Pertanika J. Sci. & Technol. 25 (S): 267 - 274 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Transformer Incipient Fault Identification Using Depolarisation Current Ratio Index Analysis Technique

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ABSTRACT

Preventive tests and diagnosis of in-service power transformer are important for early fault prediction and increased reliability of electricity supply. However, some existing diagnostic techniques require transformer outage before the measurement can be performed and need expert knowledge and experiences to interpret the measurement results. Other measurement techniques such as chemical analyses of insulating oil may cause significant variance to measurement results due to different practices in oil sampling, storage, handling and transportation of oil. A cost-effective measuring technique, which is simple, providing fast and an accurate measurement results, is therefore highly required. The extended application of Polarisation and Depolarisation (PDC) measurement for characterisation of different faults conditions in-service power transformer has been presented in this paper. Earlier studies on polarisation and depolarisation current of oil samples from in-service power transformer shows that depolarisation has provided significant information about the change of material properties due to faults in power transformer. In this paper, a new approach based on Depolarisation Current Ratio Index (DRI) was developed for identifying and classifying different transformer fault conditions. The DRI at time interval of 4s to 100s was analysed and the results show that DRI of depolarisation current between 5/100s and 10/100s provides higher correlation on the incipient faults in power transformer.

Keywords: Transformer, fault analysis, depolarisation current, ratio index analysis

ARTICLE INFO

Article history:
Received: 24 August 2016
Accepted: 03 Jun 2017

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ISSN: 0128-7680

INTRODUCTION

Demands for non-invasive or non-destructive testing techniques for diagnosing and assessing the condition of transformer insulation system have increased in recent years. The need for better and improved diagnostic methods is required due to the rapidly ageing transformer population in the electrical network and the pressure of power utility to reduce operation and maintenance cost and prolong the assets' life (Lapworth et al., 1995; Schwarz & Muhr, 2008).

The well-established electrical and chemical diagnostic testing methods have been used to assess the condition of transformers due to different fault and ageing mechanisms. The presence of moisture in insulation system can be determined by dielectric dissipation factor (DDF) and insulation resistance (IR) measurement; the mechanical integrity of winding and core clamping structure due to short circuit forces can be confirmed by Frequency Response Analysis (FRA) and the problems with bad joints or connections are identified through winding resistance measurement (Wang et al., 2002; Borsi & Gockenbach; 2007). The changes in properties of insulating oil and its degree of deterioration, on the other hand can be discovered through chemical diagnostic analysis (Gradnik, 2002). In addition, decomposition of the hydrocarbon chain caused by thermal and electrical faults will liberate small quantities of gases which can be classified and quantified by means of Dissolved Gases Analysis (DGA) (Duval & DePablo, 2001; Sherif et al., 2012).

An advanced dielectric response in frequency and time domain have gained immense popularity as supplements to the existing insulation assessment techniques, and more recently, polarisation and depolarisation current (PDC) measurement has been used to estimate the moisture content and ageing of insulation system (Küchler et al., 2003) as a result of decomposition of insulation structure.

In addition, this will change the material properties which likely will change the material conductivity level as well as its charging and discharging current response behaviour. Initial research has been done by Muhamad et al. (2013) and Talib et al. (2013, 2014) on the effect of faults to dielectric response in time domain. PDC measurement on oil insulation that had experienced overheating and arcing faults showed higher polarisation and depolarisation current. Bhumiwat (2004, 2013) and Jun-Hao et al. (2008) found overheating in transformer is identified by the curved shape of depolarisation current.

The authors of this paper have investigated and analysed the effect of different faults in power transformer on polarisation current and depolarisation current spectrum of the insulating oil (Talib et al., 2015). In this paper, a new method of analysing the depolarisation current using ratio index was introduced for detecting incipient fault in power transformers.

EXPERIMENTAL MEASUREMENTS

This section describes the experimental set-up and measurement of polarisation and depolarisation current (PDC) of oil samples.

Measurement Set-Up

The polarisation and depolarisation currents are measured using the commercial PDC Analyser-1MOD Alff Engineering Switzerland, which can supply the excitation voltage up to 2kV DC and measure the dielectric response in time domain up to 10000s. The analyser is then connected to the test cell with electrode gap of 1.5mm and capacitance of 60pF. Two electrodes circuit are used, one for application of the test voltage and the other is for current measurement. The amount of insulating liquid required for the measurement is about 210ml. Figure 1 shows the measurement set-up used in the laboratory experimental works. All the measurements are carried out at 1000V and 10,000s both for polarisation and depolarisation time.

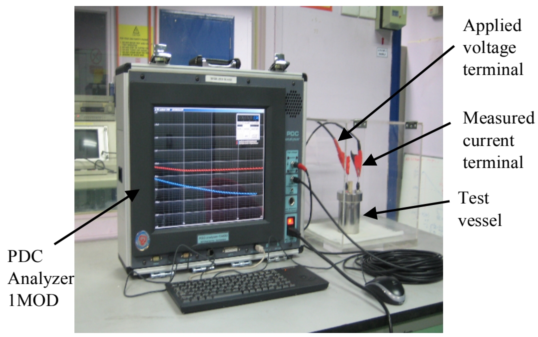


Figure 1. Experimental measurement set-up [16]

Measurement Procedure

An oil sample was taken from in-service transformers and tested for its condition using Dissolved Gases Analysis (DGA). The test samples were classified into four conditions: normal, partial discharge, overheating and arcing. The charging and discharging current of the oil samples were determined by polarisation and depolarisation current measurement. For every condition, at least 10 transformers with rated voltage of 33/11kV were selected which cover the capacity of 15MVA to 30MVA. In addition, three oil samples were taken on every transformer and the testing was repeated five times for each oil samples to ensure consistency of the results.

Before the excitation voltage is applied to the test sample, the oil will be discharged initially for 500s to minimise the effect of residual charges on measurement results. In addition, to reduce the effect of noise on polarisation and depolarisation current, all the measurements were conducted in the shielded case. Figure 2 shows the flow chart of experimental works.

TRANSFORMER INCIPIENT FAULT ANALYSIS USING DEPOLARISATION RATIO INDEX (DRI)

The analysis of both polarisation and depolarisation current has shown that different fault conditions have changed the property of oil insulation and affect the initial duration of measured current. Figure 3 (a) and (b) shows the average measured polarisation and depolarisation current.

It can be seen that polarisation and depolarisation current starts to stabilise and saturate almost after 100s of being charged and discharged. The oil with normal condition has the lowest

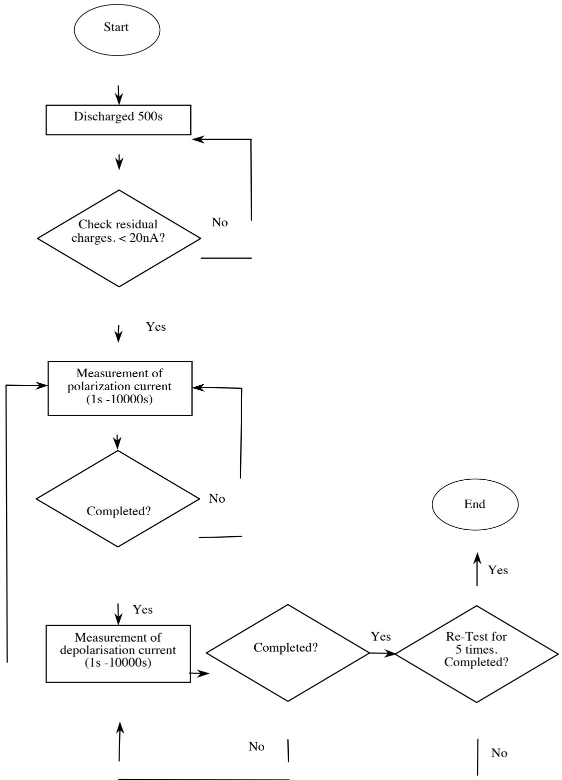
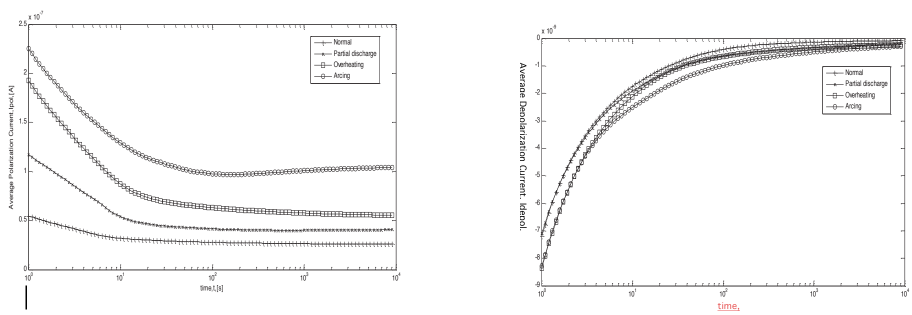


Figure 2. Flow chart of experimental works



(a) polarisation current (b) depolarisation current

Figure 3. Polarisation and depolarisation current of transformer with different conditions

magnitude current and the values were progressively higher on oil sample with partial discharge, overheating and arcing fault conditions. The high measured current of oil samples with fault conditions can be attributed to the fact that faulty power transformers cause breakdown of hydrocarbon structures of oil, thus, leading to higher charge carrier mobility and high current magnitude when any external electric field is applied (Houhanessian & Zaengl, 1996).

Talib et al. (2015) using Artificial Nueral Network (ANN) demonstrated that depolarisation current has better accuracy in identifying incipient fault in power transformers and the current pattern at duration of 4s to 100s was found to have deviated differently between normal, partial discharge, overheating and arcing fault of oil samples as illustrated in Figure 4.

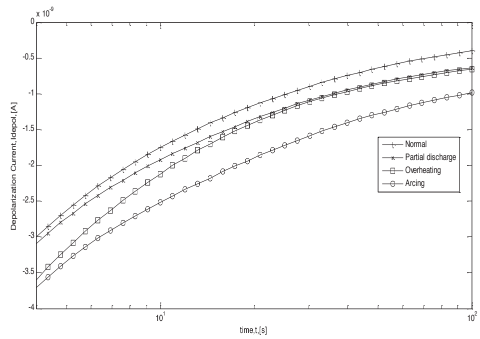


Figure 4. Depolarisation current pattern of oil samples at duration of 4s to 100s

On the other hand, the incipient fault in the transformer can be further analysed by determining the steepness of each of the current pattern to denote the changes in depolarisation current. In this research, a single unique numerical dimensionless quantity known as Depolarisation Ratio Index (DRI) was proposed to characterise different faults in power transformers.

Depolarisation current is continuously decreased and after 100s, the currents reach its steady condition and almost zero current is finally recorded. Thus, depolarisation current at 100s can be used as denominator of the dimensionless variable.

Meanwhile, the numerator of the dimensionless variable of depolarisation current is initially selected from the period of 5s to 40s and was analysed for every 5s interval. The Depolarisation Ratio Index (DRI) on every sample is then calculated using (1) and a detailed analysis is made on the respective DRI interval that gives the highest correlation.

$$DRI = \left(\frac{Depolarisation\ Current\ at\ n^{th}}{Depolarisation\ Current\ at\ 10C}\right. \quad (1)$$

RESULTS AND DISCUSSION

The DRI of dimensionless variables between 5s to 40s intervals and its correlation with different transformer conditions are shown in Table 1. The correlation is determined based on number of transformers that the calculated DRI is within the range and consistent with the condition identified from Dissolved Gases Analysis.

Table 1
Results of DRI between 5s to 40s interval for transformer with normal, partial discharge, overheating and arcing condition

Transformer Condition	Dimensionless Variable	DRI	% Correlation
Normal	5s/100s	>6.305	91.62%
	10s/100s	>4.463	66.67%
	15s/100s	>3.657	25.00%
	20s/100s	>2.958	25.00%
	25s/100s	>2.637	16.67%
	30s/100s	>2.345	25.00%
	35s/100s	>2.066	16.67%
	40s/100s	>1.935	16.67%
Partial Discharge	5s/100s	6.052<x<6.305	25.00%
	10s/100s	4.015<x<4.463	25.00%
	15s/100s	2.239<x<3.657	37.50%
	20s/100s	1.845<x<2.958	37.50%
	25s/100s	1.682<x<2.637	37.50%
	30s/100s	1.541<x<2.345	37.50%
	35s/100s	1.419<x<2.066	37.50%
	40s/100s	1.365<x<1.935	37.50%
Overheating	5s/100s	5.644<x<6.052	72.72%
	10s/100s	3.784<x<4.015	72.72%
	15s/100s	2.136<x<2.239	63.63%
	20s/100s	1.757<x<1.845	81.81%
	25s/100s	1.607<x<1.682	63.63%
	30s/100s	1.481<x<1.541	63.63%
	35s/100s	1.373<x<1.419	27.27%
	40s/100s	1.327<x<1.365	45.45%
Arcing	5s/100s	2.846<x<3.564	66.67%
	10s/100s	2.223<x<2.612	58.33%
	15s/100s	1.945<x<2.136	25.00%
	20s/100s	1.688<x<1.757	16.67%
	25s/100s	1.571<x<1.607	25.00%
	30s/100s	1.466<x<1.481	16.67%
	35s/100s	1.371<x<1.373	33.33%
	40s/100s	1.327<x<1.365	16.67%

The longer time interval selected as the dimensionless variable, the higher the DRI calculation compared with the shorter time interval as depolarisation current at lower time response is higher and slowly diminishes at the end of completion of discharging process.

The DRI of 5/100s and 10/100s has higher correlation and percentage correlation calculated for normal condition is 91.62% and 66.67%. The overheating fault has correlation of 72.72% for both variables and arcing fault was 66.67% and 58.33% respectively. However, it can be seen that the DRI of 20/100s for overheating fault has higher correlation with calculated value of 81.81%. On the other hand, it is observed that partial discharge fault has low correlation with only 25% accuracy calculated for both variables. Multiple faults in the test samples is one of the possible reasons that contributed to the difficulty in differentiating the partial discharge fault using the DRI.

Meanwhile, DRI for the dimensionless variable of 15/100s, 20/100s, 25/100s, 30/100s, 35/100s and 40/100s was found to have lower correlation with less than 50% accuracy. This can be explained by the fact that the changes in depolarisation current are relatively small at higher time response as the current has been fully discharged.

The result demonstrated that the time interval of depolarisation current between 5/100s and 10/100s provide significant information on the incipient faults in power transformer as the percentage of correlation calculated is more than 50% accurate.

CONCLUSIONS

In this paper, changes of depolarisation current pattern of different transformer conditions was further analysed by Depolarisation Ratio Index (DRI) technique. The dimensionless quantity at time interval of 4s to 100s was analysed and it is found that DRI of depolarisation current between 5/100s and 10/100s provide higher correlation on the incipient faults in power transformer especially the units with normal, overheating and arcing condition.

The result demonstrated that DRI analysis technique of depolarisation current is feasible as diagnostic indicator for incipient fault analysis and immediate action can be taken at an early stage to prevent outage of power transformers.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of TNB and Malaysia Ministry of Higher Education, Universiti Teknologi Malaysia (Vot 10H16 and 4F515) for technical and financial support.

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