Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Development of Expected-life Assessment Methodology for the Large Transformer and Its Application

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1. Introduction

The nuclear power plant has been developed for improvement of degradation assessment methods of the large transformer. The dissolved gas analysis, sonic/ ultrasonic noise analysis and vibration analysis are effective methods for degradation assessment. However, these methods are difficult to evaluate the expected-life of the large transformer. So, the nuclear power plant needs quantitative expected-life assessment methodology. Therefore, this study presents the expected-life assessment methodology of the large transformer and application.

2. Methods and Results

The expected-life assessment methodology of the large transformer consists of four courses such as, identification of scope and features, operating experience analysis, key failure mechanisms selection and application of degradation model.

2.1. Identification of Scope and Features

This methodology can be applied to all kinds of mineral oil immersed transformers in the nuclear power plant like the main transformer, auxiliary transformer and start-up transformer and so on. The subcomponents in these transformers are core, windings, insulation for windings, tank and so on [1].

2.2. Operating Experience Analysis

Based on EPIX and NRC's operating experience database, failure frequency of subcomponents is shown Fig. 1. The failures are grouped into two general areas of failure. The first category is core, windings, insulation and internal wiring. The second is bushings. As shown Fig. 1, failure of the first category that occurred after twenty years of operation is greater than the second category.

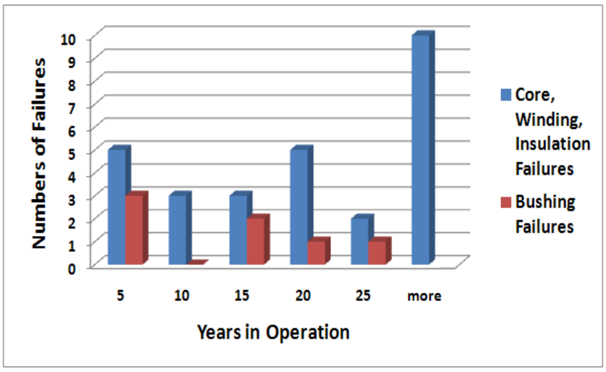

Fig. 1. Failures in transformers from EPIX and NRC's database

2.3. Key Failure Mechanisms Selection

The general failure rate of typical equipment in the nuclear power plant has the bath-tub curve, as shown in Fig. 2. A bath-tub curve describes behaviors of the failure rate of equipment versus time in service. Also, a bath-tub curve is related to the degradation mechanisms. In other words, a bath-tub curve is the composite failure distribution of all individual failure mechanisms on subcomponents. This phenomenon is called "failure envelopment" [1].

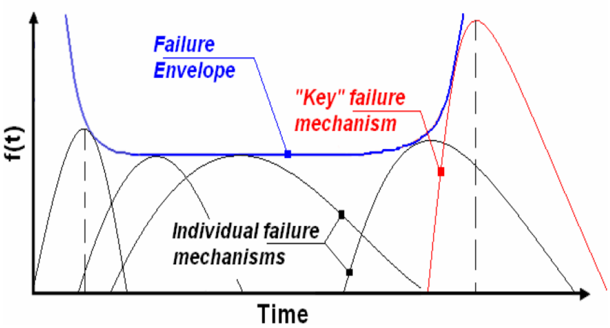

Fig. 2. Bath-tub curve

Table I: The Key Failure Mechanisms(K) of the Large Transformer

Subcomponent→ Degradation Mechanism↓	Core	Insulation for Windings	Tank	Bushing	Gaskets	Shielding	Tap Changers
Uniform Corrosion	K		K	K			
Pitting Corrosion			K	K			
Erosion				K			
Wear/Fretting							K
Fatigue	K		K			K	
Chain Scission		K			K		

When the slope of the bath-tub curve begins to increase, it is important to know that the dominant mechanisms are most likely to increase in the failure rate. These dominant mechanisms are defined as key failure mechanisms. The key failure mechanisms (K) of the large transformer are shown in Table. I.

2.4. Degradation Model

2.4.1. Degradation Model Equation

Based on the operating experience of large transformer and key failure mechanisms selection, the insulation for winding and core provide the greatest threat to life of the large transformer. In this study, the insulation for winding is the major selected component, because arcing and core failure can be caused by a reduction of the insulation properties. There are three mechanisms that contribute to degradation of the insulation: hydrolysis, oxidation and heat. The expected-life of the large transformer can be predicted by following equations reflecting the insulation degradation factors [2, 3].

$$F_{AA} = k_{H_2O} k_{O_2} e^{\left(\frac{15000}{383} - \frac{15000}{T_H + 273}\right)} \quad (1)$$

$$T_H = T_{TO} + T_A + T_{HR} \quad (2)$$

$$F_{EQA} = \frac{\sum_{n=1}^{N} F_{AAn} \times \Delta t_n}{\sum_{n=1}^{N} t_n} \quad (3)$$

$$L_{life}(\%) = \frac{F_{EQA} \times T \times 100}{L_{normal}} \quad (4)$$

$$T_{life} = \frac{100}{L_{life}} \quad (5)$$

F_{AA} : Aging Acceleration Factor
k_{H2O} : Aging Rate Correction Factor for H_2O in Paper
k_{O2} : Aging Correction Factor for O_2 Content of Oil
T_H : Hot-spot Temperature
T_A : Ambient Temperature
T_{TO} : Top-Oil Temperature
T_{HR} : Winding Hot-spot rise over Top-oil Temperature
F_{EQA} : Equivalent Life Consumed in A Given Period
L_{life} : Loss of Life rate[%]
T : Operating Time
L_{normal} : Normal life of insulation
T_{life} : Predictive Life

2.4.2. Application of Degradation Model Equation

The value of the nuclear power plant's main transformer's expected-life can be calculated by the expected-life assessment methodology. Firstly, T_{TO} is collected from the nuclear power plant's main transformer from 2005 February to 2006 January. T_A is based on monthly average temperature in site of the nuclear power plant. Also, T_{HR} assumes approximately 15℃. Lastly, k_{H2O} and k_{O2} are applied to 2 and 1 respectively.

Table II: Input data of degradation model equation

N	Time	T_{TO}(℃)	T_A(℃)	T_H(℃)	F_{AA}	t(date)
1	2005. Feb	50	4.9	69.9	0.02	28
2	2005. Mar	53	8.6	76.6	0.05	31
3	2005. Apr	61	13.6	89.6	0.22	30
4	2005. May	61	17.5	93.5	0.34	31
5	2005. Jun	59	20.7	94.7	0.39	30
6	2005. Jul	69	24.1	108.1	1.65	31
7	2005. Aug	63	25.9	103.9	1.06	31
8	2005. Sep	61	22.3	98.3	0.58	30
9	2005. Oct	56	17.6	88.6	0.20	31
10	2005. Nov	56	11.6	82.6	0.10	30
11	2005. Dec	50	5.8	70.8	0.02	31
12	2006. Jan	51	3.2	69.2	0.02	31

Table III: Aging rate factor for moisture in paper

Moisture Content in Paper(roughly)	k_{H2O}
Dry(<0.5%)	1
Moist(0.5~2.0%)	2
Wet(>2.0%)	4+

Table IV: Aging rate factor for oxygen content of oil

Oxygen Content	k_{O2}
Low	1
High	3-5

Based on these datas, aging acceleration factors are calculated by equation(1), as shown Table II: F_{AA} value. Using aging acceleration factors calculated by previous process, the value of expected-life is calculated by equation (3), (4), (5), as shown Table V.

Table V: Result of Application

F_{EQA}	L_{life}(%)	T_{life}(year)
0.39	1.90	52.54

3. Conclusion

This study presents the prediction of expected-life assessment process composed of four courses. This methodology will help to avoid power interruption and maintain the reliability of power supply due to one power transformer failure. However, development of database related hot-spot temperature and applying life of another major component are required to determine exact value of expected-life of the large transformer.

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