Research on Comprehensive Evaluation Method of Transformer Noise Based on AHP Matter Element Model

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Abstract. Aiming at the problem of transformer condition evaluation, a comprehensive evaluation system for transformer noise is constructed according to the mechanism of transformer noise generation and propagation. Using matter-element theory and AHP, a state analysis method for transformer noise evaluation based on AHP matter-element model is proposed. The case analysis proves that the method is feasible for non-contact evaluation of transformer faults, and can accurately evaluate the state of the transformer, providing guidance for the operation and maintenance of the transformer.

1. Introduction
The transformer is an important equipment in the power system, which serves as an important function of voltage conversion, transmission and distribution in the power system. The safe and reliable operation of the transformer is related to the reliability of the entire system. The use of large-capacity transformers makes transformer noise more and more complicated.

Cao Zhen et al. used matter-element theory to establish a multi-information evaluation index system to effectively evaluate the winding looseness and severe deformation of the winding deformation fault types: radial tension and compression, axial insulation shedding and end overlap. The correct rate of diagnosis by this method is ≥92% [1]. Yu Hongbo et al. proposed a comprehensive state assessment method for power transformers based on asymmetric closeness cloud matter-element model, which effectively avoided the problem of deviations in the evaluation results caused by different reliability values and inconsistent with the actual situation [2]. Zhang Mengyao et al. proposed a method for evaluating transformer insulation status based on grey matter element analysis. On the basis of mining the relevance of multiple index data, the data is normalized from a qualitative and quantitative perspective. The transformer insulation state is evaluated by variable weights for weighting to comprehensively[3]. Yu Changting and others analyzed the noise and vibration mechanism of transformer core and winding. A vibration and noise measurement system is established to analyze the location of the noise source and the characteristic value test of the vibration signal to determine the fault point of the transformer [4]. Wang Y[5], Dong J[6] and others constructed a cloud matter-element model of a transformer to detect online status. This paper proposes a comprehensive evaluation method of transformer noise signal based on matter-element theory, aiming at using transformer noise to diagnose faults.
2. The source and propagation of transformer vibration and noise

The noise of the transformer is caused by the vibration of the structural parts of the transformer. According to the vibration position, it can be divided into winding vibration noise, iron core vibration noise, and cooling system operation noise.

The core vibration of the transformer is mainly caused by magnetostriction. The vibration and noise is caused by the electromagnetic attraction between the joints of the silicon steel sheets and the laminations. The winding vibration is mainly caused by the leakage flux generated by the load current. The vibration and noise of the transformer are transmitted from the vibration sound source to the transformer tank through multiple paths, and finally the body noise is expressed through the vibration of the tank; The noise of the cooling system is caused by the commissioning of cooling equipment such as transformer cooling fans and oil pumps. The vibration of the transformer body and the vibration noise of the cooling system propagate outward through three ways of solid, liquid and air, and superimpose on the noise of the transformer, as shown in Figure 1.

$$\text{Rao Group Vibration} \xrightarrow{\text{Solid path}} \text{Insulating oil} \xrightarrow{\text{Gas path}} \text{Fuel tank} \xrightarrow{\text{Liquid path}} \text{Cooling device} \xrightarrow{\text{Vibration of transformer components}} \text{Transformer noise}$$

Figure 1. Transmission path of transformer vibration and noise.

3. Matter-element model

A matter-element model for comprehensive evaluation is constructed according to the matter-element theory, in which an ordered triple composed of a given thing’s name $N$, a characteristic $C$, and the value of the characteristic $C$ is used as the description of things $R=(N,C,V)$. Basic matter-element. The abbreviated matter element is shown in formula 1. Among them, $V$ is determined by $N$ and $C$, denoted as $V=C(N)$.

$$R = \begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{bmatrix}$$

(1)

The classic matter-element model can be represented by the data range of the corresponding features in the criterion layer, which is expressed as formula (2). In formula (2), $N_j$ is the target layer of the $j$-th level. $<a_1, b_1>$ shows the value range of $C_1$ under the $j$-th level acoustic signal. The node-domain matter element of the evaluation is the whole range of the value of a certain feature, expressed in the form of formula (3). In the formula (3), $N$ represents the total level of the evaluation index; $<c_1, d_1>$ represents the total range of all the evaluation levels of $C_1$. A group of data to be evaluated is expressed as the matter to be evaluated in the form of matter as formula (4). In formula (4), $N_0$ represents a group of acoustic signal data to be evaluated; $x_i$ is the measured $C_i$ value.

$$R_j = \begin{bmatrix} N_j \ C_1 < a_1, b_1 > \\ \ C_2 < a_2, b_2 > \\ \vdots \\ \ C_n < a_n, b_n > \end{bmatrix}$$

(2)
After determining the classical domain matter-element, node-domain matter-element, and the matter-evaluation for the comprehensive evaluation of transformer noise signal, the correlation function is used to quantify the relationship between the evaluation matter-element, the classical domain matter-element, and the node-domain matter-element. When the conditions $X_0=\langle a, b \rangle$ and $X=\langle c, d \rangle$, and the optimal value $X_0$ is not the midpoint of the interval $X_0=\langle a, b \rangle$, the correlation function is equation (5)

$$k(x) = \begin{cases} \frac{\rho(x, X)}{\rho(x, X) - \rho(x, X_0)}, & \rho(x, X) - \rho(x, X_0) \neq 0 \\ -\rho(x, X_0) - 1, & \rho(x, X) - \rho(x, X_0) = 0 \end{cases}$$

$$\rho(x, X_0) = \left| x - \frac{a + b}{2} \right| - \frac{b - a}{2}$$

$$\rho(x, X) = \left| x - \frac{c + d}{2} \right| - \frac{d - c}{2}$$

The $n$ indicators of transformer noise is divided into $m$ levels. After applying matter-element theory and correlation function to calculate, an $n \times m$-order correlation value matrix $K$ will be formed, which represents the degree of correlation between the value to be evaluated and each index level.

$$K = \begin{bmatrix} k_{11} & \cdots & k_{1m} \\ \vdots & \ddots & \vdots \\ k_{n1} & \cdots & k_{nm} \end{bmatrix}$$

After getting the correlation function matrix $K$, if you want to get the final evaluation result, you need to determine the weight of each evaluation index. AHP is a more commonly weighting method, in which each element of the layer and the element of the next layer dominated by the element constitute a sub-region. The expert consultation method is used to construct several judgment matrices for each element in the sub-region. Finally, through normalization processing, the final grade is determined.

$$P = \sum_{i=1}^{n} p_i k_{ij}$$

4. Comprehensive evaluation index system construction

The noise generated during the operation of the transformer is not determined by its own body condition, but also by the electrical state of its operation. From the perspective of transformer maintenance history, electrical indicators, and acoustic information, the following comprehensive evaluation indicators for transformer noise are constructed. Among them, the first layer is the target layer, and the second layer is the criterion layer, which mainly includes four aspects: maintenance indicators, operating electrical indicators, noise signal indicators, and transformer factors. The factor layer is composed of 11 indicators. Refer to Table 1 below for details. Each index in the table is rated, which are good, normal, warning, abnormal, and dangerous. The limits of each index are shown in Table 2.
Table 1. Comprehensive Evaluation Index System of Transformer Operation Noise.

| First level indicator | Secondary indicators | Lower limit | Index ceiling |
|-----------------------|----------------------|-------------|--------------|
| Maintenance indicators | Historical overhaul B₁ | Min | Max |
| A₁                    | Similar overhaul B₂ | Min | Max |
| Operating electrical indicators A₂ | Continuous running time B₃ | 0 | 20 |
|                       | Operating current B₄ | 0 | 1 |
|                       | Maximum signal amplitude B₅ | 0 | 2 |
| Noise signal indicators | Number of crests B₆ | 0 | 50 |
| A₃                    | Primary octave sound pressure B₇ | 0.02 | 2 |
|                       | Sub-octave sound pressure B₈ | 0.02 | 2 |
|                       | Cooling device status B₉ | 0 | 1 |
| Transformer factors A₄ | Measuring point height B₁₀ | 0 | 1 |
|                       | Measuring point distance B₁₁ | 0 | 2 |

Table 2. Index range and strategy for transformer noise evaluation.

| Ranges          | status description | Maintenance strategy       |
|-----------------|--------------------|----------------------------|
| (0, 0.2]        | good               | Deferred maintenance       |
| (0.2, 0.4]      | normal             | Planned overhaul           |
| (0.4, 0.6]      | warning            | Prioritize maintenance     |
| (0.6, 0.8]      | abnormal           | Overhaul as soon as possible |
| (0.8, 1.0]      | dangerous          | Repair now                 |

5. Case Analysis

The paper takes the noise test signal of a 100kV transformer as the analysis object, as shown in Figure 2. The basic situation of the transformer is shown in Table 3.

Table 3. Basic status of transformer.

| Project indicators | B₁ | B₂ | B₃ | B₄ | B₉ | B₁₀ | B₁₁ |
|--------------------|----|----|----|----|----|-----|-----|
| Times/Set | mm | m |
| T₁ | 0  | 0.62 | 3 | 46.50 | switch on | 2445 | 1 |

Figure 2. Transformer noise test signal.

It can be found from Figure 2 that the amplitude of the transformer is 173.63 respectively; the number of peaks is 5 respectively. Through the analysis of the collected signal, the main multiplier is mainly concentrated at 100Hz; the secondary multiplier is concentrated at 200Hz. The sound pressure of the transformer at 100 Hz is 0.183 and the sound pressure at 200 Hz is 0.118. Using the AHP matter-element model to obtain the weights and the matter-element evaluation results are shown in Table 4.
Table 4. The process and results of AHP matter-element model evaluation.

| A₁ Weights | A₂ Weights | A₃ Weights | A₄ Weights | Comprehensive index | state   |
|------------|------------|------------|------------|---------------------|--------|
| 0.2023     | 0.2507     | 0.4637     | 0.0833     | 0.0179              | Good   |

6. Conclusion
A comprehensive evaluation model of transformer noise based on AHP and matter-element theory is established. From the operating state and noise of the transformer, the state of the transformer is comprehensively evaluated. The entire evaluation and analysis process is based on an objective perspective, reducing the influence of human subjective factors. It has a good degree of distinction, and provides a reasonable decision-making basis for the condition maintenance of the transformer.

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