Program Development Using Dissolved Gas Analysis Method for an Analysis of Power Transformer Oil Testing Results

Thanapong Suwanasri and Cattareeya Suwanasri

***Abstract*— This paper presents a program development for an analysis of power transformer oil testing results. The Dissolved Gas Analysis (DGA) method is applied. This method is generally used to determine transformer condition and failure causes by analyzing quantities of combustible gases in oil. The DGA method consists of three well known methods as the key gases method, the total combustible gases method, and the ratios method. In addition, the failure pattern and reliability of transformer components are analyzed by applying statistic methods as Weibull distribution and Normal distribution methods. Different cases of power transformers were examined in this paper by taking the historical data of power transformers into consideration. Finally, the failure rate and reliability of power transformer components are determined. This program development is designed to be a tool for systematic database management and failure analysis program on web-application to determine the criticality of power transformer components. The strategy and process for preventive maintenance can be built up from causes of failure to improve power transformer as well as system reliabilities.*

***Keywords*— Asset management, condition monitoring, dissolved gas analysis, failure statistics, power transformer, preventive maintenance.**

1. INTRODUCTION

Power transformer is one of the important equipment in an electrical power system. Its functions are to transfer an electrical power and change voltage levels. It has high cost and high weight equipment, which is usually used for 20-25 years depending on its life time design [1]. Practically after a new power transformer is operated in an electrical power system, it has been slowly degraded. Abnormal conditions such as overload, lightning strikes, over voltage, harmonics and short circuit events impact significantly to aging of a power transformer until failure occurred. The failures are dangerous for operating personal from firing explosion and others, when severe fault is taken place. In addition, there are environment impacts as oil leakage and supply interruption in a wide area. Those affects on both economics and stability of country. Thus, it is extremely necessary that the power transformer should be provided an appropriate maintenance to maintain availability and reliability in operation [2], [3]. Preventive maintenance on power transformer has been performed following the traditional method using pre-determined time schedule. Transformer testing and maintenance are regularly performed with good knowledge and experiences. However, testing results are scattered and not systematically recorded. This leads to very high cost and long time in service for maintenance because of insufficient and inappropriate data used for condition evaluation. Thus, this following method is setup. At first, the DGA method is selected to evaluate the transformer condition because this method can performed without service interruption and indicated nearly actual condition of transformer because of the up to date result. The scattering failure events are systematically recorded and its database is subsequently setup. Then, the failure analysis is statistically performed to determine the weak component of transformer. Moreover, the expected lifetime of transformer components is determined by using Weibull and Normal distributions for spare part management. The known causes of failure are used to prevent the repeated failure. Next, the web application is applied to grant the remote access of maintenance officer to central data.

2. WORKING PROCEDURE

The working procedure for this paper is as follows. Firstly, the scattering technical data from previous maintenance and historical testing record are obtained and used for database setup and systematic record.

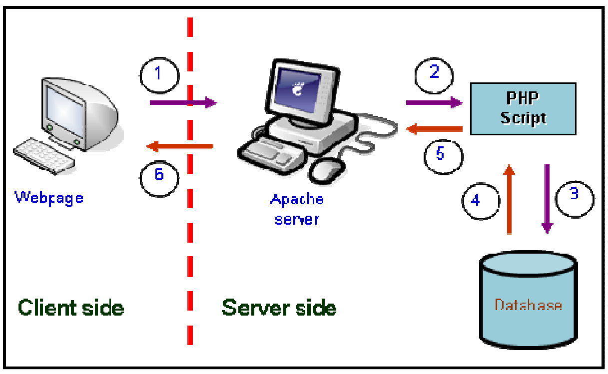

Fig.1. PHP and MySQL for Database Management Program.

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Secondly, webpage is designed for practical and convenient usage. It is performed using web application and relational database. In Fig. 1, the web application design, PHP language, apace server and PhpMyAdmin program is developed for database management.

Thirdly, power transformer models are selected for the study based on the available technical data from maintenance, historical testing record and number of power transformer in service.

Fourthly, the scattering existing data according to region, location, manufacturer and rating and etc are classified. The failure data are divided into major and minor failures by their definitions before recording into the database.

Next, the technical data, which is performed by the analysis of the existing maintenance data for failure statistic and historical testing data for condition evaluation, are analyzed. In data analysis, the percentage of component failure is calculated and condition evaluation is performed by using the Dissolved Gas Analysis (DGA) method [4]-[6]. By this mean, the failure pattern and deterioration trend can be observed and protected. The DGA historical testing results will be interpreted by key gas method [7] and verified by total combustible gas [7], the amount of key gas [7], Dörnenburg and Roger ratio methods [8]. Additional to this step, Weibull and Normal distribution statistical methods are applied to find the failure rate and system reliability caused by each component. Compared to expert system, this program is less complex and suitable for a rough analysis to predict possible problem of transformer. However this program should be subsequently improved by adapting the analysis with the expert system.

Finally, the maintenance activities can be optimally specified from component criticalities, failure causes. Therefore, the aging pattern and trend of the power transformer deterioration can be determined. The result is used to determine the suitable maintenance activities according to component failure, component condition and demand. Moreover, the failure rate of power transformer can be reduced by implementing the preventive measure according to the known causes of failure.

3. BASIC THEORY

3.1 Condition Evaluation by the DGA Technique

The historical testing record has been analyzed by using the DGA. This method is generally used to determine transformer condition by analyzing quantities of combustible gases in oil. The DGA method consists of three well known methods as key gases method, total combustible gases method, and ratios method.

Key Gases Method

The key gas method can basically classify the into four cases abnormal key gas conditions; firstly arcing in oil with acetylene (C_2H_2) as a key gas, secondly corona in oil with hydrogen (H_2) as a key gas; thirdly overheated oil with ethylene (C_2H_4) as a key gas, and lastly overheated cellulose with carbon monoxide (CO) as a key gas.

Total Combustible Gases Method

The total combustible gases method provides the rough estimation of power transformer degradation and abnormal condition by analyzing the amount of gasses from oil testing. For example, if hydrogen in sampled oil is in between 0-500ppm, it indicates satisfactory operation; however, if hydrogen is more than 1000ppm, it indicates corona occurred in power transformer. Similarly, when ethylene in oil shows the value in between 0-20ppm, it is in satisfactory operation; however, when ethylene is more than 150ppm, this means severe overheating happened in the transformer. Other key gases as acetylene and carbon monoxide, when they are found more than 70ppm and 1,000ppm, the transformer faces arcing and severe overheating problems, respectively.

The Ratio Method

The ratio method is separated into two different ratios for transformer oil testing results analysis, which are Dörnenburg ratio method and Rogers ratio method [7], [8]. The Dörnenburg ratio and Rogers ratio methods are used in the analysis. The Dörnenburg ratio indicates three of the four ratios of CH_4/H_2, $C_2H_2/\ C_2CH_4$, C_2H_2/CH_4 and C_2H_6/C_2H_2. Therefore, the results will fit into three analysis categories of thermal decomposition, corona with low intensity partial discharge, and arcing with high intensity partial discharge. The Roger ratios indicate the two of the three ratios of C_2H_2/C_2H_4, C_2H_4/H_2, C_2H_4/C_2H_6. The result will fit into four analysis categories as low energy density arcing with partial discharge problem, arcing with high energy density discharge, low temperature thermal, and high temperature thermal.

3.2 Failure Statistic Analysis

Generally, the failure data of power transformer has been presented as event reports. It was usually recorded by preventive maintenance officer of the utilities, consisting of date, time, location, transformer rating, importance failure details and repair/replacement measures. The details of failure are classified into two categories as major/minor failure in order to divide the group of failure data. The major failure is defined as an unplanned service interruption of equipment caused by a lack of one or more fundamental functions with or without supply interruption. This results in a sudden change in system operating conditions and requires non-scheduled repair action [9]. The minor failure is defined as a detection or damage on equipment, which does not lead to a service interruption of equipment. It is not either immediately required a repair action or even could be repaired by a scheduled maintenance measure [9].

In the analysis, life time is defined as the time that product operated successfully or the time that product operated before it failed, measured in hrs, miles etc. Before life data analysis, failure modes and life units such as hrs, miles, cycles etc. must be clearly specified using a stochastic processes. Similarly, reliability engineering was applied to avoid catastrophic events (loss of life or property). In this paper, Weibull distribution and normal distribution methods are applied.

3.2.1 Weibull Distribution [10]

Weibull distribution is one of the most commonly used distributions in reliability engineering. Procedures for Weibull distribution are data acquisition, ranking data, plotting data on Weibull probability plot and interpreting the result. It provides reasonably accurate failure analysis and failure forecasts with extremely small samples and provides a simple and useful graphical plot. The horizontal scale is the age or time to failure (t). Vertical scale is a cumulative percentage failed or cumulative distribution function (CDF), which is proportion the units that will fail up to age (t) in percent. The Weibull parameters comprise of:

Beta parameter (β) is the shape parameter or the slope of Weibull plot. It indicates class of failure mode. The beta (β) less than 1 indicates decreasing failure rate that is called run-in or burn-in failure period. The beta (β) is equal 1, which indicates constant failure rate. This period is called design life or random failure period. The beta (β) more than 1 indicates an increasing failure rate, which is called wear out period.

Eta parameter (η) is Weibull characteristic life. It is measure of the scale or spread in the distribution of data. The eta (η) parameter is equal to the time at 63.2 percent of the unit has failed. In the other words, the eta (η) is equal to the time at 36.8 percent surviving units or reliability is equal 0.316.

Gamma parameter (γ) is the location parameter utilized when the data do not fall on a straight line, but fall on either a concave up or down curve. It is location of the origin of a distribution (time shift) and provided an estimation of the earliest time-to-failure. Period between 0 and γ is failure free time.

Weibull Statistical Properties

- Probability distribution function (PDF)

$$f(t) = \left(\frac{\beta}{\eta}\right)\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}, t \geq \gamma \quad (1)$$

- Cumulative distribution function (CDF)

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \quad (2)$$

- Reliability (R(t))

$$R(t) = 1 - F(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \quad (3)$$

- Failure rate (λ(t))

$$\lambda(t) = \frac{f(T)}{R(t)} = \left(\frac{\beta}{\eta}\right)\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \quad (4)$$

3.2.2 Normal Distribution

Maximum Likelihood Estimation (MLE)

Two quantities have been specified for the normal distribution, which are mean value (μ) and standard deviation (σ).

- Mean value (μ)

$$\mu = \frac{\sum_{i=1}^{n} t_i}{N} \quad (5)$$

- Standard deviation (σ)

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(t_i - \mu^2)}{N-1}} \quad (6)$$

Normal Statistical Properties

- Probability distribution function (PDF)

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2} \quad (7)$$

- Cumulative distribution function (CDF)

$$F(t) = \int_0^t \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2} \quad (8)$$

- Reliability (R(t))

$$R(t) = 1 - F(t) \quad (9)$$

- Failure rate (λ(t))

$$\lambda(t) = \frac{f(t)}{R(t)} \quad (10)$$

4. RESULTS

4.1 Condition Evaluation by DGA Technique Results

The condition evaluation of power transformer was studied by considering the scattering historical data of power transformers but only one example unit of power transformer was presented in this work. The oil testing record is analyzed.

The Sample Transformer

A transformer is of rated 115/22kV, 25MVA. The transformer oil was sampled in July 28, 1982 and tested in July 28, 1982. The DGA testing results are shown in Table 1. The data is analyzed from the methods in

Section 3.1.

Table 1. DGA Testing Result in July 28, 1982 of a Rated 115/22kV, 25MVA Transformer

GAS	CO	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2
VALUE	273	403	0	113	109	212

- *Key Gas Method*

From the data, it is analyzed and plotted as in Fig. 2. Acetylene (C_2H_2) is key gas with large amount of hydrogen and acetylene, which indicates the problem involving the arcing in oil.

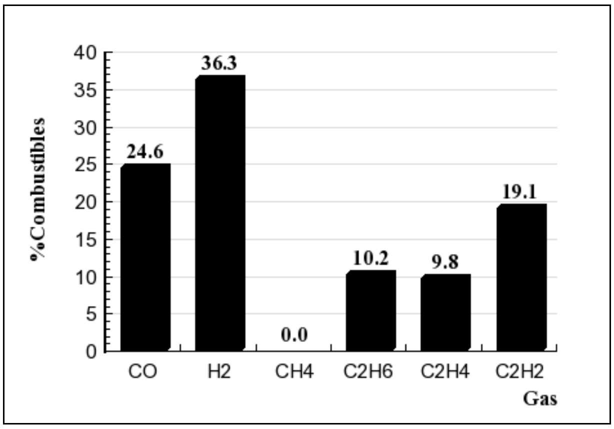

Fig.2. Percentage of Combustible Key Gases for Arcing in Oil Problem.

- *Total Combustible Gases Method*

The total combustible gases method provides the rough estimation of power transformer degradation. Fig. 3 shows the amount of total combustible gases, which reaches 1199 ppm in July 28, 1982.

This indicates the significant decomposition and the increasing trend should be carefully observed. If the amount of combustible gases remains constant, the decomposition process is stopped due to the self-healing effect. If the amount increases, then the unit can be in the danger zone.

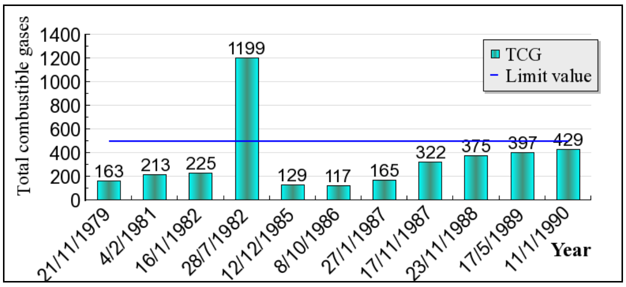

Fig.3. Relationship Between the Total Combustible Gases and Age.

From the DGA historical testing results each year, the trend of generating combustible gases is presented in Fig. 4. The increasing trend of combustible gases relative to service year of power transformer can be determined. Each combustible gas indicates the cause and severity of the problem.

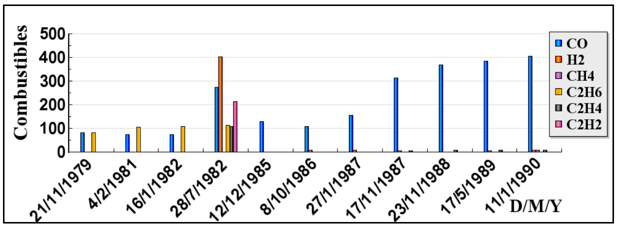

Fig.4. Relationship between Key Combustible Gases and Age.

- *Ratios Method*

The Dörnenburg ratio and Rogers ratio method are used in the analysis. The calculation of gas ratios in Table 2 and Table 3 are compared with the reference table for result interpretation. Dörnenburg ratio method indicates three of the four ratios, CH_4/H_2, C_2H_2/CH_4, and C_2H_6/C_2H_2, which fit in the category of corona (low intensity PD). Rogers Ratio Method indicates two of the three ratios, CH_4/H_2 and C_2H_4/C_2H_6, which fit in the category of low-energy density arcing-PD.

Table 2. Dörnenburg Ratio Result

DOERNENBURG RATIO METHOD APPLIED TO HISTORICAL CASES			
R1 (CH_4/H_2)	R2 (C_2H_2/C_2H_4)	R3 (C_2H_2/CH_4)	R4 (C_2H_6/C_2H_2)
0	1.94	0	0.53

Table 3. Rogers Ratio Result

ROGERS RATIO METHOD APPLIED TO HISTORICAL CASES		
R1(CH_4/H_2)	R2(C_2H_2/C_2H_4)	R5(C_2H_4/C_2H_6)
0	1.94	0.96

These analytical results are partly verified, when it is possible to untank the transformer for internal inspection. The accuracy of this analysis is now examining with the possible cases.

4.2 Failure Statistic Analysis Results

The applied power transformers consist of two sample models of 107 units of rated 115/22kV and 44 units of Rated 230/115/22kV are studied. The failure statistics consists of 157 failure events for 115/22kV and 63 failure events for 230/115/22kV power transformer respectively. The data are compared with the failure statistics according to Cigré [11].

Failure Statistics According to Cigré

According to [11], the group of power transformer components can be divided into, on/off-load tap-changer, leakage concerning tank and insulating fluid, bushing, winding, core, and others such as temperature problem. The failure of power transformer as reported in [11] is presented in Fig. 5.

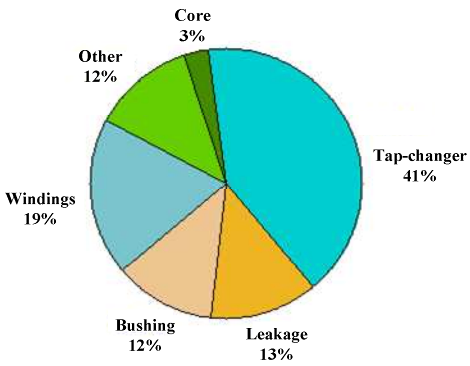

Fig. 5. Failure Statistics of Power Transformer Components Reported by Cigré [11].

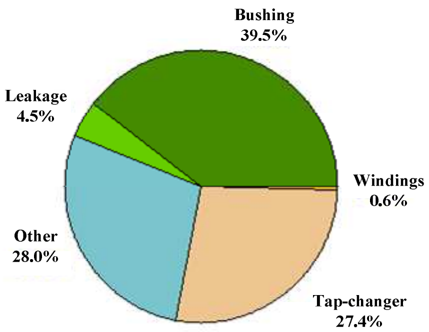

Fig. 6. Failure Statistics of Power Transformer Components for 115/22kV Power Transformer.

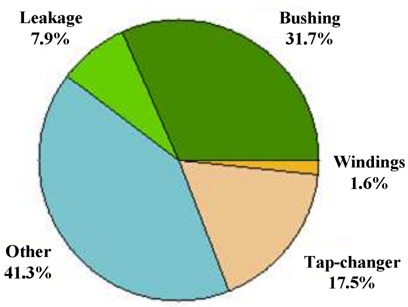

Fig. 7. Failure Statistics of Power Transformer Components for 230/115/22kV Power Transformer.

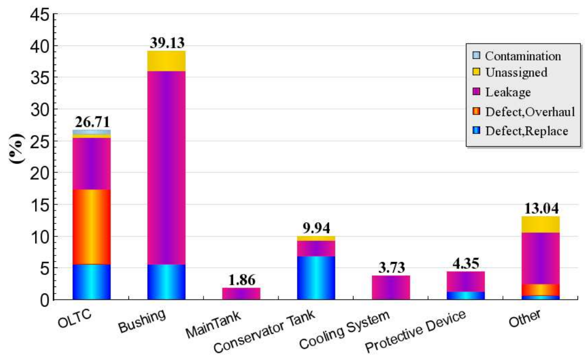

Fig. 8. Percentage of Component Failures and Their Associated Causes for 115/22kV Power Transformer.

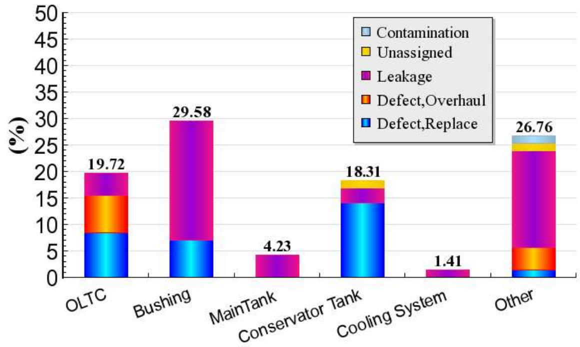

Fig. 9. Percentage of Component Failures and Their Associated Causes for 230/115/22kV Power Transformer.

Failure Statistics of Adopted Power Transformers

By dividing the failure data in the similar categories as above, the failure statistics of adopted power transformer models can be presented in Fig. 6 and Fig. 7. The failure results show the similar contribution of component failure. The critical components of both power transformer types with the highest failures are bushing and tap changer respectively.

Critical Components and Failure Causes

The percentage of component failures and their associated causes are shown in Fig. 8 for 115/22kV power transformer. From the total 158 minor failures of 107 transformer units, the components with high percentage of failure are bushing 39.13% and OLTC 26.71%. The major causes of failure are leakage for bushing, and defect and leakage for tap changer. Fig. 9 shows the percentage of component failures and their associated causes of 230/115/22kV power transformer. From the total 68 minor failures of 44 transformer units, the components with high percentage of failure are bushing 29.58% and OLTC 19.72%. The major causes of failure are leakage for bushing, and defect for tap changer.

Life Time Estimation of Power Transformer Components

For life estimation, three models of power transformers are performed as follows; 115/222kV with 25MVA and 50MVA as well as 230kV/115kV 200MVA, based on the available technical data, historical testing record and numbers in service of 53, 49 and 28 units, respectively.

The failure components, causes and results of Weibull parameters' calculation are presented in the Table 4. From data, the failure analysis is further calculated.

However, because of limitation of paper, only a tank for 115/22kV, 25MVA transformer is shown as an exemplar. The probability density function, reliability, and failure rate for tank leakage are presented in Fig. 10 to Fig. 12, respectively.

In Fig. 10, the PDF curve shows the probability density failure of tanks, which mostly fail in the age about 20 years. This because of all existing data, the age is in average of 20 years. Fig. 11 and Fig.12 show that the failure rate of the tank keeps increasing with the age; by contrast the reliability of the tank keeps reducing. As a result, the component needs to be often focused when it is operated for such a period in order to avoid any severe fault.

Table 4. Life Time Estimation by Weibull Distribution

Component	Failure causes	Rating	Weibull parameters		MTBF
			β	η	
Load Tap Changer	damage	115/22kV, 25MVA	2.92	14.83	13.23
Load Tap Changer	leakage	115/22kV, 25MVA	1.98	17.61	15.61
Bushing	leakage	115/22kV, 25MVA	2.29	24.94	22.09
Tank	leakage	115/22kV, 25MVA	2.97	22.02	19.66
Tank	leakage	115/22kV, 50MVA	3.55	16.11	14.51
Tank	leakage	115/22kV, 200MVA	2.78	22.65	20.16
Bushing	leakage	230/115kV, 200MVA	3.99	18.82	17.06

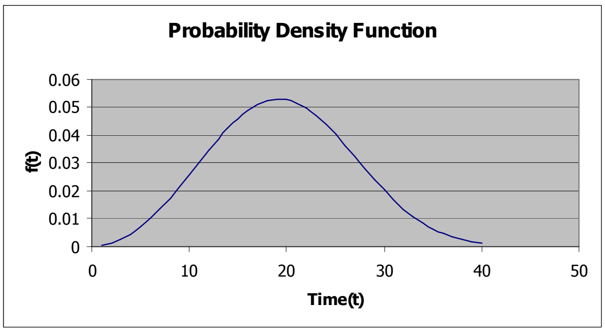

Fig. 10. Probability Density Function for Tank Leakage of 115/22kV, 25MVA Power Transformer.

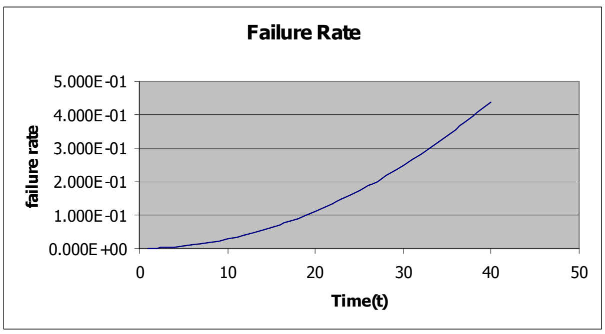

Fig. 11. Failure Rate for Tank Leakage of 115/22kV, 25MVA Power Transformer.

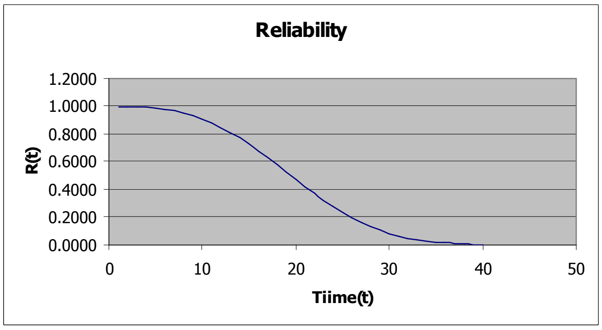

Fig. 12. Reliability for Tank Leakage of 115/22kV, 25MVA Power Transformer.

Because, the calculation result, such as percentage of component failure, its associated causes, estimated of component lifetime, MTBF, failure rate, reliability of components, are based on statistical method, the reliable result could be obtained from the reasonable number of event records and trustable data. Thus, after obtaining more and more such a good input data, the result should be more reliable.

5. CONCLUSION

The scattering historical data of power transformers was managed in a systematic database and analyzed by using developed program in the designed web-application. The different cases of power transformers were examined. The oil testing analysis was performed by applying the dissolved gas analysis in order to evaluate power transformer conditions such as normal or abnormal operating conditions. By the way, the statistic methods as the Weibull distribution and normal distribution were applied to historical failure record in order to obtain the failure rate and reliability of the transformer components. Because this program development offers data pooling, remote access by web application with user friendly interface, simple to use and allowing for further development, it is very useful for maintenance management. From the determination of the critical power transformer components and its associated causes, the strategy and process for preventive maintenance can be effectively set up. The critical components can be carefully maintained. The known causes of failure can help to avoid repeated failure and improve the transformer and system reliability. The procedure in this work can be further adapted to the other equipment in power system.

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