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Life Estimation of Power Transformers Based on Information Management System

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Abstract: Generally, power transformers degrade ahead of time. To increase the operational reliability and decrease losses, an integrated life estimation model is built. First, four types of parameters are contained in our model: basic, operational, reliable, undesirable parameters, synthetic weight. We also quote the hierarchical architecture model. Second, the multi-objective evaluation based on fuzzy logic algorithm is introduced and the reliable parameters are estimated through a Weibull distribution. Finally, it is verified through a case and the effectiveness is proved. Therefore this model provides a reference for the drafting optimal maintenance scheme and prolongs the service life of power transformers.

Key words: Life assessment, transformer, information management system, fuzzy logic algorithm, reliability

INTRODUCTION

Power transformers have relatively high premature degradation rate during each operating period, according to the practices in Jiangsu Province and it has caused much extra losses. The readily available data from power utilities motoring system include (Wang *et al.*, 2002):

- Dissolved gas analysis (DGA)
- Operating meteorology
- Maintenance data
- Defect management data
- Condition assessment reports

Oil quality tests (visual inspection, acidity, dielectric strength, interfacial tension).

Routine and diagnostic tests: Bushing tests (capacitance, dissipation factor) (Saha, 2003). Only the first two among the above data are changing with time, others have a longer test period and l ess historical data. The elimination and record of defects also take unexpected cycles. To increase the operational reliability and decrease maintenance costs, there is a need to develop an information management system to estimate remaining life of power transformers.

The limitation of operating observations and field inspection generally leads to lack of available data which are underutilization. There is no widely adopted composite life estimation based on information management system currently. Researches related mainly include time-temperature-superposition (TTSP), the value of leveling-off degree of polymerization (LODP) and the Health Index (HI)-based model (Yang, 2009).

This paper puts up a practical HI calculation and the hierarchical architecture model trough combining all available data which are acquired from the database, updated by experimenter or adjusted by experts. Accessories' defects cumulative occurrence are estimated through Weibull distribution to lower down the impact of individual differences. It is recommended undesirable working conditions be used to correct the model.

A BRIEFVIEW OF FORMER RESEARCHES

The architecture of model has four stages, as shown in Fig. 1.

Service layer: Providing users with visual interfacial, including data interface offered to updating tests data by experimenters, the details of each estimation stratum, the "Caution" dialog boxes, the browser and so on. It is convenient and practical for users to employ the operating system put forward.

Function layer: Involve the management of each layer in the evaluation model, as shown in Fig. 1 and the implementation of the background algorithm.

Architecture layer: This layer provides system with the core structure and quotes the hierarchical architecture model between functional modules to make sure the methodically management.

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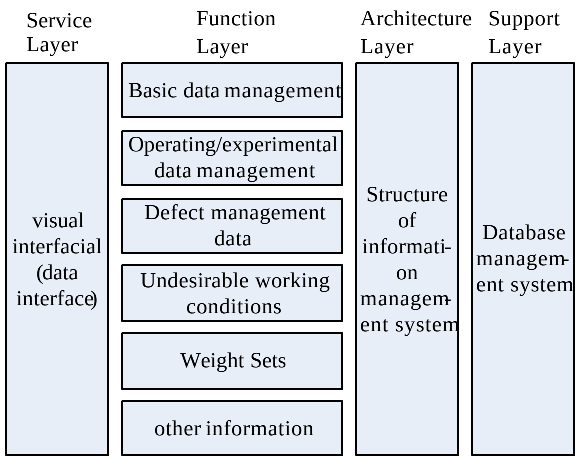

Fig. 1: Power transformer life assessment architecture

Support layer: This layer provides data manipulate function through the relational database management system. (Ma *et al*., 2012)

The data information management development: It includes 6 categories, as shown in function layer in Fig. 1. These data cover all the information (Factory Version, installation, operation, degradation) of the power utilities. To ensure the compatibility between the individual model and the overall module, the system must realize the automatic data processing, high degree of sharing, interaction, etc. (Wang *et al*., 2002)

There are interference, measurement precision and other issues during operation, leading to the part of data unreasonable in the database and should be removed. The wavelet analysis theory and curve fitting method are employed to achieve the monitoring data processing, eliminate the false information and retain the true, ensure the accuracy and truth of data and provide subsequent calculations with scientific data.

The monitoring master Intelligent Electronic Device (IED) networks establish a unified data sharing and integration of information interaction platform via a variety of communication methods. And the swap among external operating conditions, the historical information of family utilities and interface data occurs anytime. It is mainly composed by the database servers, data storage, backup and interface devices, database management software, etc.

The security and confidentiality of data also need to be considered in the transmission and it is required to increase "Address Management System" and "Identity Management System" which are corresponding to the information management system of power utilities. Here put the transmission channel design principles: the higher real-time and security data possessing priority over others, could employ the dedicated communication networks for power systems and others may choose wireless or wired public communications networks.

ESTABLISHMENT OF THE LIFE EVALUATION MODEL

System development framework: All the information is split into several groups on the basis of the attribute, then the attribute hierarchical model is formed, as is shown on Fig. 2. The assessment of basic parameters is defined as the primary structure, analysis of operating and experimental parameters as the second structure and the defect management of accessories as the third structure. Undesirable working conditions data will modify the model. (Zhu *et al*., 2004)

Data structure: assessment parameters are classified into three categories: evaluation factor sets, weight sets, evaluation sets. According to them, two-dimensional table data structure is built, as shown follow:

Evaluation factor sets:

- Basic data X_1 (device mode x_{11}, anticipated life x_{12},…, x_{1n})
- Operating and experimental data X_2 (methane content in the oil x_{21}, acetylene content in the oil x_{22},…, x_{2n})
- Defect management data X_3 (general or slight defects x_{31}, severe defects x_{32},…, x_{3n})
- Undesirable working conditions data X_4 (short-circuit current x_{41}, short-circuit frequency x_{42},…, x_{4n})

Weight sets:

- Weight sets of HI in the second structure W_1 (DGA weighting w_{21}, furfural content w_{22}, oil quality w_{23}, the paper insulation condition w_{24}, routine tests w_{25}, diagnosis tests w_{26})
- Weight sets of final HI grade W_2 (the primary structure weighting w_{21}, the second structure w_{22}, the third structure w_{23})

Evaluation sets:

- Processing vectors in the primary structure F_1 (environmental correction factor f_{11}, loading f_{12})
- Processing vectors in the second structure F_2 (methane score f_{21}, acetylene score f_{22},…, f_{2n})
- Processing vectors in the second structure F_3 (two parameters in the probability of accumulated failure

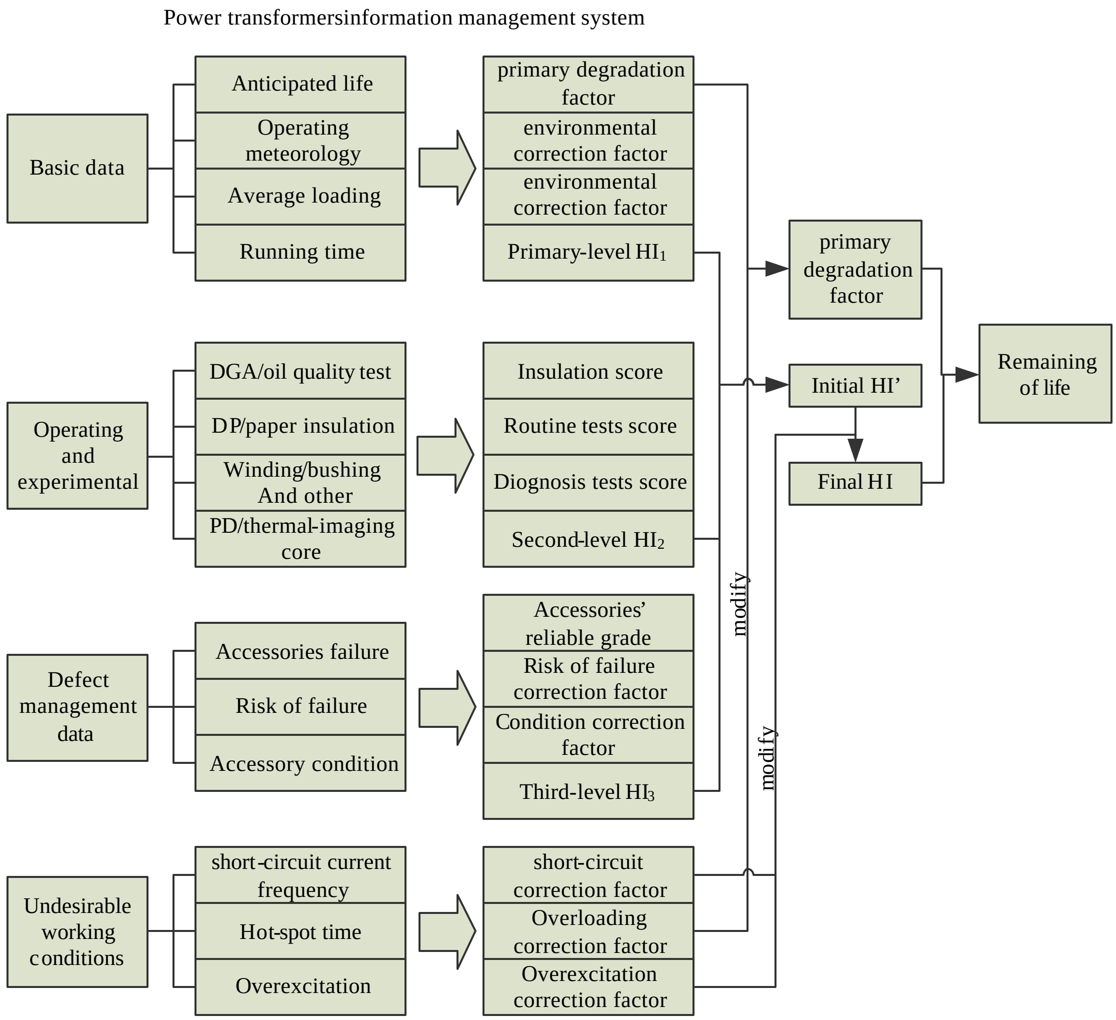

Fig. 2: Power transformers information management system

density function of main tank (f_{31}^1, f_{31}^2), two parameters in the probability of accumulated failure density function of radiator system(f_{32}^1, f_{32}^2),…, (f_{52}^1, f_{52}^2))

- Processing vectors in the third structure F_4 (probability of main tank accumulated failure f_{41}, probability of radiator system accumulated failure f_{42}, …, f_{45})
- Risk of failure R = (risk of failure in main tank r_1, risk of failure in radiator system r_2, …, r_5)
- Result vectors in the primary structure Y_1 (primary degradation factor y_{11}, primary HI)
- Esult vectors in the second structure Y_2 (DGA score y_{21}, furfural content y_{22}, oil quality y_{23}, the paper insulation condition y_{24}, routine tests score y_{25}, diagnosis tests y_{26})
- Result vectors in the third structure Y_3 (main tank reliable grade y_{31}, radiator system y_{32} tap-changer tests y_{33}, non-electricity protection equipment y_{34} bushing y_{35})
- Result vectors of undesirable working conditions Y_5= (modified degradation factor y_{51}, final HI y_{52}, remaining life y_{53}, probability of failure y_{54})

MODELING STEPS

Step 1: Initialize the information management system, update the information acquired from the power utilities motoring system and the database of this system

Step 2: $X_1 = (x_{11}, x_{12}, \ldots, x_{1n})$. The model makes automatic selection for the first two parameters of F_1

according to the corresponding tables in the database. Meanwhile f_{13} =x↓12/[f]↓11×f↓12). Next automatic computation are running background and Y_1 (y_{11}, y_{12}) is done

Step 3: Operating and experimental evaluation factor set $X_2 = (x_{21}, x_{22},\dots, x_{2n})$, $F_2 = (f_{21}, f_{22}$, to $f_{2n})$, are calculated background automatically. If $\min[f_{21},f_{22},\dots, f_{2j}]>0.7$:

$$y_{21} = \frac{1}{j}\sum_{i=1}^{j} f_{2i}$$

Otherwise. $y_{21} = \min[f_{21}, f_{22},\dots, f_{2j}]$. Several experts are invited to fulfill the elements of judgment matrix W_j. Taking Analytic Hierarchy Process (AHP) in the background, the N×6-order weight matrix are got. Averaging each column, then normalize the elements to a new matrix W_1 which satisfies a sum of 1. The second-level $HI_2 = W_1^T Y_2$

Step 4: $X_3 = (x_{31}, x_{32},\dots, x_{3r})$. Update the utilities' deficiencies records coming from the management system. The elements of F_3 should recalculate or refit by data-analysis software, if there exist newly-increased data. Otherwise, the former elements are reserved. Next, elements of F_4 are calculated automatically. Reliable grade of accessories sets Y_3 = 1-F_4.Click "Next" button to analysis the five accessories risk of failure. R = (r_1, r_2, r_3, r_4, r_5).Then we get corresponding correction factor sets F_5 and the accessories condition correction factor sets F_6. Finally, the deficiency grade sets $Y_4 = Y_3 F_5^T F_6^T$.

Step 5: The calculation of W_2 are similar to procedure of getting W_1 and the weight sets of final HI grade $W_2 = (w_{21}, w_{22}, w_{23})$. Result vectors of final HI $Y_e = (y_{e1}, y_{e2}, y_{e3})$, of which $y_{e3} = \min\ [y_{4i}]$. Initial HI' is defined as $Y_e W_2^T$

Step 6: $X_4 = (x_{41}, x_{42},\dots, x_{4n})$, among which x_{41} and x_{42} provide an index to acquire short-circuit current correction factor f_{71}. Click "next" and the model fetches data from evaluation factor sets and calculate the loss ratio of life f_{72}. So the processing vectors of undesirable working conditions are finished, $F_7 = (f_{71}, f_{72})$. Result vectors in the step are defined as $Y_5 = (y_{51}, y_{52}, y_{53}, y_{54})$. Each of their calculation is listed as: $y_{51} = y_{11} f_{71}$, y_{52} = HI'f_{72}, y_{53} is got according to Eq. 6, $y_{54} = \max [F_4]$

Step 7: Display the various steps in the process of assessment on the user interface, furthermore selecting corresponding maintenance strategies. State variables score below 0.5 or the evaluation result of fair/poor in any step, should be paid more attention. The remaining life of transformers are displayed by four-color flash-point with red (1 year and below), orange (1-3 years), yellow (3-5 years) and green (more than 5 years) in the power grid monitoring of Jiangsu GIS (Geographic Information System)

ALGORITHM BACKGROUND SYNOPSIS

HI formulation: It presents HI has obvious changing rule from newly-operating to degradation. HI varies from 0-1,, where 1 represents excellent health and 0.35 represents poor health. (Cai, 2012) It's proposed as:

$$1 - HI - (1 - HI_0) \times e^{B\times(T_2 - T_1)} \tag{1}$$

HI_0 and HI are the HI of running time T_1 and T_2, B for degradation factor.

Fuzzy comprehensive evaluation method: Scoring operation and experimental data mainly adopt the fuzzy-logic expert system. The membership functions are selected according to the current practice of a utility which embody any condition from a good condition represented by 1 to a very poor condition represented by 0.

Reliability of accessories: The failure pattern of utilities follows a "bathtub curve" which presents a higher failure rates at start-of-life or end-of-life (Pradhan *et al*., 2005).

Fatal or severe defects can probably lead to emergency repair, in order to avoid further consequence cost. It is recommended the fatal or severe deficiencies data be used to score the reliability grade rather than actual failure data available, since the formers are more available. The failure rate expectancy curve of each accessory is estimated through a Weibull distribution. Here the probability density functions are achieved by Weibull as shown in Fig. 3 and 5. F is accumulative failure probability of 220 kV bushing that is the failure rate of utility. Reliable grade of accessories are defined as 1-F. (Zhai *et al*., 2011):

$$F(x) = 1 - \exp\left[-\left(\frac{x}{2100}.6009\right)^{0}.9524\right] \tag{5}$$

Aging coefficient modification: The relationship between insulation life and hot-spots temperature follow the

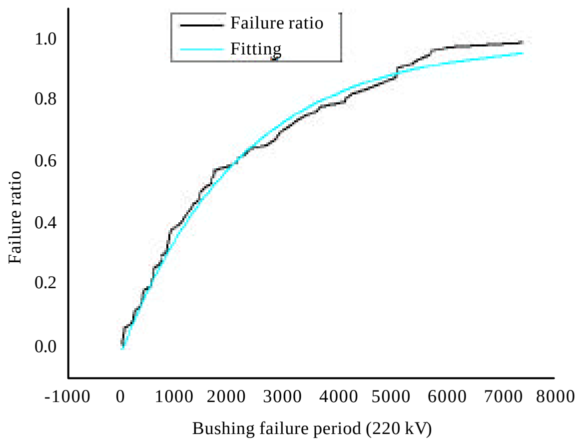

Fig. 3: 220 kV bushing cumulative POF density functions

Arrhenius Law (Swift *et al.*, 2001). Overheating caused by overloading and their long service durations are stored at the undesirable working conditions management system. The loss ratio of life L% in the motoring time t are gained automatically by invoking these two kinds of data. The remaining life is changing with the assessment time, the operating condition, etc. And the basic number of loss ratio is not the anticipated life in the primary structure any more. Therefore, this model modifies the primary degradation factor by the loss ratio of life which makes sure the loss matches the current health condition. The modified degradation factor is:

$$B = \frac{B_0}{1 - L\%} \quad (7)$$

The composite HI is:

$$HI = k_1 \times \sum_{i=1}^{3} \omega_i HI_i \quad (8)$$

where, ω_i is the assigned weighting factor and k_1 is short-circuit current correction factor (State Grid Corporation, 2008).

And remaining life of a power transformer is proposed as:

$$L = \frac{\ln(1 - HI_{end}) - \ln(1 - HI)}{B} \quad (9)$$

CONCLUSION

Massive parameters of transformer life assessment and influence mechanism are not clear, so this model is designed to utilize the overall data of transformers and introduce the hierarchical architecture thoughts. The data sharing and security transmission ensure the timeliness of information and enhance the model precision.

The HI formulation is adopted to establish the life evaluation model and using AHP to receive weighting which lowers the subjectivity of judgment matrix. The effectiveness of the method is verified through a case analysis and provides a reference for drafting optimal maintenance scheme.

The model assumes that all parameters are independent. In fact, the health condition of the device is complicated. This process will impact the assessment accuracy inevitably, so the mutual influence mechanism between variables need further researches.

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