Transformer State Evaluation Based on Improved TOPSIS Method

Gan Binbin    Li Zhong    Yuan Jinsha    Yao Lijing
North China Electric Power University  Baoding 071003  China
15176315831@163.com

Abstract. Transformer is one of the main equipments in power system. Its operation state directly affects the reliability of power system. Therefore, it is very important to carry out the research of transformer state evaluation. Since the current state evaluation method can only evaluate a single transformer, this paper proposes an algorithm for simultaneous assessment of multiple transformers. Firstly, the transformer condition evaluation index system is established. Secondly, TOPSIS is improved by using the grey correlation degree, and a transformer condition assessment model is established by using the improved algorithm. Finally, the state of 6 transformers is evaluated according to the relevant data, and the rationality and validity of the proposed method are verified by examples.

1. Introduce

The power transformer is one of the main equipments in the power system. Its health state directly affects the safe and stable operation of the entire power grid. A scientific and efficient evaluation of the operation state of the transformer can reduce the probability of its occurrence and also identify potential defects[1-2].

At present, scholars at home and abroad have carried out researches on the transformer state evaluations. Literature [3-4] proposed a transformer state evaluation method based on artificial neural networks and other intelligent algorithms; literature [5] combined cooperative game theory with the cloud model and applied them to the transformer state evaluation. The literature [6] applied the Bayesian network theory to the transformer state evaluation; the literature [7-10] combined two of the matter-element theory, cloud model, extension theory, rough set to evaluate the transformer state. From the above, it can be seen that the current state evaluation of transformers focuses on a single transformer. This kind of algorithm is difficult to give a reasonable overhaul strategy when multiple transformers are at the same evaluation level. The TOPSIS algorithm can reflect the degree of overall similarity between each transformer’s state and their ideal state in a function curve manner, thus ranking the states of multiple transformers. However, this method cannot reflect the relationship bewtween the changes of the internal indicators of the transformer and the ideal transformer state. Therefore this paper will carry out the following research.

Firstly, this paper selects 16 representative indicators from the three aspects of transformer operation index, technical indicators and historical records to build the transformer status evaluation index system; secondly, it uses the grey correlation degree to improve the traditional TOPSIS algorithm and uses the improved algorithm to establish a transformer state evaluation model; Finally,
the state of six transformers is evaluated based on relevant data, and the rationality and validity of the proposed method are verified by examples.

2. Establishment of transformer state evaluation index system

Due to the huge transformer structure and complex components, there are many factors that affect the health state of transformers, and the influence of various factors is different. Only comprehensive consideration of various factors can make a reasonable assessment of the state of transformers [11-13]. Due to the limitation of the current technology level, it is difficult to use all the indicators to evaluate the transformer state. Therefore, this paper selects 16 representative indicators to evaluate the state of the transformer from the three aspects of the operational indicators, technical indicators and historical records. Evaluation index system for transformer state is shown in Fig. 1 [14].

3. Establishment of Transformer state evaluation model

For the transformer state evaluation index system, this paper uses the improved TOPSIS method to evaluate the transformer status. The traditional TOPSIS method is mainly to calculate the distance between the best and worst solutions of multiple schemes, and uses the relative closeness of the ideal solution as the evaluation criterion [15-17]. This method can't reflect the correlation between various schemes and ideal schemes well. Therefore, this paper adopts the grey correlation degree to improve the TOPSIS model, and uses the improved method to evaluate the transformer state. The steps of transformer state evaluation based on the improved TOPSIS method are as follows:

A subsection Some text.

(1) Normalization of index matrix

Assuming that there are m transformers, select n indicators for evaluation (n=17 in Figure 1), ask relevant experts to quantify each indicator according to 0-1 scoring method, and the corresponding indicator value is \( r_{ij} \), and its corresponding indicator matrix is \( R \) for:

\[
R = \begin{bmatrix}
    r_{11} & \cdots & r_{1n} \\
    \vdots & \ddots & \vdots \\
    r_{m1} & \cdots & r_{mn}
\end{bmatrix}
\]  

(1)

Because there is a big difference between the units and orders of magnitude between the evaluation indicators, it is necessary to standardize the indicator matrix and obtain the dimensionless index matrix after normalization. \( X = (x_{ij})_{m \times n} \). The formula of the normalization processing is as follows:
\[ x_{ij} = r_{ij} / \left( \sum_{i=1}^{n} (r_{ij})^{2} \right)^{1/2} \]  \hfill (2)

(2) Determination of index weights
This paper uses entropy weight method to calculate the weight of each index. The entropy of the j-th index \( b_{j} \) is:

\[ b_{j} = -\frac{1}{\ln m} \left( \sum_{i=1}^{n} \left( \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \right) \ln \left( \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \right) \right) \]  \hfill (3)

The entropy weight of the jth indicator is:

\[ v_{j} = \frac{(1 - b_{j})}{\sum_{j=1}^{n} (1 - b_{j})} \]  \hfill (4)

Where \( j = 1, 2, ..., n \)

(3) Determine positive and negative ideal solutions
Multiply the normalized index matrix by the corresponding index weight to form a weighted normalization matrix \( Y \)

\[ Y = (y_{ij})_{mn} = (v_{j}x_{ij})_{mn} \]  \hfill (5)

Determine the maximum and minimum values for each indicator set (that is, the indicators of the same attribute), \( Y_{ij}^{+} \) represents the positive ideal solution and \( Y_{ij}^{-} \) represents the negative ideal solution. Then there are:

\[ Y_{ij}^{+} = \left( \max_{i \in S_{j}} y_{ij} \right) \mid i = 1, 2, ..., m \) \hfill (6)

\[ Y_{ij}^{-} = \left( \min_{i \in S_{j}} y_{ij} \right) \mid i = 1, 2, ..., m \)  \hfill (7)

(4) Calculate the Euclidean distance from the sample to the sample to the positive and negative ideal solutions.
Assuming that the Euclidean distances between the positive and negative ideal solutions of the i-th transformer are respectively \( D_{i}^{+} \) and \( D_{i}^{-} \), we can obtain:

\[ D_{i}^{+} = \sqrt{\sum_{j=1}^{n} v_{j} (y_{ij} - y_{ij}^{+})^{2}} \]  \hfill (8)

\[ D_{i}^{-} = \sqrt{\sum_{j=1}^{n} v_{j} (y_{ij} - y_{ij}^{-})^{2}} \]  \hfill (9)

(5) Calculate the grey correlation degree between the sample and positive and negative ideal solutions
1) The grey correlation coefficient between the i-th transformer and the positive ideal sample with respect to the j-th index is:

\[ s_{ij}^{+} = \frac{\min_{i \in S_{j}} \mid y_{ij}^{+} - y_{ij} \mid + 0.5 \max_{i \in S_{j}} \mid y_{ij}^{+} - y_{ij} \mid}{\max_{j \in S_{i}} \mid y_{ij}^{+} - y_{ij} \mid + 0.5 \max_{j \in S_{i}} \mid y_{ij}^{+} - y_{ij} \mid} \]  \hfill (10)

The grey correlation matrix composed of each sample and positive ideal sample is:

\[ W^{+} = \begin{bmatrix} s_{11}^{+} & s_{12}^{+} & \cdots & s_{1m}^{+} \\ s_{21}^{+} & s_{22}^{+} & \cdots & s_{2m}^{+} \\ \vdots & \vdots & \ddots & \vdots \\ s_{n1}^{+} & s_{n2}^{+} & \cdots & s_{nm}^{+} \end{bmatrix} \]  \hfill (11)

The grey correlation degree between the i-th transformer and the positive ideal sample is:
\[ W_{ij}^+ = \frac{1}{n} \sum_{j=1}^{n} s_{ij}^+ \quad i=1,2,\ldots,m \quad (12) \]

2) The grey correlation coefficient between the i-th transformer and the negative ideal sample with respect to the j-th index is:

\[ s_{ij}^- = \min_i \min_j | y_j^+ - y_j^- | + 0.5 \max_j \max_i | y_j^+ - y_j^- | \quad (13) \]

The grey correlation matrix composed of each sample and the negative ideal sample is:

\[ W^- = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1N} \\ s_{21} & s_{22} & \cdots & s_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ s_{N1} & s_{N2} & \cdots & s_{NN} \end{bmatrix} \quad (14) \]

The grey correlation of the i-th transformer and the negative ideal sample is:

\[ W_{ij}^- = \frac{1}{n} \sum_{j=1}^{n} s_{ij}^- \quad i=1,2,\ldots,m \quad (15) \]

(6) Relative closeness calculation

1) Normalize the Euclidean distance and gray correlation, the formula is as follows:

\[ \varphi_i = \frac{\Phi_i}{\max(\Phi_i)} \quad i=1,2,\ldots,m \quad (16) \]

Wherein \( \Phi_i \) stands for \( D_i^+, D_i^-, W_i^+, W_i^- \), \( \varphi_i \) stands for its normalized value and is denoted by \( d_i^+, d_i^-, w_i^+, w_i^- \).

2) After comprehensively normalizing the Euclidean distance and grey relational degree, the analysis shows that the larger the \( d_i^+, w_i^+ \) value is, the closer the sample is to the ideal value. The larger the \( d_i^-, w_i^- \) value is, the more the sample is far from the ideal value. Combine these two factors, then:

\[ T_i^+ = ed_i^+ + (1-e)w_i^+ \quad (17) \]
\[ T_i^- = ed_i^- + (1-e)w_i^- \quad (18) \]

Wherein \( i=1,2,\ldots,m \), \( e \in (0,1) \), generally \( e \) takes 0.5. \( T_i^+ \), \( T_i^- \) indicates the proximity of each transformer to positive and negative ideal solutions.

3) Calculate relative closeness

The relative closeness indicates the degree of closeness of the evaluated transformer to positive and negative ideal solutions on the change of situation. The specific expression is as follows:

\[ \delta_i = \frac{T_i^-}{T_i^- + T_i^+} \quad i=1,2,\ldots,m \quad (19) \]

Wherein \( \delta_i \) is relative closeness.

(7) Transformer status determination

According to the relative degree of closeness, the state of the evaluated transformer is judged. The larger the value of \( \delta_i \) is, the better the state of the transformer is, representing that the evaluated transformer is closest to the positive ideal solution; conversely, the smaller \( \delta_i \) is, the worse the state of the transformer, representing the evaluated transformer is closest to the negative ideal solution. When \( \delta_i < 0.465 \), the transformer state is worse; when \( 0.465 < \delta_i < 0.675 \), when the transformer state is normal; when \( \delta_i > 0.675 \), then the transformer state is better.
4. Results

This article selects six 500kV transformers in a city and city company for state evaluation, and scores 17 indicators of operation indicators, technical indicators and historical records according to the expert scoring method. The larger the score is, the better the indicator state is, whereas the smaller the score, the worse the indicator state is. The specific scoring results are shown in Tab 1.

The R matrix formed by the above scoring results is normalized, and the index weights are calculated for the normalized matrix X according to equations (3) and (4). The weights of each index calculated are: operating environment 0.084, load condition 0.023, temperature rise Level 0.103, switch operation condition 0.017, overvoltage condition 0.167, dissolved gas in oil 0.042, insulation resistance value 0.034, absorption ratio 0.057, leakage current value 0.093, oil dielectric loss 0.058, oil breakdown voltage 0.078, oil micro-water 0.079, Maintenance records of 0.054, defect cleaning 0.037, years of operation 0.029, family defect 0.033, attachment situation0.012.

The weighted normalization matrix Y obtained by multiplying the normalized index matrix by the corresponding index weights is:

\[
Y = \begin{bmatrix}
0.0378 & 0.0605 & 0.0756 & 0.0546 & 0.0689 & 0.0294 \\
0.0145 & 0.0214 & 0.0150 & 0.0131 & 0.0103 & 0.0214 \\
0.0958 & 0.0855 & 0.0577 & 0.1009 & 0.0917 & 0.0896 \\
0.0129 & 0.0148 & 0.0158 & 0.0099 & 0.0163 & 0.0139 \\
0.0752 & 0.1119 & 0.0802 & 0.1536 & 0.1286 & 0.1319 \\
0.0269 & 0.0378 & 0.0407 & 0.0395 & 0.0344 & 0.0357 \\
0.0218 & 0.0235 & 0.0292 & 0.0313 & 0.0214 & 0.0303 \\
0.0330 & 0.0382 & 0.0467 & 0.0507 & 0.0371 & 0.0450 \\
0.0818 & 0.0856 & 0.0735 & 0.0828 & 0.0642 & 0.0791 \\
0.0232 & 0.0563 & 0.0389 & 0.0406 & 0.0476 & 0.0458 \\
0.0717 & 0.0616 & 0.0538 & 0.0694 & 0.0679 & 0.0726 \\
0.0616 & 0.0545 & 0.0758 & 0.0624 & 0.0672 & 0.0624 \\
0.0421 & 0.0443 & 0.0502 & 0.0308 & 0.0410 & 0.0443 \\
0.0218 & 0.0285 & 0.0296 & 0.0333 & 0.0292 & 0.0326 \\
0.0194 & 0.0226 & 0.0267 & 0.0261 & 0.0232 & 0.0252 \\
0.0178 & 0.0271 & 0.0244 & 0.0271 & 0.0257 & 0.0297 \\
0.0112 & 0.0079 & 0.0102 & 0.0095 & 0.0113 & 0.0096 \\
\end{bmatrix}
\]

Tab 1 Results of evaluation of transformer evaluation index

| Transformer serial number | 1#   | 2#   | 3#   | 4#   | 5#   | 6#   |
|---------------------------|------|------|------|------|------|------|
| Operating environment     | 0.45 | 0.72 | 0.90 | 0.65 | 0.82 | 0.35 |
| Load conditions           | 0.63 | 0.93 | 0.65 | 0.57 | 0.45 | 0.93 |
| Temperature rise          | 0.93 | 0.83 | 0.56 | 0.98 | 0.89 | 0.87 |
| Switch operation          | 0.76 | 0.87 | 0.93 | 0.54 | 0.96 | 0.82 |
| Overvoltage condition     | 0.45 | 0.67 | 0.48 | 0.92 | 0.77 | 0.79 |
| Dissolved gas in oil      | 0.64 | 0.90 | 0.97 | 0.94 | 0.82 | 0.85 |
| Insulation resistance     | 0.64 | 0.69 | 0.86 | 0.92 | 0.63 | 0.89 |
| Absorption ratio          | 0.93 | 0.67 | 0.82 | 0.89 | 0.65 | 0.79 |
| Leakage current value     | 0.88 | 0.92 | 0.79 | 0.89 | 0.69 | 0.85 |
| Oil loss                  | 0.40 | 0.97 | 0.67 | 0.70 | 0.82 | 0.79 |
| Oil breakdown voltage     | 0.92 | 0.79 | 0.69 | 0.89 | 0.87 | 0.93 |
| Oil in water              | 0.78 | 0.69 | 0.96 | 0.79 | 0.85 | 0.79 |
| Maintenance record        | 0.78 | 0.82 | 0.93 | 0.57 | 0.76 | 0.82 |
| Defect cleaning           | 0.59 | 0.77 | 0.80 | 0.90 | 0.79 | 0.88 |
| Years of operation        | 0.67 | 0.78 | 0.92 | 0.90 | 0.80 | 0.87 |
| Family defect             | 0.54 | 0.82 | 0.74 | 0.82 | 0.78 | 0.90 |
From the weighted normalization matrix \( Y \), it can be inferred that the positive and negative ideal solutions corresponding to each index are 

\[
Y^+ = (0.0756, 0.0214, 0.1009, 0.0163, 0.1119, 0.0707, 0.0313, 0.0530, 0.0856, 0.0563, 0.0717, 0.0758, 0.0502, 0.0326, 0.0267, 0.0297, 0.0113),
\]

\[
Y^- = (0.0294, 0.0103, 0.0577, 0.0092, 0.0752, 0.0269, 0.0214, 0.0371, 0.0642, 0.0232, 0.0538, 0.0545, 0.0308, 0.0218, 0.0194, 0.0178, 0.007),
\]

respectively.

Substituting the positive and negative ideal solutions into the above formula to calculate the Euclidean distance and gray correlation degree, the calculation results are shown in Table 2.

The Euclidean distances and gray correlations of the obtained transformers are normalized by using formula (16). The normalized results are shown in Table 3. Next, formula (17) and (18), where \( e \) takes 0.5, are used to calculate the closeness degree of each transformer and positive and negative ideal solutions, and the calculation results are shown in Table 3. Finally, the relative closeness of each transformer is calculated according to formula (19). The state of the transformer is determined by closeness, and then is sorted. The calculation results are shown in Table 4.

### Table 2 Euclidean Distance and Grey Correlation Degree Calculation Results

| Transformer | Positive ideal solution Euclidean distance | Negative ideal solution Euclidean distance | Positive ideal solution grey relational degree | Negative ideal solution grey relational degree |
|-------------|---------------------------------------------|---------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| 1#          | 0.0816                                      | 0.0443                                      | 0.7312                                          | 0.6703                                        |
| 2#          | 0.0326                                      | 0.0297                                      | 0.5811                                          | 0.8831                                        |
| 3#          | 0.0607                                      | 0.0465                                      | 0.7071                                          | 0.5409                                        |
| 4#          | 0.0476                                      | 0.0382                                      | 0.4336                                          | 0.6203                                        |
| 5#          | 0.0703                                      | 0.0609                                      | 0.5165                                          | 0.7123                                        |
| 6#          | 0.0653                                      | 0.0473                                      | 0.8203                                          | 0.6504                                        |

### Table 3 Results of the approximate degree of positive and negative ideal solution

| Transformer | Positive ideal solution proximity | Negative ideal solution proximity |
|-------------|-----------------------------------|-----------------------------------|
| 1#          | 0.8443                            | 0.6885                            |
| 2#          | 0.7876                            | 0.8928                            |
| 3#          | 0.5637                            | 0.8994                            |
| 4#          | 0.9476                            | 0.4336                            |
| 5#          | 0.8730                            | 0.7635                            |
| 6#          | 0.5633                            | 0.9437                            |

### Table 4 Calculation results of close degree of transformer

| Transformer | 1# | 2# | 3# | 4# | 5# | 6# |
|-------------|----|----|----|----|----|----|
| Closeness   | 0.5508 | 0.4687 | 0.3853 | 0.6861 | 0.5335 | 0.3738 |

### 5. Conclusion

This paper uses the grey correlation degree to improve the traditional TOPSIS method, and uses the improved algorithm to carry out state evaluation for multiple transformers. Relevant to the existing assessment methods, this method can evaluate and rank multiple transformers as a whole, and it can also reflect the difference between the changing trend of various factors inside each transformer and the ideal solution. Therefore, it is a comparatively effective evaluation method.

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