Big Data Lean Evaluation of Transformer Operating Information

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Abstract: Current status information of transformer is various and irregular. The difficult problem is how to reasonably analyze, process and comprehensive use the information. This paper, according to characteristics, repair strategies and management experience of transformers, extracts, integrates, optimizes and normalizes current status evaluation standards, and establishes a set of status accurate evaluation model based on transformer operating information with big data analysis and mining algorithm to get accurate portrayal of transform, so as to find out potential defects in time, and improve transformer control efficiency, operating stability and reliability. The operation in certain city shows the model could greatly reduce workload of status evaluation and save large amount of labor and equipment costs.

1. Introduction
Transformer type equipment plays an important role in power transmission and transformation system. With development of transformer status monitoring technology, varieties of information representing transformer status are increased with different levels. How to analyze, process and comprehensively use large amount of status information of transformer to accurately evaluate transformer status is the difficult problem at present. For aforesaid problem, this paper comprehensively summarizes transformation equipment operation and repair management experience of the Company system for years according to transformer equipment characteristics and original overhaul strategies, extracts, integrates, optimizes and normalizes current status evaluation standards, and establishes a set of status accurate evaluation model based on transformer operating information with big data analysis and mining algorithm to display transformer operating status visually and vividly, and improve transformer operating stability and reliability[1].

2. Design and process of this study

2.1 Transformer big data source
With development of information technology, transformer status data size is larger[2]. In accordance with transformer equipment status overhaul guideline released by State Grid, this paper deeply analyzed status evaluation strategies of such equipment, comprehensively summarized power transformation equipment operation and repair management experience of the Company system for years, and acquired main transformer ledger, supervision report, factory test report, handover test report, installation acceptance record, and drawings about extension projects; daily inspection, maintenance, operating record, defect record and defect elimination record; routine test report, online
monitoring data and poor operating condition data.

2.2 Data merger and processing stage

After data is acquired, since original data has problems of missing value, abnormal value and duplicate record, it is necessary to clean data and handle data problems such as abnormal value and missing value, describe data distribution, build and extract characteristics, form data wide table of analysis data through database operation, and design big data mining and analysis plan and visualized scenario contents, including technical route and model selection[3]. Data processing can be seen in Figure 1.

In accordance with specific data type of equipment failure influential factors, this paper selected suitable correlation analysis method, removed characteristic variables not strongly correlated with failure or without redundancy, and picked the optimal failure characteristic variables set as input variables of equipment failure prediction model[4]. For quantitative factors such as temperature, commissioning year, load rate and oil temperature, correlational analysis method is adopted to confirm correlation degree between indexes and sort factors according to size of relevant coefficient. Irrelevant indexes are removed. Then in combination with business understanding, parameters with significant correlation of equipment status evaluated are selected and calculated, including operating life, interval from previous overhaul and load-capacity ratio. The equation is as follows: Operating life = current time – equipment commissioning life; days of interval from previous overhaul = current time – time of previous overhaul; load-capacity ratio = (load/capacity) *100%.

2.3 Data discretization

Apply discretization to partial parameters including pollution grade, strategies of previous overhaul and voltage grade. Only pollution grade discretization is described hereby. See Table 1.

| Pollution grade | Discretization processing | Voltage class | Voltage class discretization |
|-----------------|---------------------------|---------------|-----------------------------|
| a               | 01                        | 220kV         | 01                          |
| b               | 02                        | 110kV         | 02                          |
| c               | 03                        | 35kV          | 03                          |
| d               | 04                        |               |                             |
| e               | 05                        |               |                             |

2.4 Index standardization

Apply standardization processing to continuous variables, such as transformer oil temperature, ambient temperature and load-capacity ratio according to Z-score standardization method[5] [6]. The formulas are respectively as follows:

\[ X' = (x - \mu) / \delta \]  

(1)
2.5 Sample data
The sample data of transformer comprehensive evaluation is acquired through pretreatment of transformer ledger information, operating information, overhaul information and equipment test data. The sample data can be seen in table 2 (only 7 columns of data are offered due to length limit).

2.6 Status evaluation rules refining
In accordance with equipment test data, and refined status evaluation rules, this paper carried out equipment status refining scoring as per proportion of all parts and deduction criteria.

### Table 2. Data sheet of partial samples

| Equipment Name | Voltage Class | Commissioning Life | Strategy of previous overhaul | Capacity | Load-capacity ratio | Load-capacity ratio standardization | Maximum load | Maximum load standardization | Transformer oil temperature | Transformer oil temperature standardization | Ambient oil temperature difference | Ambient oil temperature difference standardization | Decision-making target |
|----------------|---------------|-------------------|-----------------------------|----------|---------------------|-------------------------------------|--------------|----------------------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------------------------|----------------------|
| xx #1 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.20 | 0.0185 | 1.95 | 0.0174 | 20.22 | 0.1204 | 0.78 | 0.0050 | 21 |
| xx #2 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.18 | 0.0168 | 1.77 | 0.0158 | 21.28 | 0.1267 | 0.72 | 0.0046 | 22 |
| xx #3 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.25 | 0.0236 | 2.49 | 0.0222 | 39.5 | 0.2353 | 7.5 | 0.0482 | 32 |
| xx #4 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.40 | 0.0374 | 3.95 | 0.0352 | 34.87 | 0.2077 | 3.87 | 0.0249 | 31 |
| xx #5 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.30 | 0.0284 | 3 | 0.0267 | 36.61 | 0.2180 | 12.61 | 0.0810 | 24 |
| xx #6 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.53 | 0.0504 | 5.32 | 0.0474 | 46 | 0.2740 | 25 | 0.1606 | 21 |
| xx #7 Main transformer | AC 35kV | 2012.09 | CLA SS C | 10 | 0.65 | 0.0611 | 6.45 | 0.0575 | 40.86 | 0.2434 | 5.86 | 0.0376 | 35 |

3. Algorithm of this paper
The core idea of AHP is to build a distinct hierarchical structure based on experience to break down complex problems; meanwhile it introduces measurement theory, scalarizes logical judgment of people with relatively quantitative value by comparing evaluation conditions, establishes corresponding judgment matrix layer by layer, solves weight of judgment matrix and lastly calculates comprehensive weight of evaluation. AHP aims to layer all problems to be analyzed; break problems down to different component elements according to nature of problems and overall objective, and agglomerate and combine factors by different layers in accordance with correlative influence and membership function of those factors to form a multi-layer analytical structure model[7]; lastly, the paper compared those problems for pros and cons and put to order. The basic steps are as follows:

1. Establish hierarchical structure model, as shown in Figure 2.

![Figure 2. Hierarchical structure model](image-url)
2. Build judgment matrix $A$. Improved AHP adopts index scale $e^{0/5} \sim e^{8/5}$[8]. $a_{ij}$, $a_{ji}$ (i, j=1, 2, ..., n) mean factors. $a_{ij}$ is the relative importance value of $a_i$ for $a_j$.

The scale $a_{ij}$ shall be $e^{0/5}$, $e^{1/5}$, $e^{2/5}$, $e^{3/5}$, $e^{4/5}$, $e^{5/5}$, $e^{6/5}$, $e^{7/5}$ and $e^{8/5}$, respectively showing relative importance of two indexes. Compared to $a_{ij}$ and $a_{ji}$, the importance degrees are extremely important, more intensely important, intensely important, more important, obviously important, more important, slightly important, finely important, and equally important; moreover, $a_{ji}=1/a_{ij}$ is tenable for any judgment matrix[9].

(3) Calculation and sorting of importance: get corresponding eigenvector $\omega$ for maximum eigenvalue $\lambda_{max}$ according to judgment matrix $A$. The equation is set below:

$$\lambda_{max} A\omega = \omega$$

Normalization process is carried out to the eigenvector $\omega$ acquired, i.e., to rank importance of each evaluation factor, or allocate weight.

(4) Carry out consistency check. To know whether weight allocation is correct, it is necessary to carry out consistency check to judgment matrix[9]. The equation is as follows:

$$CR = CI / RI$$

In the formula, $CR$ is the random consistency ratio of judgment matrix; $CI$ is common consistency ratio, as shown in Equation (4).

$$CI = (\lambda_{max} - n) / (n - 1)$$

$RI$ is the average random consistency ratio of the judgment matrix, and the $RI$ value of Order 1~9 of judgment matrix can be seen in Table 3.

| $n$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----|---|---|---|---|---|---|---|---|---|
| $RI$ | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

When $A$’s $CR<0.1$ or $\lambda_{max}=n$, $CI=0$, $A$ has satisfying consistency; otherwise, it is necessary to adjust elements of $A$ to make it possess satisfying consistency.

4. Test results

4.1 Evaluation results

For status accuracy evaluation model of transformer, this paper further divided threshold value for scoring results and understanding of all transformers, and rated equipment status[10][11]. The threshold value shall be scored as follows:

| Comprehensive score scope | Equipment status rating |
|---------------------------|-------------------------|
| Score > 80 Points         | Normal                  |
| 60 ≤ Score ≤ 80 Points    | Cautious                |
| 20 ≤ Score < 60 Points    | Abnormal                |
| Score < 20 Points         | Serious                 |
4.2 Evaluation results of Table 2 data sheet of samples

AHP evaluation parameters contain ten indexes including operating life, capacity, load-capacity ratio, maximum load, voltage class, transformer oil temperature, overhaul strategy, ambient oil temperature difference, ambient temperature, pollution grade, and hidden defects. The evaluation results of sample data table 2 can be seen in Table 5:

| Equipment name      | Status evaluation scoring | Status evaluation scoring standardization | AHP comprehensive evaluation | Equipment status rating |
|---------------------|---------------------------|------------------------------------------|------------------------------|-------------------------|
| XX#1 Main transformer | 88.8                      | 0.5385                                   | 81.52                        | Normal                  |
| XX#2 Main transformer | 88.8                      | 0.5385                                   | 81.15                        | Normal                  |
| XX#3 Main transformer | 88.8                      | 0.5385                                   | 65.61                        | Cautious                |
| XX#4 Main transformer | 88.8                      | 0.5385                                   | 65.96                        | Cautious                |
| XX#5 Main transformer | 88.8                      | 0.5385                                   | 68.28                        | Cautious                |
| XX#6 Main transformer | 88.8                      | 0.5385                                   | 67.30                        | Cautious                |
| XX#7 Main transformer | 87                        | 0.3077                                   | 59.10                        | Abnormal                |

5. Case analysis

At 9:22, March 16, 2019, after the end of tour inspection on 1# main transformation in the 35kV XXX Substation, the model hinted main transformer is under abnormal status. Further inspection showed H2 content is 629.88ul/l, C2H2 content is 269.67ul/l and total hydrocarbon content is 489.22ul/l, which all exceed standard scope seriously and failed to meet actual operating requirements. Type B repair was arranged urgently. Through inspection by hoisting the cover, the screw on tap switch was found loosed, resulting to short distance between lead and screw. The lead was burnt due to discharge. After repair and test, the main transformer was put into operation.

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