,272 medium-voltage lines, 175,710 distribution transformers, and 96,594 transformer substations.
We establish the operation efficiency and power supply capability model of the four types of equipment based on the collected samples above, and analyse and verify the power supply quality and operation status of the public transformer station area. The specific parameters are shown in Table 1.

| City name | High voltage distribution line | Distribution transformer | Medium voltage distribution line | Main transformer | Public transformer station area |
|-----------|--------------------------------|--------------------------|---------------------------------|-----------------|--------------------------------|
| City_1    | 43                             | 18398                    | 193                             | 69              | 7 951                          |
| City_2    | 32                             | 4791                     | 104                             | 41              | 3 294                          |
| City_3    | 78                             | 52671                    | 711                             | 189             | 28 016                         |
| City_4    | 18                             | 27286                    | 405                             | 101             | 17 172                         |
| City_5    | 20                             | 9773                     | 138                             | 48              | 6 693                          |
| City_6    | 56                             | 22567                    | 200                             | 90              | 12 740                         |
| City_7    | 28                             | 17128                    | 89                              | 31              | 6 951                          |
| City_8    | 50                             | 11000                    | 81                              | 49              | 7 365                          |
| City_9    | 39                             | 12096                    | 351                             | 94              | 6 412                          |
| Total     | 364                            | 175710                   | 2272                            | 712             | 96 594                         |

4.1. Operation Efficiency Analysis Results

The operating efficiency of the single equipment is calculated and use the value of equipment’s each layer as the weight to calculate the system operating efficiency, and calculate the system operating efficiency coordination degree according to the operating efficiency coordination degree formula. The City_3 and City_7 systems have higher operating efficiency and City_2 has lower operating efficiency. From the perspective of coordination of operational efficiency, City_6 has the best coordination and City_5 has the worst coordination, which is shown in Figure 3.

By comparing and analysing the operation efficiency of the equipment level of City_6 and prefecture-level City_5, as shown in figure 4, it can be seen that the lowest coordination degree of prefecture-level City_5 is due to the fact that the overall operating efficiency of main transformers and high-voltage lines is severely lower than that of prefecture-level City_6.

As shown in figure 5, the correlation between equipment operation efficiency and years of operation is analysed. For equipment with a period of less than 10 years, the operating efficiency as a whole increases rapidly with the increase in the period; for devices with a period of 10 to 20 years, the operating efficiency changes relatively smoothly; for the period is greater than 20 years Equipment, the operating efficiency is slowly declining.

Figure 3. The efficiency and coordination degree of each city.
Figure 4. The equipment efficiency of City_5 and City_6.

4.2. Power Supply Capacity Analysis Results
From the equipment level, the margin of high-voltage line power supply capacity is relatively high, and the distribution transformer is relatively low. From the perspective of the company, the margin of power supply capacity of City_2 is relatively high, and that in City_7 is relatively low, as shown in figure 6.

From the perspective of power supply capacity margin coordination, the best coordination degree is City_3 and the worst is City_1, which is shown in figure 7.

Figure 5. The Correlation analysis of efficiency and operation years.

Figure 6. The power supply capacity margin distribution of each city.
5. Summary
With the continuous advancement of the power company's big data construction work, the speed of data-based technological innovation and application development has gradually accelerated. The data model has penetrated all aspects of the company's business development and has become an important engine for promoting innovation and appreciation of the core competitiveness. Through high-quality data models, the data analysis is fed back to the operation. A large amount of value data is provided for production, equipment supplier services, etc. These data are analysed to improve the overall operation efficiency of the distribution network scientifically and efficiently.

The evaluation of the operation of four types of equipment in the distribution network is an important economic evaluation method for the reliable operation of power systems. At present, the domestic power grid operation is still in the stage of qualitative evaluation, lacking quantitative evaluation and analysis methods. This paper selects four types of equipment: high-voltage distribution lines, main transformers, medium-voltage distribution lines and distribution transformers, to carry out operational evaluation. The use of big data analysis technology, based on the distribution network data of four types of single equipment, in-depth mining of power data to provide business support for decision support. Experimental tests and verifications of the operational efficiency and power supply capacity models proposed in this paper have been conducted in several cities. The results show that this method can find the weak links in the specific operation of the power grid, which can provide theoretical basis and practical experience for further research.

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