Research on Comprehensive Decision-Making of Distribution Automation Equipment Testing Results Based on Entropy Weight Method Combined with Grey Correlation Analysis

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Abstract. The traditional evaluation process of distribution automation equipment relies on the judgment of experts. In order to solve the problem of insufficient objectivity of the comprehensive evaluation process, a comprehensive decision-making method of distribution automation equipment testing results based on entropy weight method combined with grey correlation analysis is proposed. Firstly, the test and evaluation index system considering eight big indexes and thirty-five small indexes is established. Secondly, the entropy weight method is used to determine the objective weight, which can avoid subjective influence and make the weighting process more objective. Then, the improved grey correlation analysis method is used to achieve the sorting of the test results of distribution automation equipment. Finally, the effectiveness of the proposed method is verified by the analysis and comparison of case studies.

1. Introduction
With the number of distribution automation equipment is increasing in recent years, higher quality has been put forward for the distribution automation equipment [1]. To improve the safety and reliability of the operation of the power distribution system, the high quality of the distribution automation equipment must be guaranteed through the comprehensive decision-making of distribution automation equipment testing results [2].

At present, there are few researches on the comprehensive decision-making of distribution automation equipment testing results. The test and evaluation index system of distribution automation equipment involves multiple indicators, such as dustproof level, waterproof level [3][4]. For the comprehensive evaluation of multi-index systems, it is necessary to scientifically determine the index weights. At present, in terms of comprehensive evaluation methods for testing of distribution automation equipment, traditional comprehensive evaluation methods mostly adopt subjective expert decision-making methods for weighting. The commonly used methods mainly include fuzzy comprehensive evaluation method and analytic hierarchy process [5][6]. The objectivity of the evaluation results is not enough [5]. The objectivity and accuracy of the evaluation results are easily affected by subjective factors [6]. The difference between different comprehensive evaluation methods lies only in the evaluation provided by experts. In the case of incomplete information, subjective preferences are more affected, and it is difficult to ensure the objectivity and rationality of the selection of indicator weights. This leads to strong subjectivity and contingency, and the evaluation results are not accurate.
In order to solve the problem of insufficient objectivity of the comprehensive evaluation process, a comprehensive decision-making method of distribution automation equipment testing results based on entropy weight method combined with grey correlation analysis is proposed. Firstly, the test and evaluation index system considering eight big indicators and thirty-five small indicators is established. Secondly, the entropy weight method which can utilize the amount of information contained in the indicator data is used to determine the objective weight, avoiding subjective influence, and making the weighting process more objective and fairer. Then, the improved grey correlation analysis method is used to achieve the sorting of the test results of distribution automation equipment. Finally, the effectiveness of the proposed method is verified by the analysis and comparison of case studies.

2. Evaluation index system of distribution automation equipment
Considering that the distribution automation equipment testing results involve multiple indexes, the test and evaluation index system of distribution automation equipment considering eight big indexes and thirty-five small indexes is established [6][7]. The evaluation index system is shown in Figure 1.

Figure 1. The test and evaluation index system of distribution automation equipment
The test and evaluation index system involves eight big indexes. (structure testing, power-on stability testing, main function testing, power influence testing, environmental impact testing, insulation performance testing, electromagnetic compatibility testing, mechanical performance testing). The test and evaluation index system involves thirty-five small indexes. The structure testing involves equipment structure and appearance testing, electrical clearance and creepage distance testing, terminal fire inspection testing, dustproof level testing, waterproof level testing. The power-on stability testing involves Continuous power-on stability testing. The main function testing involves correctness of communication with higher-level stations testing, basic error of ac input testing, allowable input capability of ac quantity testing, total error of analog to digital conversion testing,
status quantity testing, remote control function testing, fault detection testing, safety protection level testing, information response time testing, effect of ac input testing. The power influence testing involves power out of phase testing, power supply voltage change testing, backup power testing, power consumption testing, timing function testing. The environmental impact testing involves high temperature testing, low temperature testing, dump heat testing. The insulation performance testing involves insulation resistance testing, insulation strength testing, impulse voltage withstand testing. The electromagnetic compatibility testing involves voltage transients and short interruptions, power frequency magnetic field immunity testing, radio frequency electromagnetic field radiation immunity testing, electrostatic discharge immunity testing, electrical fast transient pulse group immunity testing, damped oscillating magnetic field immunity testing, surge immunity testing. The mechanical performance testing involves mechanical vibration testing.

3. Comprehensive evaluation method

3.1. Index standardization method
Based on the test results of each evaluation index, each index is processed to become of the same direction and dimensionless. The above process can make the data more objective and effective and construct the standard evaluation matrix \( A \). In the process of the same direction, the moderate index and the negative index are converted into the positive index. The moderate index refers to an index with an ideal expected interval. The moderate index can be converted into the positive index by the formula (1) which is formulated as follows:

\[
y_j = \begin{cases} 
0 & x_j < m_j \\
\frac{p_j - x_j}{\max(p_j - m_j, M_j - q_j)} & m_j \leq x_j < p_j \\
1 - \frac{q_j - x_j}{\max(p_j - m_j, M_j - q_j)} & p_j \leq x_j \leq q_j \\
1 & q_j < x_j \leq M_j \\
0 & x_j > M_j
\end{cases}
\]  

(1)

where, \( x_j \) is the original testing data of the \( j \)-th index of the \( i \)-th distribution automation equipment; \( y_j \) is the index which is processed to become of the same direction; \( m_j \) and \( M_j \) are the minimum and maximum values of the \( j \)-th index specified by the evaluation standard; \( p_j \) and \( q_j \) are the lower and upper bounds of the ideal interval of the \( j \)-th index.

Especially, when the ideal expected interval of the moderate index has only a specific value, the moderate index can be converted into the positive index by the formula (2) which is formulated as follows:

\[
y_j = \begin{cases} 
0 & x_j < m_j \\
1 - \frac{|x_j - L_j|}{L_j} & m_j \leq x_j \leq M_j \\
0 & x_j > M_j
\end{cases}
\]  

(2)

where, \( L_j \) are the ideal value of the \( j \)-th index specified by the evaluation standard.

The negative index can be converted into the positive index by the formula (3) which is formulated as follows:

\[
y_j = \begin{cases} 
0 & x_j < m_j \\
\frac{M_j + \min(x_j) - x_j}{M_j} & x_j \leq M_j
\end{cases}
\]  

(3)
where, $x_{ij}$ is the original testing data of the $j$-th index of the $i$-th distribution automation equipment; $y_{ij}$ is the index which is processed to become of the same direction; $M_j$ is the maximum value of the $j$-th index specified by the evaluation standard; $\min(x_{ij})$ is the minimum value of the $j$-th index.

Especially, when the $j$-th index is a positive index, the index can be converted into the positive index by the formula (4) which is formulated as follows:

$$
y_{ij} = \begin{cases} 
0 & x_{ij} < m_j \\
1 & x_{ij} \geq m_j
\end{cases}
$$

(4)

Each index is processed to become dimensionless. In this paper, we make indexes being dimensionless by the formula (5) which is formulated as follows:

$$
a_{ij} = \frac{y_{ij}}{\sum_i y_{ij}}
$$

(5)

where, $n_j$ is the total number of the distribution automation equipment; $y_{ij}$ is the index which is processed to become of the same direction; $a_{ij}$ is the standardized index which is processed to become dimensionless.

### 3.2. Grey correlation analysis

The grey correlation analysis method is to determine the ideal optimal sequence according to the actual situation of a certain problem. Then, the degree of correlation between the sequence curve and geometric shape of the distribution automation equipment and the curve and geometric shape of the ideal optimal sequence are judged by the degree of similarity [8][9]. Finally, according to the grey correlation degree vector to output the evaluation results.

Based on the standard evaluation matrix $A$, the maximum value of each index is selected to obtain the ideal equipment evaluation index, and the evaluation index of the equipment is compared with the ideal equipment evaluation index. The grey correlation coefficient matrix $H$ can be calculated by the formula (6) which is formulated as follows:

$$
h_{ij} = \frac{\min_{j} \min_{i} |a_{ij}^* - a_{ij}| + \delta \max_{j} \max_{i} |a_{ij}^* - a_{ij}|}{|a_{ij}^* - a_{ij}| + \delta \max_{j} \max_{i} |a_{ij}^* - a_{ij}|}
$$

(6)

where, $h_{ij}$ is the grey correlation coefficient between the $j$-th index of the $i$-th distribution automation equipment; $a_{ij}$ is the standardized index; $a_{ij}^*$ is the ideal value of the $j$-th index; $\delta$ is the resolution coefficient.

### 3.3. Entropy weight method

Considering the different importance of each index, the weight of each index must be determined in the comprehensive decision-making processing of distribution automation equipment testing results.

The weight needs to reflect the importance of each index. Therefore, the determination of the weight will directly affect the accuracy of the final evaluation results [10]. The entropy weight method is an objective weighting method that uses the amount of information contained in the index to determine the weight of the indicator. The smaller the entropy value, the more information contained in the index. The objective weights calculated by entropy weight method is more objective and reasonable [11].

Based on the standard evaluation matrix $A$, the entropy vector $S$ can be calculated by the formula (7) which is formulated as follows:

$$
S_j = \frac{\sum_{i} a_{ij} \ln(a_{ij})}{\ln(n_j)}
$$

(7)
where, $S_j$ is the entropy value of the $j$-th index; $n_1$ is the total number of the distribution automation equipment; $\frac{1}{\ln(n_1)}$ is the information entropy coefficient.

Based on the entropy vector $S$, the objective weight vector $w$ can be calculated by the formula (8) which is formulated as follows:

$$w_j = \frac{1 - S_j}{n_2 - \sum_{j=1}^{n_2} S_j}$$

where, $w_j$ is the entropy weight of the $j$-th index; $S_j$ is the entropy value of the $j$-th index; $n_2$ is the total number of evaluation indexes.

### 4. Solution methodology

According to the above algorithm, the flow chart of the comprehensive evaluation method of distribution automation equipment based on entropy weight method combined with grey correlation analysis is shown in Figure 2. The specific operation process includes seven steps: ① basic data inputting; ② calculation of the standard evaluation matrix; ③ calculation of the gray correlation coefficient matrix; ④ calculation of the entropy value vector; ⑤ calculation of the objective weight vector; ⑥ calculation of the entropy weight gray correlation degree vector; ⑦ results outputting.

![Flow chart of the comprehensive evaluation method of distribution automation equipment based on entropy weight method combined with grey correlation analysis](image)

**Figure 2. Flow chart of the comprehensive evaluation method of distribution automation equipment based on entropy weight method combined with grey correlation analysis**

### 5. Results & Discussion

In this paper, the analysis and comparison of case studies are based on the test results of two power distribution automation equipment. Based on the test results of two power distribution automation equipment, each index is processed to become dimensionless and of the same direction by the formula (1), (2), (3), (4) and (5). The original testing data matrix $X$ is shown in (9) and the standard evaluation matrix $A$ is shown in (10).
The first row of the original testing data matrix $X$ is equal to $[100, 100, 100, 100, 100, 100, 100, 70, 60, 88, 100, 100, 100, 100, 100, 100, 100, 70, 78, 100, 100, 77, 100, 80, 100, 100, 100, 100, 100, 100, 100, 100, 70, 100, 60, 96, 70, 78, 100, 100, 77, 100, 100, 80, 100, 100, 100, 100]$. The second row of the original testing data matrix $X$ is equal to $[100, 100, 100, 100, 100, 100, 100, 80, 65, 79, 100, 95, 100, 100, 100, 95, 100, 100, 100, 80, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 66, 87, 74, 95, 88, 95, 90, 95, 95, 85, 98, 95, 96, 100]$.

The first row of the standard evaluation matrix $A$ is equal to $[0.5000, 0.5000, 0.5000, 0.5000, 0.5000, 0.5000, 0.5000, 0.4667, 0.4800, 0.5269, 0.5000, 0.5128, 0.5000, 0.5000, 0.5000, 0.5128, 0.5000, 0.5263, 0.5000, 0.4118, 0.5000, 0.4762, 0.5246, 0.4861, 0.4509, 0.5319, 0.5128, 0.4611, 0.4762, 0.5246, 0.4861, 0.4509, 0.5319, 0.5128, 0.4611]$. The second row of the standard evaluation matrix $A$ is equal to $[0.5000, 0.5000, 0.5000, 0.5000, 0.5000, 0.5000, 0.5000, 0.5333, 0.5200, 0.4731, 0.5000, 0.4872, 0.5000, 0.5000, 0.5000, 0.4872, 0.5000, 0.4737, 0.5000, 0.5882, 0.5000, 0.5238, 0.4754, 0.5139, 0.5491, 0.4681, 0.4872, 0.5389, 0.5238, 0.4754, 0.5139, 0.5491, 0.4681, 0.4872, 0.5389]$. Based on the standard evaluation matrix $A$, the grey correlation coefficient matrix $H$ can be calculated by the formula (6). The grey correlation coefficient matrix $H$ is shown in (11).

Based on the standard evaluation matrix $A$, the entropy vector $S$ can be calculated by the formula (7). $S=[1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 0.9668, 0.9988, 0.9979, 1.0000, 0.9995, 1.0000, 1.0000, 1.0000, 0.9995, 1.0000, 0.9980, 1.0000, 0.9774, 1.0000, 0.9984, 0.9983, 0.9994, 0.9930, 0.9971, 0.9995, 0.9956, 0.9995, 0.9993, 0.9999, 0.9995, 0.9997, 1.0000]$. Based on the entropy vector $S$, the objective weight vector $w$ can be calculated by the formula (8). $w=[0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0604, 0.0217, 0.0394, 0.0000, 0.0089, 0.0000, 0.0000, 0.0089, 0.0000, 0.0376, 0.0000, 0.4248, 0.0000, 0.0308, 0.0328, 0.0105, 0.1313, 0.0553, 0.0089, 0.0823, 0.0089, 0.0823, 0.0125, 0.0014, 0.0089, 0.0057, 0.0000]$. Based on the objective weight vector $w$ and the entropy vector $S$, the entropy weight grey correlation degree vector $O$ can be calculated by the formula (5). $O=[0.8439, 0.9805]$. Based on the entropy weighted grey correlation degree vector $O$, the evaluation result of the distribution automation equipment 1 is equal to 0.8439, the evaluation result of the distribution automation equipment 2 is equal to 0.9805. By contrast, the final evaluation ranking result: the evaluation result of the distribution automation equipment 2 is better than the distribution automation equipment 1. The result shows that the proposed method can solve the problem of insufficient
objectivity of the comprehensive evaluation process and make the final evaluation and sorting results more objective and accurate.

6. Conclusion

This paper proposes a comprehensive decision-making method of distribution automation equipment testing results based on entropy weight method combined with grey correlation analysis, so the objective information of index data is fully utilized. The proposed method combines the entropy weight method and the grey correlation analysis in the comprehensive evaluation process of the distribution automation equipment. The grey correlation analysis method can handle the grey system with incomplete information, and has the advantages that the data requirements are relatively low, the amount of calculation is relatively low, and the sorting accuracy of multi-index evaluation problem is higher. At the same time, the entropy weight method is used to determine the objective weight, which can avoid subjective influence and make the weighting process more objective and fairer. The results show that the proposed method can solve the problem of insufficient objectivity of the comprehensive evaluation process of distribution automation equipment testing results and make the final evaluation results of distribution automation equipment more objective and accurate.

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