LIFE ASSESSMENT MODEL OF THE POWER TRANSFORMERS BASED ON CONDITION ASSESSMENT

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Abstract: Statistical analysis of 500kV power equipments in East China Grid is performed in this paper. The transformer reliability life modelling method is then proposed based on condition characteristic evaluation technology. The elements and data sources are determined for sub-model. The overall model is established and verified through Monte-Carlo analysis.
Keywords: Life assessment model, power transformers, condition assessment

1 INTRODUCTION

Due to the competition of the electricity market, the life assessment technology of power transformers has drawn more and more attention. Despite of the technical difficulties, many achievements have been made by the researchers from all over the world. Based on the current condition assessment method, this paper proposed a life model of the power transformers based on characteristic data, combined with performance experience.

The study of life assessment model includes three aspects:1) establishing the models combination representing the thermal, mechanical and electrical characteristics of equipment based on operation experience; 2) making utility of existing data and operation experience, selecting key information representing the initial and current status of the equipment. Through calculation, analysis, weighting and expert system scoring, the submodels are valued; 3) making combination of the submodels by probability method. Through trial calculation of several equipment, modification and adjustment could be made to the combination and value of the submodels. Finally the life assessment model of the power transformers based on status evaluation could be built.

2 OVERALL STUDY APPROACH

The concept “reliability life evaluation” is used in this study. It refers to the estimate of the period, during which the equipment maintains continuously steady operation within a specified reliability level (or fault rate). Reliability life evaluation takes into account combinations of various categories of faults resulted from electrical, mechanical or thermal aging. These faults may require replacement of main components or supplemental parts of the equipment.

The process of reliability life modeling is described as follows. First, characteristic indices that represent transformers operation conditions are identified based on statistical analysis of transformer failure and prevention tests data. Second, relationship between the indices and operation time or that between the indices and failure rate (reliability) is established. Third, variation of each single characteristic index is evaluated according to the technical standards, operation practices and research results. Finally, adjustment for various fault types is performed based on operation experiences, particularly through analysis of failure information. The reliability life model is then built up. Reliability life of a transformer is determined in accordance with the operation requirements.

3 STATISTICAL ANALYSIS OF SUPPORTING DATA

3.1 Data overview

Typical substations with various years of operation experience are investigated in this study. Through the investigation, information related to transformers’ manufacturing, transit, operation, maintenance and defects is collected for 185 transformers and reactors installed in over 40 substations. Both the substations of over 15 years operation experience and those of only 5 years operation experience are investigated.

3.2 Analysis methods

Four different statistical methods as listed below are used to analyze various types of characteristic data. Method One and method Two are used for insulation tests and bushing related data analysis. Method Three and method Four are employed for incidents statistics and short-circuit related computation.

Method One: Determine the variation principles of the characteristic indices through statistical analysis of a large quantity of samplings. The major aspects of the analysis are as follows.

1) Data distribution characteristic may be used as criteria for data filtering.

2) Correlation analysis of data with various factors (years of operation not included) may be used for identification of characteristic indices. For instance, if a correlates highly with b and in principle, a and b represent the same characteristic, only one of them (either a or b) will be taken as input for the model.

3) Correlation analysis of characteristic indices with years of operation, as core of reliability life model, determines whether the model is time extendable. In other words, correlation analysis will show whether the reliability life is predictable or not.

Method Two: The variation tendencies for the characteristic indices of single equipment are studied based on statistical analysis of a large quantity of samplings. The major considerations are as follows.

1) The number of the samplings with over 10 years' operation is very limited. Therefore, their variation characteristics might be submerged.

2) The prevention tests data are obtained mainly through limits checking. Its measurement part is affected by various uncertain factors. However, the factors and the errors might be relatively fixed for single equipment, which helps the investigation of the tendency.

3) Operation experience shows that the characteristic data varies considerably for equipments with different design, manufacturing and operation conditions. For example, the fundamental tendencies are similar for the media loss curves while the starting points and the variation rates for these curves are remarkably different.

Method Three (fault statistics): Perform failure events statistics based on operation and management experience. Transformer faults are categorized according to the caused of fault occurrence. The categorized fault statistics results will then be employed as important basis for reliability life modeling.

Method Four (estimate of short-circuit fault probability): Employ the research results to identify the factors that affect the anti-short-circuit capability. The factors mainly involve design margin, manufacturing technology and operation environment (relay protection and multiple times short-circuit effect accumulation and etc.). The influence of each type of factors is evaluated based on analysis of failure events and design check. The approach and procedures for estimation of equipment short-circuit fault probability.

4 ESTABLISHMENT OF SUB-MODEL

4.1 Main components of the model

Through statistical analysis, the major structure and data sources of the reliability life model are determined. As shown in Table 1, the sub-models are grouped into four categories, which are related to electrical performance, mechanical performance, supplemental performance and operation scenarios respectively. The data sources involve failure events, equipment transiting and prevention tests.

Table 1: Main components of transformer reliability life model

Submodel	Characteristic parameters	Index
electrical	Overall insulation	dielectric loss, absorption ratio, polarized index
	oil	Withstand voltage, water,contamination,TCG,gas,
	DGA	C_2H_2
	Dc resistance	Imbalance rate
mechanical	anti-short-circuit capability	Design reliability
	Winding deformation	short-circuit impedance variation rate
		capacitance variation rate
supplemental	bushing	dielectric loss,capacitance
		Fault rate
	tap	Fault rate
	oil	Physical index
operation	Over-voltage and etc	Fault rate

4.2 Analysis method

In the sub-models, the characteristic indices are employed in three ways, which are time extending, limits checking and fixed parameter method.

1) Time extending

Time extending method is applicable for the characteristic indices that are correlated with operation time. To use this method, single equipment data shall demonstrate certain principles which may be approximated through primary polynomials or exponentials. When assuming relationship exists between characteristic index and accumulative fault rates, the variation tendency of the fault rates corresponding to the characteristic index is then acquired. The sub-model is then time extendable. Statistics results show that the characteristic indices with time extending ability include the overall dielectric loss, dielectric loss of bushing and oil, CH4, micro-water, and PH value of oil.

2) Limits checking

Limits checking method is applicable when neither characteristic indices-operation time correlation nor certain principle of the characteristic indices for single equipment exists. Through the assumption that relationship exists between the characteristic index limit and the accumulative fault rates, the fault rate corresponding to the characteristic index is then acquirable. At present, the characteristic indices suitable for limits checking include absorption ratio, polarized index, C2H2, short-circuit impedance variation rate, capacitance variation rate and voltage withstand ability of insulation oil.

3) Fixed parameters

Fixed parameters are the ones that repent the equipment characteristics and remain unchanged in operation. Fixed parameters include anti-short-circuit capability evaluation index and average fault rates which are used in random fault simulation.

4.3 Assumptions of accumulative fault rates and reliability

The assumptions of accumulative fault rates and reliability are mainly based on related standards and operation experience.

5 ESTABLISHMENT OF THE OVERALL MODEL

5.1 Development of the problem

According to reliability fundamentals, transformer reliability is determined by series-wound connection of the reliability of each part. Transformer reliability is then represented as the product of the reliability from each sub-model (Ra*Rb*Rc*Rd), where Ra, Rb, Rc and Rd are the reliability for sub-models related to electrical performance, mechanical performance, supplemental performance and operation scenarios respectively. Statistical results show that the fault rate for transformers of 110kV and higher voltage levels in East China is only 0.11 per hundred units per year. Therefore, the reliability index for each sub-model shall be about 99.9% according to the above analysis. However, this brings forward two problems.

1) The present sub-models can not meet this precision requirement, which may directly result in the establishment failure of the overall reliability life model.

2) It is difficult to identify the major restriction factors (fault types) of transformer reliability life. Correspondingly, the development of the strategies followed will be affected.

The present research and data sources make it difficult to establish sub-models of considerably higher precision. To solve the problems above, improvement has to be made to mitigate the influence of sub-models precision problem.

5.2 Modification and integration approach for sub-models

1) Basic considerations

Sub-model modification is based on operation experience. It refers to modification of sub-model reliability indices through reasonable assumptions and technical measures. The transformer reliability life is then determined through series-wound combination of sub-models. The reliability indices may be modified in three ways: multiplying a coefficient, adding a value or using exponentials. Considering the former two ways may result in increased reliability indices of over 1.0 or remarkable increase / decrease of the reliability indices, exponentials are selected in this study to avoid such unreasonable modification results. After modification, the reliability index is as follows.

$$R_{total} = R_a{}^a \times R_b{}^b \times R_c{}^c \times R_d \tag{1}$$

2) Summarization of operation experience

Summarization of operation experience mainly refers to acquisition of average transformer fault rate and the relative ratio of each type of fault. Fault statistical results for transformers of 330 kV and above in State Grid of China are used for summarization.

3) Solution of modification factors

According to Table 1, Ra, Rb, Rc and Rd are calculated respectively. Now, according to definition of reliability, single equipment fault rate may be represented as 1-$R_{total,\ I}$. When the number of the equipment samplings is large enough, the overall fault rate $\sum_{i=1}^{n}(1-R_{total,i})/N$ corresponds to the number of faulted equipments. Accordingly, $\sum_{i=1}^{n}(1-R_{b,i}{}^{b}\times R_{c,i}{}^{c}\times R_{d,i}\ )/N$ corresponds to the number of faulted equipments without electrical fault (factor a), and etc. These should consistent with the operation experience as described in “2) Summarization of operation experience”. The modification factors may be acquired through Monte-Carlo approach.

Related solution parameters and results are listed in Table 2 Results show that all values of the modification factors are less than 1.0. a and b are especially smaller. It is mainly due to strict setting of fault rates and large number of input parameters.

Table 2: Solution results

parameters	a	b	c
results	0.05	0.45	0.1

The overall reliability distribution of 500 kV transformers in East China is shown in Fig.1 and Fig.2.

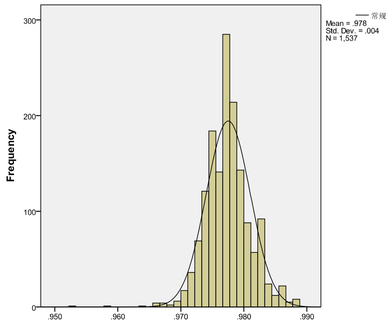

Figure 1: Overall reliability distribution

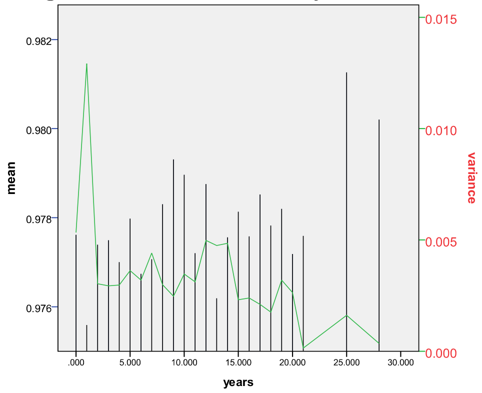

Fig.2: Variation of overall reliability means and variances with respect to time

It is observed from the figures above that:

1) There is no much variation of mean and variance values, which matches the fact that the equipments are in stable operation.

2) The overall reliability rises first and then decreases. The reliability of year 2010is high which may result from the completion of equipments' state adaptation period.

3) The variance rises first and then decreases. It shows that equipments' reliability gets close after years of operation. Management of these equipments may be of high generality.

4) Correlation of various parts with time differs, which provides technical basis for differentiated management in life-cycle.

5) There is difference between the variation of overall reliability and that of single equipment.

6 CONCLUSION

This paper presents state characteristics evaluation-based approach for transformer reliability life modeling. Components and data sources are determined for the sub-models. Modification and integration of the sub-models are performed through Monte-Carlo method. The life-cycle management of the equipments is expected to be enhanced through this study.