A Weight Calculation Method for Reducing Mutual Interference of Transformer State Evaluation Indicators

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Abstract. Aiming at the problem that the traditional indicator weight calculation method ignores the mutual influence between indicators and causes the deviation of the calculation results, this paper proposes a transformer state evaluation calculation methods combining of FAHP (Fuzzy Analytical Hierarchy Process) — DEMATEL (Decision-making Trial and Evaluation Laboratory) method and CRITIC (Criteria Importance Through Intercriteria Correlation) method; after selecting the index parameters and dividing the state level, the state evaluation index system is established; based on the combination weighting method to calculate the two methods The optimal weight is combined with the transformer status score to obtain the status evaluation of the transformer. After the case analysis, it can be seen that the method is practical compared with the actual situation obtained from the maintenance; based on the traditional FAHP method and the experimental method in this paper, the Gaussian white noise is added to experimental data increase the interference between enhancement indicators. After simulation analysis, it is found the final state score of the transformer obtained by this method is smoother and more stable. Compared with traditional methods, this paper reduces the errors caused by the mutual influence of indicators and makes the evaluation results more accurate.

1. Introduction

The safety of power equipment is the primary factor for the normal operation of the power grid. As the main primary equipment of the power system, the operation status and health level of large transformers are very critical. Once a failure occurs, it will have a huge impact on the operation and stability of the entire power system. Cause huge asset loss and social impact [1]. Therefore, preventing transformer failures, choosing the time for transformer repair and maintenance in a timely and reasonable manner, and improving the operation and maintenance level of power transformers are currently urgent problems to be resolved [2]. Conditional maintenance relies on the condition assessment close to the actual operating state of the transformer to select the maintenance time and plan. It is the most advanced maintenance strategy with the lowest cost today. However, due to the complex structure of the transformer, the numerous state quantities, and the mutual interference between various index quantities, it is very difficult to accurately assess the state of the transformer.

Literature [3] takes the set pair analysis method as the theoretical basis of transformer condition evaluation, and establishes a quantitative and qualitative evaluation index system according to relevant experimental guidelines of the State Grid and the experience of experts at home and abroad [4,5], and then various indicators in the index system It forms a set pair with the divided state levels. After calculating the degree of identity, difference and opposition between the two, the fuzzy attribute rules are used to
obtain the connection between the index and the state level to determine the health status of the transformer grade. Compared with the comprehensive evaluation method based on fuzzy state, the method is more intuitive and more effective. However, the mutual influence between indicators is ignored when selecting indicator weights, which is not accurate enough, and only the state level of individual indicators is analyzed. Literature [6] selects the positive and negative ideal solutions, and then relies on the gray correlation between the experimental value and the ideal value and the Euclidean distance to determine the state of the transformer. However, when calculating the positive and negative ideal solutions, the weight is calculated solely by subjective quantities to obtain the positive and negative ideal solution and the actual ideal value are prone to large errors.

The structure of this paper is as follows: Section 2 constructs the transformer condition assessment model and divides the grade standards; Section 3 combines the DEMATEL method with the FAHP method at the subjective level, and uses the CRITIC method to calculate the weights at the objective level, and adopts the most optimal weight calculation method calculates the optimal weight; Section 4 is an example analysis, and at the same time, based on the traditional FAHP method and the experimental method of this article on MATLAB, the experimental data is added to the experimental data to enhance the interference between the mutual influences of the Gaussian white noise. The simulation analysis verifies the method of this article.

2. Construction of Transformer Condition Assessment Model

2.1 Establishment of state assessment index system

This article refers to the domestic DL/596-1996 "Prevention Test Regulations for Power Equipment" [7] and GB/T7252-2001 "Guidelines for the Analysis and Judgment of Dissolved Gases in Transformer Oil" to create a transformer evaluation system, as shown in Table 1. The index system is divided into three layers from top to bottom: target layer, factor layer and indicator layer [6].

2.2 Grading of evaluation

The classification of transformer status in this paper is shown in Table 2.

Table 1 Transformer evaluation index system

| Target level | Factor level | Index level | Index level |
|--------------|--------------|-------------|-------------|
| Transformer status | Winding fault a1 | H2 content a11, winding insulation loss a12, Initial value difference of winding capacitance a13, initial value of winding short-circuit impedance a14 | Moisture of insulation a6 |
| | Iron core fault a2 | Iron core ground current a21, iron core insulation resistance a22, C2H6 content a23, C2H4 content a24 | Insulation aging a7 |
| | | H2 content a31, winding DC resistance difference a32, C2H2 content a33, partial discharge a34 | Deterioration of insulating oil a8 |
| | Partial discharge a4 | Water content in the oil a41, H2 content a42, winding DC resistance mutual difference a43, partial discharge a44, gas content in the oil a45, CH4 content a46 | CO2 relative gas production rate a91, winding DC resistance mutual difference a92, C2H4 content a93, CO relative gas production rate a94 |
| | Oil discharge a5 | Insulating oil dielectric loss a51, volume resistivity a52, C2H2 content a53, gas content in the oil a54, neutral oil flow electrostatic current a55 | |
Table 2: Transformer health condition corresponds to condition score

| Status score | 0.0–0.2 | 0.2–0.6 | 0.6–0.8 | 0.8–1.0 |
|--------------|---------|---------|---------|---------|
| Health status| serious | abnormal| attention| normal  |

3. Transformer status evaluation model

In this paper, the subjective level is based on the principle of the traditional DEMATEL method, and the FAHP-DEMATEL method is further used to calculate the weight of the transformer state index; the objective level is calculated using the CRITIC method. And calculate the optimal combination of weights obtained under the two methods, and use this as a basis for state evaluation. The specific process is shown in Figure 1.

3.1 DEMATEL method

DEMATEL calculates the degree of mutual influence among factors by analyzing the internal relations among factors at each level in the evaluation process.

The steps of DEMATEL method are as follows [8]:

1) Delphi method was used to determine each factor

2) Determine the direct influence matrix A between the factors. Use expert scoring method to judge the degree of influence between various factors, which is divided into 5 levels, 0-none, 1-weak, 2-relatively weak, 3-relatively strong, 4-very strong, and build matrix A based on this.

3) Normalization directly affects the matrix to get G. \( G = A / \max_{i < j < n} \sum_{j=1}^{n} a_{ij} \).

4) Calculate the comprehensive impact matrix. T is obtained by calculation \( T = G(I - G)^{-1} \), where I is the identity matrix and is the inverse matrix of \((I - G)\).

5) Determine the degree of influence and to be influenced. The sum of the quantities in each row in the matrix T represents the interference degree of index I to other indexes, and is set as \( f_i \).

The sum of each column quantity in the matrix T represents the interference degree of other indexes on the index \( i \), set as \( e_i \).

\[
\begin{align*}
 f_i = & \sum_{j=1}^{n} t_{ij}e_i = \sum_{i=1}^{n} t_{ij} \\
\end{align*}
\]
3.2 Comprehensive weight calculation method based on FAHP-DEMATEL

1) FAHP method to calculate the initial weight  \( W_1 \). \([9]\)

2) DEMATEL method is used to calculate the influence weight  \( W_2 \). According to the formula  \( d = f^T * e \), the influence degree vector  \( d = f^T * e \) of the diagonal elements to constitute the index was taken to calculate the degree of influence of index  \( i \), and the corresponding weight value  \( W_2 \) was obtained. And  \( 0 \leq W^2 \leq 1 \).

\[
W^2 = d_i / \sum_{i=1}^{n} d_i
\]

(2)

3) Determine the comprehensive weight. Get the weight  \( W \) by formula  \( W = W_1 \times W_2 \), and the comprehensive weight is obtained after normalization.

3.3 CRITIC assignment method

The CRITIC method is an objective method that takes into account the conflict between state quantities and the intensity of contrast to calculate weights \([10]\). The contrast intensity is the difference between different individuals in the same state quantity, expressed by the standard deviation  \( \sigma_j \), and the size of  \( \sigma_j \) represents the difference between the state quantities. The conflict between state quantities is derived from the degree of connection between state quantities, which is represented by  \( R_j \).  \( C_j \) is the information contained in the  \( j \)-th state quantity.

\[
R_i = \sum_{j=1}^{n}(1 - r_{ij})
\]

(3)

\[
C_j = \sigma_j R_j
\]

(4)

\[
W_j = \frac{C_j}{\sum_{j=1}^{n} C_j}
\]

(5)

\[
r_{xy} = \frac{\sum(x - \bar{x})(y - \bar{y})}{\left[\sum(x - \bar{x})^2(y - \bar{y})^2\right]^{1/2}}
\]

(6)

The state quantities  \( i \) and  \( j \) have a correlation coefficient  \( r_{ij} \), which is calculated as equations (6):

In this paper, the CRITIC method is used to assign weights to 24 state quantity data of different transformers. Standardize the data with 'standardized amount=(this value-lowest value)/(highest value-lowest value)', and then calculate the corresponding contrast, conflict, and value according to equations (3), (4), and (5). The amount of information and objective weight.

3.4 Determine the optimal combination weight

According to the calculated subjective weights of the indicators and objective weights of the indicators, the optimal weight is calculated based on the principle of minimum variance through the method of finding the extreme value of the Lagrangian daily number, and the total difference between the weight vector obtained by the optimal weight and the weight vector obtained by each method The smallest. The optimal weight calculation method is as follows.

The weight vector of the  \( j \)-th index of a certain weight calculation method is  \( W_j=(W_{j1}, W_{j2}, W_{j3}, \ldots, W_{jn}) \), and the most reasonable attribute weight vector under the weight of the two weight calculation methods is  \( W=(W_1, W_2, W_3, \ldots, W_m) \),  \( m \) and  \( n \) are the number of indicators under a certain factor level. To establish a single-objective planning model;

\[
\min P = \sum_{j=1}^{m} \sum_{k=1}^{n} \sum_{j=1}^{n} (a_k \lambda_{ik} - a_j \lambda_{kj})^2
\]

\[
\sum_{k=1}^{m} a_k = 1
\]

(7)

Construct the corresponding Lagrangian function and find the extreme value:

\[
L(a, \lambda) = \sum_{j=1}^{m} \sum_{k=1}^{n} (a_k u_{ik} - a_j u_{kj})^2 + \lambda \left(\sum_{k=1}^{m} a_k - 1\right)
\]

(8)


\[ \frac{\partial L(a, \lambda)}{\partial a_k} = 2a_i \sum_{i=1}^{m} u_{ik}^2 - (a_i \sum_{i=1}^{m} u_{ik} + a_j \sum_{i=1}^{m} u_{jk}) + \frac{\lambda}{2} = 0 \]  

Derivation available;

\[ \frac{\partial L(a, \lambda)}{\partial \lambda} = \sum_{i=1}^{n} a_i - 1 = 0 \]

After the solution, two methods can be obtained to occupy the weight \( a=(a_1, a_2) \) respectively, so that the optimal weight vector can be obtained.

### 4. Example analysis

This paper selects a 220kV oil-immersed transformer in a substation in the southwest region for experimental analysis. After using the method in this paper to calculate its weight, the factor level status score and factor level weight value are obtained as shown in the following table.

| Fault type          | Status score | Fault type          | Status score |
|---------------------|--------------|---------------------|--------------|
| Winding fault       | 0.7444       | Insulation damp     | 0.5120       |
| Core failure        | 0.0404       | Insulation aging    | 0.7697       |
| Arc discharge       | 0.6570       | Deterioration of insulating oil | 0.6379     |
| Partial discharge   | 0.6516       | Current loop overheating | 0.5910     |
| Oil discharge       | 0.8437       |                      |              |

| Fault type          | Weights      | Fault type          | Weights      |
|---------------------|--------------|---------------------|--------------|
| Winding fault       | 0.0927       | Insulation damp     | 0.1139       |
| Core failure        | 0.2094       | Insulation aging    | 0.0908       |
| Arc discharge       | 0.0998       | Deterioration of insulating oil | 0.1015     |
| Partial discharge   | 0.1003       | Current loop overheating | 0.1058     |
| Oil discharge       | 0.0857       |                      |              |

After calculating the weight value of the fault type of the factor layer, the state score of the target layer power transformer can be obtained by weighting as 0.5362.

Using the obtained results to determine that the transformer is abnormal, it should be repaired immediately. After the transformer was actually overhauled, it was found that some of the winding cakes were squeezed and stretched to varying degrees, the distance between the cakes changed, and local deformations occurred. It shows that the fault diagnosis results in this paper are more consistent with the actual situation, and the evaluation method can more accurately diagnose the fault type and reflect the actual situation.

### 5. Evaluation of stability comparison

In this paper, the measurement error is simulated by adding Gaussian white noise proportionally to the same input quantity, so as to enhance the mutual influence between the indicators. The stability comparison of the calculation results is shown in Figure 2.

Among them, the abscissa represents the interference amount of white noise simulation, that is, the maximum measurement error accounts for \( \pm 1\%~\pm 10\% \); the ordinate is the standard deviation of the evaluation results in 200 simulations. In Figure 2, the standard deviations of the two types of algorithms increase with the increase in the proportion of errors, but compared to the FAHP algorithm, the standard
deviation of the algorithm in this paper increases more slowly, and the evaluation results are more stable under the influence of the same error.

6. Conclusion
This article refers to expert experience and regulations, classifies transformer status indicators in an orderly manner, and establishes a systematic transformer evaluation system. In the weighting algorithm, the subjective level uses the DEMATEL method combined with the FAHP method, and the objective level uses the CRITIC method to calculate the index weight, and then based on the principle of the minimum variance method, the two weighting methods are comprehensively calculated to obtain the optimal weight, which reduces the error caused by the mutual influence on the final experimental result, the comprehensive state score is calculated to determine the health of the transformer. And while analyzing the actual cases to verify the rationality of the method, MATLAB is used to compare the stability of the algorithm in this paper with the FAHP method. The final result proves that the proposed scheme has the rationality of the evaluation, and at the same time reduces the error caused by the mutual influence between the indicators, making the evaluation result more accurate and more stable

Fig. 2 Standard deviation of transformer final state score under white noise

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