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Risk assessment research for power transformer based on fuzzy synthetic evaluation

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ABSTRACT

Risk assessment for power transformer is an important means to guide the condition based maintenance of transformer and enhance the reliability of power system operation, but also to strengthen the power transformer to provide an important basis for quality control. In this paper, an index system for comprehensive evaluation of transformer is put forward and a risk assessment model for power transformer based on fuzzy synthetic evaluation is built, which based on the quality problems of large power transformer statistics of State Grid Corporation of China(SGCC) in 2012 and combined with multilayer and multi-factor features of the transformer life cycle management process. The assessment example analysis shows that the method can effectively estimate the risk of each stage for the life cycle management of power transformer and provide feasible decision basis for the risk management and maintenance decision of transformer.

Key words: power transformer; risk assessment; life cycle management; fuzzy synthetic evaluation

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INTRODUCTION

Power transformer is one of the key equipment in the power system. Its quality is directly related to the continuous and stable operation of the power system. It is necessary to carry on the risk assessment of power transformer, identify the possible risks and the impact of these risks, and take appropriate safety measures to effectively reduce or avoid these risks[1-2].

The traditional risk assessment of power transformer is primarily based on fault diagnosis, influence analysis and fault prediction of the operation condition. The methods include traditional oil analysis[3],fuzzy decision analysis[2], artificial neural network[4], wavelet analysis[5], fuzzy reasoning[6], grey clustering[7],small-world network[8], information fusion[9], probability reasoning[10], decision tree[11], petri nets[12-13]. But all those method did not consider the manufacture level and hidden defects. The manufacturing supervision can find the hidden defects immediately, and the information can be used to risk assessment. The synthetic evaluation index system with multiply factors of power transformer is established, which is based on the life cycle quality information including manufacturing, installation, commissioning and operation status. The fuzzy synthetic evaluation method is adopted. The multilayer fuzzy synthetic evaluation model is built with life cycle quality information of power transformer.

II. RISK ASSESSMENT INDEX SYSTEM OF POWER TRANSFORMER

A. Fault analysis of power transformer

Quality defect analysis is an important link to fault diagnosis and maintenance strategy determination of power transformer[14-15]. According to the power transformer data statistical and analysis of SGCC in 2012, the quality defects during manufacturing stage are 688 cases, proportion of 84%. The detail information is show in Fig.1.

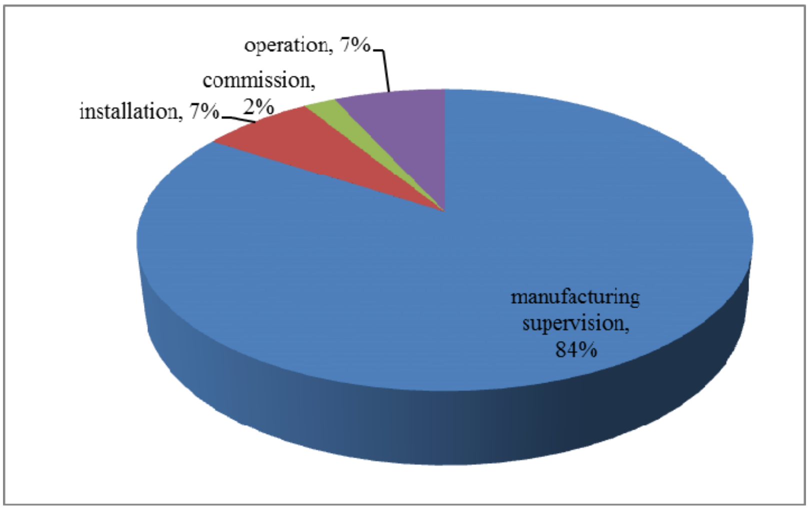

Fig.1 The problem distribution of the stages of transformer

Considering the various factors affecting power transformer quality, the causality is classified as show in table I. It is shown that the manufacturing process control and material or set of parts problems are the main causes of power transformer faults and defects.

TABLE I. STATISTICS OF TRANSFORMER QUALITY DEFECT RISK TYPE

Cause type	Proportion	Sub cause type
Manufacturing process control	43%	Final assembly
		Oil tank manufacturing
		Insulation assembly
		Core manufacturing
		Active part assembly
		Winding manufacturing
Materials and component (assembly) parts	25%	Quality defects
		Disconformity with agreement
Packing and transportation	9%	Inadequate protection
		Transportation management
Designing and structure	7%	Ill-conceived design
		Not designed according to the requirements
Routine test	5%	Routine test management
		Not test according to the requirements
Storage	1%	Improper storage
Others	10%	Mismanagement

B. Risk assessment indices of power transformer

The risk assessment of power transformer is based on the life cycle quality information, which includes the manufacturing, installation, commission and operation status.

The risk assessment index of power transformer is a three-layer hierarchy system. The second layer includes the manufacturing index X_1, installation index X_2, commission index X_3, and operation index X_4. The third layer includes 7 indices, which are manufacturing process control, material and component (assembly) parts, packing and transportation, design and structure, routine test, storage and others. The hierarchical indices system of risk assessment for power transformer is shown in figure 2.

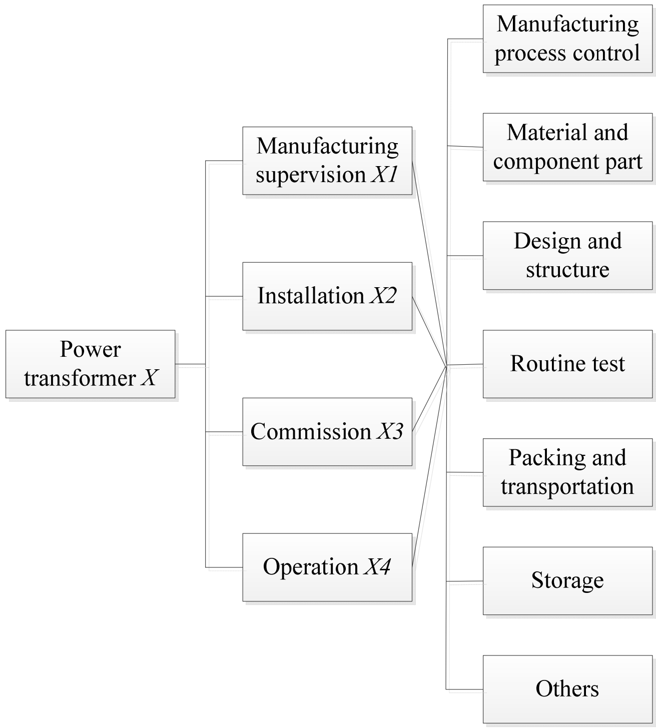

Fig. 2 Hierarchical indices system of risk assessment for power transformer

III. MULTILAYER FUZZY SYNTHETIC EVALUATION OF POWER TRANSFORMER

The fuzzy synthetic evaluation is adopted to risk assessment for power transformer. It is based on the life cycle quality information, which can reflect the comprehensive real operation status in different aspects.

The fuzzy synthetic evaluation method is used to evaluate the system with fuzziness, which is based on the fuzzy mathematics principle. It is a kind of combination with qualitative and quantitative, accurate and precise method of analysis and evaluation. At first, the method evaluates the single factor, and then fuzzy deduction with the predetermined rule set, finally, explaining the evaluation results by the certain principle. It can obtain a subjective risk assessment index system based on the parameters and status of power transformer.

A. Single level fuzzy synthetic evaluation

1)Establishment of factor set

The status related factors of power transformer were established, where the state parameters are as the evaluation factor. The evaluation system is consist of target layer, criterion layer, index layer, as shown in figure 2.

$X=(X_1, X_2, X_3, X_4)$

2)Establishment of evaluation set

The state of power transformer can be devided into 4 type, as good, general, attention, serious.

V={good, general, attention, serious}=$\{v_1, v_2, v_3, v_4\}$[17]。

Establishment of fuzzy evaluation matrix

Assume $u_i(i=1,2,...,m)$ is the one of the index set for the evaluation of power transformer. The membership degree for the state v_i of evaluation set is $r_{ij}(j=1,2,3,4)$, then the membership degree set $R_i=\{r_{i1},r_{i2},r_{i3},r_{i4}\}$ means the evaluation result of u_i. All the indices of the subitem make up the fuzzy evaluation matrix R.

$$R=\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & r_{m3} & r_{m4} \end{bmatrix}$$

3)Establishment of weighting set
The importance degree of the factor should be given during the synthetic evaluation, which is namely the relative weight between the indices and layers. The importance degree fuzzy set of power transformer's risk factor is given in the factor set domain as $A=(a_1,a_2,...,a_m)$, where a_i means the quantitation of influence degree for factor u_i in the synthetic evaluation.

The importance degree fuzzy set A of power transformer's risk factor and the fuzzy evaluation matrix R are both known. The linear transformation is done to the R, where the A transfers to the fuzzy subset of the evaluation set V of power transformer.

$$B = A \circ R = (b_1, b_2, \cdots, b_n)$$

B means the synthetic evaluation set of power transformer risk of matrix V. b_j means the membership of fuzzy synthetic evaluation set B.

4)Fuzzy synthetic evaluation for power transformer risk
By means of the maximum membership degree principle, the maximum b_j of B used as the synthetic evaluation result for the corresponding level v_j.

B. Multi-level fuzzy synthetic evaluation
If the evaluation indices have a multiple layers, the evaluation should be taken multiple times by means of the single level method. The method begins at lowest level, and evaluates from bottom to top. The single level sub-target evaluation result should be obtained at first, then the evaluation set B_{ij} of the same layer make up the new fuzzy matrix R_i.

$$R_i = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_l \end{bmatrix}$$

Subscript l means the quantity of sub-target for the same layer in the formula.

If the weights of the sub-target as

$$A_i = (A_{i1}, A_{i2}, \cdots, A_{il})$$

Then the synthetic evaluation to the above layer as

$$B_{i-1} = A_i \circ R_i = (b_{i-1,1}, b_{i-1,2}, \cdots, b_{i-1,n})$$

Where, i-1 means the above layer of i.

The method is used from the bottom layer to the top layer, and finally the synthetic evaluation for the target is obtained.

$$B_i = (b_{i,1}, b_{i,2}, \cdots, b_{i,n})$$

By means of the maximum membership principle, $\max(b_{i,1},b_{i,2}, ...,b_{i,n})$ is the final evaluation result to the corresponding layer.

IV. EXAMPLE ANALYSIS
An 110kV power transformer is used in the example. Risk assessment of the power transformer is taken, which is based on the life cycle quality information, including the manufacturing, installation, commission, operation status.

Though the statistic of the defects and faults information by means of manufacturing supervision, the quality problem were classified to 7 aspects, which includes the manufacturing process control, material and component (assembly) set, packing and transportation, design and structure, routine test, storage and others. The fuzzy synthetic evaluation matrix of R_1 manufacturing supervision is obtained.

$$R_1 = \begin{bmatrix} 0.2 & 0.47 & 0.23 & 0.1 \\ 0.91 & 0.04 & 0.04 & 0.01 \\ 1 & 0 & 0 & 0 \\ 0.97 & 0.01 & 0.01 & 0.01 \\ 0.93 & 0 & 0.02 & 0.05 \\ 1 & 0 & 0 & 0 \\ 0.97 & 0 & 0.02 & 0.01 \end{bmatrix}$$

By experts evaluation, the weight A_1 for the layer as:

$$A_1 = (0.72, 0.1, 0.01, 0.07, 0.05, 0.01, 0.07)$$

Combination the weight and evaluation matrix, the synthetic evaluation result B_1 as:

$$B_1 = A_1 \circ R_1 = (0.2, 0.47, 0.23, 0.1)$$

By means of the maximum membership degree principle, the manufacturing supervision risk is general.
In the same way, the installation evaluation as:

$$A_2 = (0.44, 0.29, 0.05, 0.1, 0.03, 0, 0.09)$$

$$R_2 = \begin{bmatrix} 0.97 & 0 & 0.01 & 0.02 \\ 0.99 & 0 & 0.01 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

$$B_2 = A_2 \circ R_2 = (0.44, 0, 0.01, 0.02)$$

By means of the maximum membership degree principle, the installation risk is good.

The commission evaluation as:

$$A_3 = (0.44, 0.29, 0.05, 0.1, 0.03, 0, 0.09)$$

$$R_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

$$B_3 = A_3 \circ R_3 = (0.44, 0, 0, 0)$$

By means of the maximum membership degree principle, the commission risk is good.

The operation evaluation as:

$$A_4 = (0.44, 0.29, 0.05, 0.1, 0.03, 0, 0.09)$$

$$R_4 = \begin{bmatrix} 0.99 & 0 & 0.01 & 0 \\ 0.99 & 0 & 0.01 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

$$B_4 = A_4 \circ R_4 = (0.44, 0, 0.01, 0)$$

By means of the maximum membership degree principle, the operation risk is good.

The second level fuzzy synthetic evaluation is taken based on the above results. Combining the manufacturing supervision, installation, commission and operation factors, the new fuzzy matrix R is obtained.

$$R = \begin{bmatrix} 0.2 & 0.47 & 0.23 & 0.1 \\ 0.44 & 0 & 0.01 & 0.02 \\ 0.44 & 0 & 0 & 0 \\ 0.44 & 0 & 0.01 & 0 \end{bmatrix}$$

The weight set A=(0.84, 0.07, 0.02, 0.07), then the fuzzy synthetic evaluation B for power transformer risk as:

$$B = A \circ R = (0.2, 0.47, 0.23, 0.1)$$

By means of the maximum membership degree principle, the life cycle quality risk is general.

CONCLUSION

The risk assessment indices system of power transformer is established based on the fuzzy synthetic evaluation method, which mainly includes the manufacturing supervision index, installation index, commission index and operation index. It provides the basis to risk assessment of power transformer. Based on the indices system, the multi-level fuzzy synthetic risk evaluation model is put forward. Though evaluating the sub-target risk of power transformer, the comprehensive risk evaluation for life cycle of power transformer is given out. The example shows that the fuzzy synthetic evaluation model is available. It can be used to the risk assessment of power transformer.

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