

Power Transformer Risk-Based Maintenance by Optimization of Transformer Condition and Transformer Importance

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Abstract—This paper presents a risk-based maintenance strategy of a power transformer in order to optimize operating and maintenance costs. The methodology involves the study and preparation of a database for the collection of the technical data and test data of a power transformer. An evaluation of the overall condition of each transformer is performed by a program developed as a result of the measured results; in addition, the calculation of the main equipment separation to the overall condition of the transformer (% HI) and the criteria for evaluating the importance (% Iml) of each location where the transformer is installed. The condition assessment is performed by analysis test data such as electrical test, insulating oil test and visual inspection. The condition of the power transformer will be classified from very poor to very good condition. The importance is evaluated from load criticality, importance of load and failure consequence. The risk matrix is developed for evaluating the risk of each power transformer. The high risk power transformer will be focused firstly. The computerized program is developed for practical use, and the maintenance strategy of a power transformer can be effectively managed.

Keywords—Asset management, risk-based maintenance, power transformer, health index.

I. INTRODUCTION

THE power system of the Provincial Electricity Authority (PEA) has been expanding and developing continuously as the demand for electricity is increasing continuously. Today's power system needs flexibility. Flexibility focuses on cost reduction and risk management; therefore, the nature of the current system needs to be managed. Decision support tools and integration of information technology (Integrated Information Technology) can improve the efficiency and competitiveness of power systems.

The management of the power system is very important and has received great attention. Due to proper power system management, cost and operation costs can be reduced and maintained. The reliability of the electrical system remains satisfactory. However, the management of a power system is complicated because it gathers knowledge in many aspects such as deterioration of power equipment, reliability of the power equipment, the importance of each device in the power system, and the reliability of the electricity delivery system, expenses for the use and maintenance of equipment, etc. The above knowledge will be used to determine the use of power

equipment close to the end of use. The reliability of the electrical equipment and the reliability required by the electrical system. That is, the continuous return of active power equipment.

Transformers are important devices for transmitting electricity and changing the voltage level to suit the application. In addition, power transformers are also expensive devices. The power transformer in the PEA system has been used for many years and sometime supplied overload capacity. The power transformer itself will deteriorate according to the age of operation and the deterioration due to abnormal conditions in the power system such as overloading and impact of lightning overvoltage harmonics and short circuit in the electrical system. Therefore, it is necessary to maintain the transformer to be ready to use again. Incidentally, damage to the transformer will result in the widespread interruption of a power system. Such power outages are wide reaching and prolonged, which results in the loss of revenue from the sale of electricity, and ultimately, it has an impact on the economy and security of the country. Therefore, it is necessary to study and develop the process of evaluating the condition and importance of an electrical power transformer. The condition of the transformer is evaluated in conjunction with the importance of the transformer to analyze risks in the use and maintenance of power transformers by using risk management metrics.

Nowadays, electric utilities try to preserve a power system's high reliability, while reducing operations and maintenance costs. But the other hand, equipment in power systems continue to age and gradually deteriorate, which increases the probability of service interruption due to component failure. An effective maintenance strategy is essential in ensuring reliable electric power supply to customers economically. The objective of this paper is to provide an optimization strategy for a risk-based maintenance and cost effective maintenance optimization program for power transformers of the PEA.

PEA's power transformers have been use since 1965 until now. The ole power transformer required to increase maintenance activity and monitoring. The priority of replacement depends on the function of the investment possibilities and different value of load loss that take into account the political decisions by the financial and manpower constraints. To identify those priorities, it is necessary to determine the reliability of existing equipment in the power system.

This paper describes the first steps in the methodology

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implementation to determine those priorities by using different technical information and consequence or impact of failure of equipment. Due to proper power system management, cost and operation costs can be reduced and maintained. Thus, the reliability of the electrical system remains satisfactory. The above knowledge will be used to determine the use of power equipment close to the end of use. The reliability of the electrical equipment and the reliability required by the electrical system. That is, the continuous return of active power equipment [1]; Inspection of the condition of the transformer oil insulation [2]; Breakdown voltage and moisture test of transformer insulating oil [3]. Factors affecting the loss of electrical power and capacitance of insulating oil and bushing, as well as on-load tap-changer oil, etc. after the power transformer were tripped out of the system with circuit breaker and protective relay. It need to test condition by special tools, such as insulating paper, single phase and three phase leakage impedance measurements, ratio and exciting current, DC winding resistance and so on. The frequency response [4], [5] and the low impulse voltage [6] is used to detect the deformation of the coil Polarization Depolarization Current (PDC) is used to determine the moisture in the paper insulation.

This paper presents the development of a program of power transformer maintenance and planning for effective decision

making support. This is done by creating a database management system consisting of technical background usage information and test results, as well as a maintenance program for the power transformers.

Based on current testing methods implemented by the PEA system, the visual inspection method has been applied and the results will be used for evaluating the power transformers in order to decide to continue to use it or replace it with a new transformer. Replacing a transformer will be determined by the ranking based on the condition of the critical loading supply of each transformer.

II. PROCEDURE

The developing method for assessing the condition and the importance of a power transformer take a long time to research. It also requires knowledge and experience to work on the power transformer. Thus, it is necessary to hire research consultants to assist in the study and preparation of the technical database and test results of power transformers, and to determine the principles of analyzing the results and the process of assessing the condition and importance of power transformers. The development of the program and process is shown in Fig. 1.

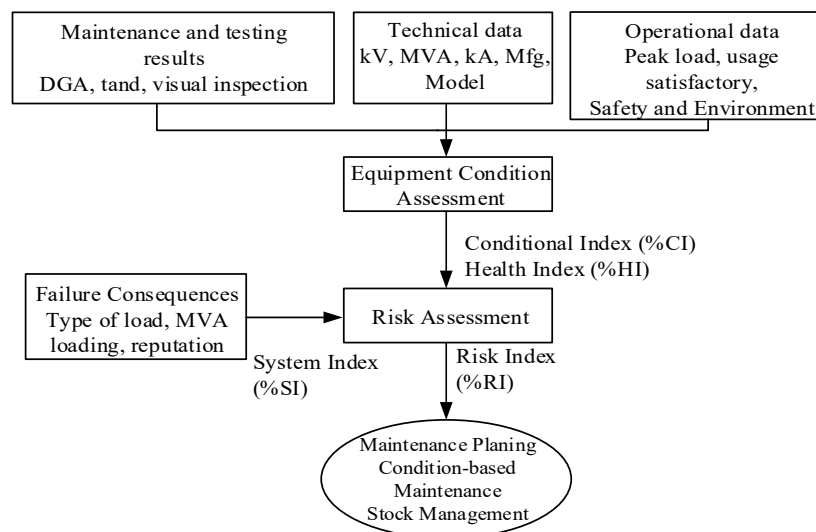


Fig.1 Procedure of Power transformer maintenance strategy

III. CONDITION ASSESSMENT

The concept of the research project began with the gathering of information on the technical data of the power transformers. The test results are collected and screening, classification was conducted in order to verify the accuracy of the data and then create a database containing a technical data sheet. Then, the transformer condition will be evaluated by a using score and weighting technique to convert data from various physics and physically tested results

The different testing method will show the different results.

The efficiency and ability of each testing method will find out the different problems and root causes that effect to the priority testing method, The Analytical Hierarchy Process (AHP) is to be applied to all concerned departments for ranking important scores. Next, it is necessary to define the calculating index of transformer component such as transformer oil, bushing, OLTC, etc., and after that, to calculate the overall index of transformer. The process of condition assessment is presented in Fig. 2.

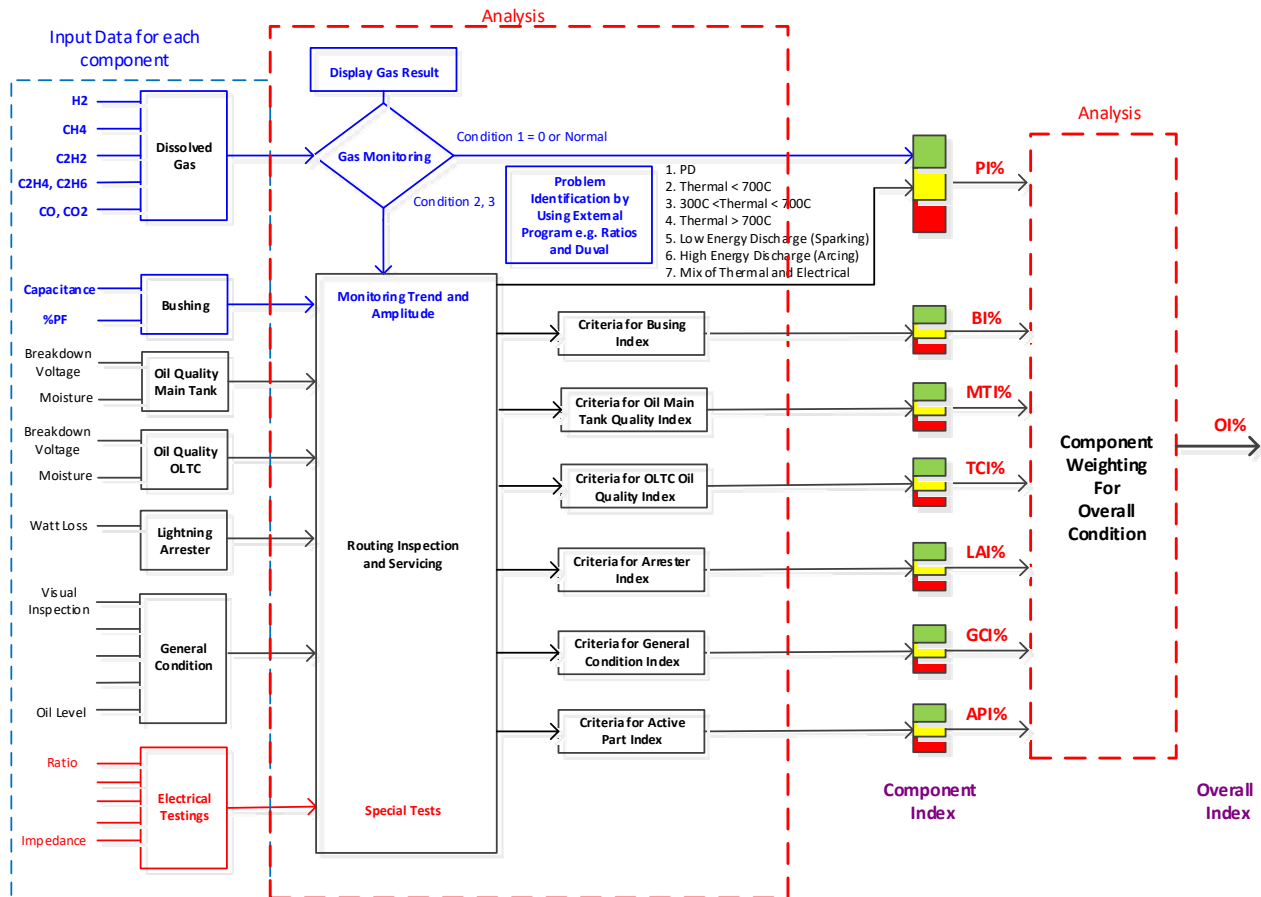


Fig. 2 Evaluation process

To assess the overall condition of a power transformer, the condition of the transformer's components is first evaluated. The components include active parts such as winding and magnetic core, OLTC, bushing, insulating oil, an arrester, protective device, and a main tank. The condition is calculated in terms of the "Health Index of Components (HIC)" of each component based on the important of test results of diagnostic tests. Subsequently, the percentage of component health index is ranked within the determined intervals in order to indicate the component [7].

Table I shows how the components of the power transformer were evaluated.

TABLE I
MAIN COMPONENT FOR EVALUATING POWER TRANSFORMER

No.	Component	Index	Weight (W)	Score (S)	Component Index
1	General	%GCI	W1	S1	%HIC
2	Active Part (Winding)	%API	W2	S2	
3	Insulation oil	%IOI	W3	S3	
4	OLTC	%TCI	W4	S4	
5	Bushing	%BI	W5	S5	
6	Lightning Arrester	%LAI	W6	S6	
7	DGA	%DGA	W7	S7	

The health index of each component is calculated using (1).

$$\%HIC = \frac{\sum_{i=1}^n (S_i \times W_i)}{\sum_{i=1}^n (S_{\max,i} \times W_i)} \times 100 \quad (1)$$

where S_i = score of a component, $S_{\max,i}$ = maximum score of a component, and W_i = weight of function.

The total condition of a power transformer can be calculated using (2).

$$\%HI = \sum_{i=GeneralCondition}^{i=DGA} (W_i \times \%HIC_i) \times 100 \quad (2)$$

where %HI = Health Index of power transformer, HIC_i = Health Index of each component, and W_i = Weighting.

The health index can be interpreted in the form of color indicators: green, yellow and red, which signifies good, suspect and poor conditions, respectively, as shown in Table II.

IV. IMPORTANT OF POWER TRANSFORMER

Power transformers are the most important components of transmission infrastructure, since their outages may create several catastrophic consequences both from economic and technical points of view. Most power transformers are generally loaded close to their operation limits and even above it for short periods due to unavoidable requirements. Moreover, because of their substantial investments, some power transformers are even operated near or beyond their intended life cycles. Therefore, it is crucial firstly to concentrate on transformer maintenance procedures.

TABLE II
HEALTH INDEX OF POWER TRANSFORMER

Overall Health Index			
%HI	Condition	Requirements	Color Band
86-100	Very Good	Normal Maintenance	Green
71-85	Good	Normal Maintenance	Blue
51-70	Fair	Increase diagnostic testing	Yellow
31-50	Poor	Start Planning Process to Replace/Rebuild the risk	Orange
0-30	Very Poor	Immediately Assess Risk	Red

In considering the importance of the transformer in the power system, can be determined from N-1 criteria, the importance of load and transformer age [8], [9] it can be used to manage the risk appropriately.

The topic and criteria to assess the importance of a power transformer was shown in Table III.

TABLE III
CRITERIA FOR EVALUATING THE IMPORTANCE OF A POWER TRANSFORMER

Criteria	Score					%W
	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	
Load	0-20	20-40	40-60	60-80	>80	26.84
Feeder	On				OFF	8.9
Importance						
N-1 Criteria	Yes				No	13.15
Fault Level (kA)	5	5-10	10-15	15-20	>20	9.63
Through Fault	<1	1-5	6-10	11-15	>15	10.28
Age) year(0-10	10-20	20-25	25-30	>30	7.22
Load importance	Rural area		City		Industrial estate	23.98

The importance index of a power transformer is calculated using (3).

$$\%ImI = \frac{\sum_{i=1}^{i=n} (S_i \times W_i)}{\sum_{i=1}^{i=n} (S_{max,i} \times W_i)} \times 100 \quad (3)$$

where S_i = score of criteria topic, $S_{max,i}$ = Maximum score of criteria topic, and W_i = weight of criteria topic.

The importance index can be interpreted in the form of color indicators: green, yellow and red, which stands for high

and low importance, respectively, as shown in Table IV.

TABLE IV
POWER TRANSFORMER IMPORTANCE (%ImI)

%ImI	Condition
70-100	High
40-69	Moderate
0-39	Low

V. RISK ASSESSMENT

Risk-based maintenance is an optimized strategy based on risk management; however, it is a complicated strategy at it requires using extensive data and an experience analyst to interpret the data [10], [11].

Risk Matrix: Risk-based maintenance of a transformer is created in the form of risk matrix between the relationship of condition and importance assessment of a power transformer, as shown in Fig. 3. In the risk matrix, the condition is classified into one of three levels that each level is suggested to maintain the tasks as inspection, maintenance and replacement, respectively. Similarly, the importance is also divided into three levels and suggested for corrective maintenance (CM), time-based maintenance (TBM), and lastly, time-based maintenance together with condition-based maintenance (TBM+CBM), respectively. Therefore, the risk can be totally differentiated into nine categories.

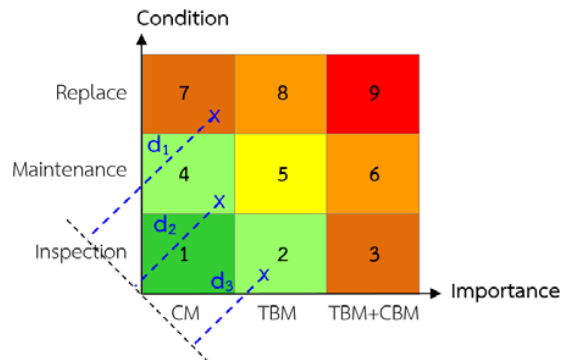


Fig. 3 Risk matrix with maintenance strategy

In addition, the risk can be measured by using the distance 'd' technique with respect to a 45 degree reference line, which specifies the equal weighting between condition and importance. The transformer with a longer distance 'd' encounters higher risk and should be firstly maintained. By using this method, the systematic maintenance task of transformer fleet can be scheduled according to Table V.

$$d = \frac{x+y}{\sqrt{2}} \quad (4)$$

where, x = Power Transformer Health Index (%HI) or Probability of Failure (%PF), and y = Power Transformer Criticality Index (%ImI)

TABLE V
MAINTENANCE PLAN FOR DIFFERENT RISK LEVELS

Distance "d"	Risk	Action
0-28	Very Low	Normal Maintenance
29-56	Low	Normal Maintenance
57-84	Moderate	Repair
85-112	High	Rebuild / Relocate
113-142	Very High	Replace

Risk Assessment for Power Transformers

The risk of all 68 power transformers in the 115 kV PEA's transmission network is assessed based on the condition and importance of individual power transformers. However, the setting of the scoring and weighting factors depends on the individual judgment of each utility. Those transformers assessed in the red and orange zones will be thoroughly investigated to mitigate the risk. The investigation results will be also used to verify and adjust the weighting factor of each criterion according to the actual condition of the power transformer.

VI. CONCLUSION

The risk-based maintenance strategy of power transformer management is achieved by the condition evaluation using a scoring and weighting technique, which is verified by accessing the actual condition of a transformer. The importance of each transformer in the network is also assessed. The combination of condition and importance develops the risk-based maintenance of power transformer in the form of a risk matrix. Since there are a large number of power transformers in the utility network, the computerized web-application program was developed as a tool to facilitate the maintenance tasks. In this paper, only 68 transformers are presented as examples. The obtained risk of each transformer is useful information for risk-based maintenance. Therefore, effective maintenance tasks can be setup, which results in high availability, low risk of failure, lower overall maintenance costs and the ability to extend the useful lifetime of power transformers.

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