Management Evaluation of Distribution Network Based on Fuzzy Evaluation Matrix

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Abstract. Focused on automation management level of distribution network, an evaluation method based on fuzzy matrix is proposed in this paper. First, data extraction efficiency, data quality and automation ratio are selected as evaluation indicators. Then, by establishing an analytical model, each indicator is compared in pairs to construct a judgment matrix. And the consistency test of the matrix is done before the follow step. Next, through the experts’ scores of the influencing factors, fuzzy mathematics is used to make a comprehensive evaluation of the automation management evaluation indicators. Finally, according to the evaluation results, the automation management level of the distribution network is analysed. According to the above method, a certain urban area is taken as an example to obtain the quantitative index of the automation management level of the distribution network. It is of great significance to strengthen the distribution network construction with the cooperation management mode, so as to realize the comprehensive improvement of the distribution network management level.

1. Introduction
Distribution network is the hot spot of development of today’s power grid. It is also the connection point between main power grid and users and the key to power safety production and quality service. In recent years, the development of power distribution technology has advanced by leaps and bounds. New technologies such as distribution automation, distribution network condition maintenance, cable fault oscillation wave detection, and high-reliability distribution network structure have emerged in an endless stream. Maintenance and management are introduced into the era of intelligence. It puts forward also higher requirements for the professional and technical level of the staff of the distribution network [1]-[4].

Developing distribution automation system and building a strong intelligent distribution network is the practical need to adapt to the individualized power supply needs of users, support distributed power access and realize intelligent operation management of power grids. It is the main direction of development and construction of distribution networks [5].

Distribution Automation System is a comprehensive information management system integrating computer technology, data transmission, control technology, modern equipment and management. The system is monitored and controlled by distribution network, power quality monitoring and analysis. Advanced functions such as distribution network fault monitoring and isolation, non-faulty area power supply recovery, and distribution network data integration applications can effectively improve the intelligent degree of distribution network and power supply reliability [6].

Therefore, with the deepening of the construction of distribution automation and the comprehensive coverage of distribution automation equipment, the establishment of a lean operation and maintenance system for distribution automation systems is to play a strong role and benefits to provide users with more pressing need for reliable, smarter power services. This paper starts with the selection of
automation management indicators for distribution network, and mainly introduces the evaluation method of automation management. Taking the distribution network of a certain urban area as an example, the realization process of the evaluation method is illustrated. The benefit evaluation of the automation management is calculated through the fuzzy evaluation matrix of the automatic management mode benefit and the automation level of the distribution network is quantitatively evaluated.

2. Distribution network evaluation index
The automatic management refers to the management of the distribution network automation system, mainly including the management of the distribution automation master station data and the establishment of the distribution network automation master station to solve the data quality problems of distribution automation for realizing the automation of the distribution network, management. After researching a distribution network in a certain urban area, it is finally determined to establish an evaluation index system for the automation management of the distribution network from the aspects of data extraction efficiency, data quality and automation ratio, as shown in Figure 1.

![Figure 1. Distribution network automation management evaluation index](image)

The data extraction efficiency in Figure 1 refers to the efficiency of extracting data from each data collection system through the construction of an automated primary station. Data quality refers to the quality of data extracted from each data collection system and whether it meets the requirements. The automation ratio refers to the proportion of the current distribution network automation construction.

2.1 An example. In this example we can see that there are footnotes after each author name and only 5 addresses; the 6th footnote might say, for example, ‘Author to whom any correspondence should be addressed.’ In addition, acknowledgment of grants or funding, temporary addresses etc might also be indicated by footnotes.

3. Automated management evaluation method

3.1. Judgment matrix construction
Analytical method is one of the most commonly used methods for evaluating index system and it is also one of the most common and basic methods for constructing evaluation index system. The so-called analysis method is to describe the established evaluation index system using specific statistical indicators and provide a simple decision-making method for solving complex decision problems.

By establishing an analysis model, each element is compared in pairs. Then the judgment matrix is constructed. The analysis method is mainly expressed by the scale value. And the acquisition of the scale value is mainly the value of the reasonable judgment given by the relative importance of each factor. Finally the required judgment matrix is formed.
After the judgment matrix is obtained, the weight vector needs to be calculated and the consistency test is performed. The maximum eigenvalue and its corresponding eigenvector are calculated for each judgment matrix. And the consistency test is performed by using the consistency index, the random consistency index and the consistency ratio. If the test passes, the normalized feature vector is the weight vector. If not, the reconstruction matrix should be considered. The approximation of the eigenvector is usually obtained by the summation method or the root method.

The n-th order positive reciprocal matrix \(A\) is a uniform matrix if and only if its largest eigenvalue is \(\lambda_{\text{max}} = n\). And when the positive reciprocal matrix \(A\) is non-uniform, it must be \(\lambda_{\text{max}} \neq n\). Therefore, \(\lambda_{\text{max}}\) can be checked whether or not the matrix \(A\) is a uniform matrix by whether it is equal to \(n\).

The steps for the consistency check of the judgment matrix are as follows [7]:

(i) Computational consistency indicator \(CI\),

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]  

Where: \(n\) is the number of rows or columns of the judgment matrix.

If \(CI\) is equal to 0, then the judgment matrix is completely consistent. If the \(CI\) is not equal to 0, it needs to be judged according to the consistency ratio \(CR\).

(ii) Find the corresponding average random consistency indicator \(RI\). The \(RI\) values for \(n = 1, 2, ..., 9\) are shown in Table 1.

| \(n\) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI   | 0   | 0   | 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45|

According to Table 1, the consistency ratio \(CR\) can be calculated by equation (2)

\[
CR = \frac{CI}{RI}
\]  

When \(CR<0.10\), it is considered that the consistency of the judgment matrix is acceptable [8], otherwise the judgment matrix should be appropriately modified.

3.2 Fuzzy comprehensive evaluation

Fuzzy comprehensive evaluation is a method to comprehensively evaluate the research object by using fuzzy mathematics under the full analysis of various influencing factors of the research object. Assuming that the set of factors affecting the object being evaluated is \(U = \{u_1, u_2, ..., u_m\}\). Each of the factors has \(n\) states, and the decision set is \(V = \{v_1, v_2, ..., v_n\}\). There are two types of fuzzy sets, that is, the degree of importance \(U\) and the fuzzy relationship of the index factor set \(U \times V\) in people's eyes. The former appears as a fuzzy weight vector \(A = \{a_1, a_2, ..., a_m\}\) on \(U\). The latter appears as a \(m \times n\) fuzzy matrix \(R\). According to a reasonable fuzzy operation method, a fuzzy subset \(B = \{b_1, b_2, ..., b_n\}\) on \(V\) is obtained for each of the two sets. Therefore, the fuzzy comprehensive evaluation refers to finding the fuzzy weight vector \(A \in F(U)\) and a fuzzy transformation \(f\) from \(U\) to \(V\). That is, making a judgment for each index factor separately. And then constructing the fuzzy matrix \(R = \{r_{ij}\}_{m \times n} \in F(U \ast V)\), which \(r_{ij}\) indicates that the index factor \(u_i\) has the degree of comment \(v_j\). Finally, a fuzzy comprehensive evaluation \(B = (b_1, b_2, ..., b_n) \in F(V)\) is obtained, where, \(b_j\) indicates the degree to which the evaluated object has a comment \(v_j\).
According to the fuzzy matrix, each individual factor in the evaluation factor plays a different role in the "evaluation target". That is, the single factor occupies different weight ratios in the comprehensive evaluation. A score method to get the A, the weight or the weight distribution set \( A = (a_1, a_2, ..., a_m) \), \( a_i \geq 0 \), \( \sum a_i = 1 \). It reflects a trade-off between factors.

Then, the fuzzy synthesis is performed. And the final result is calculated according to the result of the synthesis. The row value of the R mainly reflects the degree of membership of the individual evaluated items and the fuzzy subset of each level. The fuzzy weight vector A is used to synthesize different lines. And the degree of membership of the fuzzy subset of each level of the evaluated object is obtained from the whole. This is the fuzzy comprehensive evaluation result vector. Introducing a fuzzy subset B on V is the decision set. It is also known as fuzzy evaluation \( B = (b_1, b_2, ..., b_n) \).

According to the results of the fuzzy evaluation obtained in the previous step, the principle of maximum membership degree is used to analyse the influencing factors effectively.

4. Distribution network automation management evaluation

4.1 Weight design data collection

According to the evaluation index system of distribution network automation management constructed in section 1, the staff of the distribution network departments are invited to collect data. In each part, at least two people scored. And 13 complete judgment matrices are collected. Through the effectiveness screening, it is finally determined that 10 sets of valid data are used. Then the weight design is performed according to the data conditions. The decision matrix is established by the method described in section 2.1. According to the collection of ten valid data, the mean value is the data of the final judgment matrix. And the judgment result is shown in Table 2.

Table 2. Automated management weight judgment matrix

|     | A   | B1  | B2  | B3  |
|-----|-----|-----|-----|-----|
| B1  | 1   | 1   | 2   |     |
| B2  |     | 1   | 1   | 3   |
| B3  | 1/2 | 1/3 |     | 1   |

4.2 Fuzzy weight vector design data collection

In order to analyse the influencing factors in the automation construction of a distribution network in a certain city, we also invited ten experts to score the influencing factors and determine the height of the different comment indicators in each comment indicator. The comment set is {Excellent, Good, Acceptable, Not bad, bad}. Each expert puts forward his own opinions and suggestions according to the contribution of the automation management level to the current distribution management of a certain urban area, and scores the effect of each management mode. The statistics of the scores are shown in Table 3.

Table 3. Automated management level

|     | Excellent | Good | Acceptable | Not bad | bad |
|-----|-----------|------|------------|---------|-----|
| B1  | 1         | 3    | 4          | 2       | 0   |
| B2  | 3         | 2    | 4          | 1       | 0   |
| B3  | 1         | 2    | 4          | 2       | 1   |

4.3 Comprehensive evaluation parameter design

4.3.1 Weight design

According to section 3.1, weight of automated management indicator is obtained as follows: (1) Calculate the indicator weight,
(2) Calculate the eigenvalue,  
(3) Calculate consistency index CI,  
(4) Calculate consistency ratio CR.  

The results of the judgment matrix calculation are shown in Table 4.

|            | B1   | B2   | B3   |
|------------|------|------|------|
| Weights    | 0.387| 0.443| 0.169|
| Consistency test | CI=0.009, RI=3.018, CR=0.016 |

According to the requirements of the consistency test, here CR=0.016<0.1. And the automatic management index is considered to pass the consistency test.

4.3.2 Fuzzy weight vector design

According to the collected expert opinions, the normalized processing is transformed into a fuzzy evaluation matrix. Then the weights of each index are combined with the single evaluation of the benefit management mode and the comprehensive evaluation of the management mode benefits. For the data extraction efficiency, data quality and automation scale indicators under the automated management mode, each expert put forward his own point of view. And the fuzzy evaluation matrix degree $R$ of the automated management model benefit is obtained through the normalization of the statistical results.

$$R = \begin{bmatrix} 0.1 & 0.3 & 0.4 & 0.2 & 0 \\ 0.3 & 0.2 & 0.4 & 0.1 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0.1 \end{bmatrix}$$

4.4 Comprehensive evaluation and analysis

According to the weight of each index under the automation management and the fuzzy evaluation matrix of the automation management mode benefit, the benefit evaluation of the automation management is as follows,

$$A = \sigma \times R = \begin{bmatrix} 0.387 & 0.1 & 0.3 & 0.4 & 0.2 & 0 \\ 0.443 & 0.3 & 0.2 & 0.4 & 0.1 & 0 \\ 0.169 & 0.1 & 0.2 & 0.4 & 0.2 & 0.1 \end{bmatrix} \times \begin{bmatrix} 0.1 & 0.3 & 0.4 & 0.2 & 0 \\ 0.3 & 0.2 & 0.4 & 0.1 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0.1 \end{bmatrix} = \begin{bmatrix} 0.1885 \\ 0.2385 \\ 0.3996 \\ 0.1555 \\ 0.0169 \end{bmatrix}$$

It can be seen from the evaluation results that 19% and 24% of the experts believe that the improvement of the automation management level in the urban distribution network management mode is very obvious, and 40% of the experts believe that the improvement of the automation management level is relatively general. Only 17% of experts believe that the level of automation management has basically not improved.

5. Conclusion

The distribution automation management evaluation index system proposed in this paper scientifically selects the evaluation index and evaluation method, which can evaluate the management of the distribution automation system completely, accurately and intuitively. And at the same time a solution is proposed to solve the problems between different scales and different levels. The evaluation problem provides new ideas, theories and methods. It provides a credible theoretical basis and data support for finding the weak links of the distribution automation system, planning the system construction, improving the management level, and guiding the distribution automation work. In the future work, the
method can be further applied in the management of distribution network security and synergy, thereby improving the overall management level of the distribution network.

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