# Fault Identification of In-Service Power Transformer using Depolarization Current Analysis

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**ABSTRACT**

Preventive diagnostic testing of in-service power transformers require system outage and expert's knowledge and experiences in interpreting the measurement results. The chemical oil analysis may cause significant variance to measurement results due to the different practices in oil sampling, storage, handling and transportation. Thus, a cost effective measuring technique by means of a simpler method that is able provide an accurate measurement results is highly required. The extended application of Polarization and Depolarization Current (PDC) measurement for characterization of different faults conditions on in-service power transformer has been presented in this paper. The oil sample from in-service power transformers with normal and 3 different faults type conditions were sampled and tested for Dissolved Gases Analysis (DGA) and PDC measurement. The DGA results was used to confirm type of faults inside the transformer while the PDC pattern of oil with normal, partial discharge, overheating and arcing were correlated to the oil sample conditions. The analysis result shows that depolarization current provides significant information to defferenciate fault types in power transformer. Thus this finding provides a new alternative in identifying incipient faults and such knowledge can be used to avoid catastrophic failures of power transformers.



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## 1. INTRODUCTION

The continuous supply of electricity from generating stations to the customer is very much dependent on reliability of power transformers installed in the substations [1]. The failures of this strategic unit at any substation can cause interruption of power supply and substantial damage to other components. It may also become potentially dangerous for utility personnel as failures may result to explosions and fire. Therefore, determining their condition would be of tremendous importance to the power utilities. Presently, the maintenance paradigm has moved from scheduled based maintenance to condition based maintenance with the objective to minimize the operational cost and improve the reliability of transformers [2], [3]. A new material and maintenance techniques mainly towards condition based maintenance thus continuously developed to sustain high power reliability and availability [4].

Well established chemical and electrical diagnostic testing methods have been used to assess the condition of the transformer and classified them according to different fault and ageing mechanisms. For example, the presence of moisture in insulation system can be determined by dielectric dissipation factor (DDF) and insulation resistance (IR) measurement [5], while the mechanical integrity of winding and core clamping structure due to short circuit forces can be confirmed by Frequency Response Analysis (FRA) [6], [7] and the problems with bad joints or connections are identified through winding resistance measurement [8]. For instance, decomposition of the hydrocarbon chain caused by thermal and electrical faults will liberate small quantities of gases and can be classified and quantified by means of DGA [9-11].

Nevertheless, the existing diagnostic technique particularly electrical measurement require electrical isolation or transformer outage before the measurement can be performed. Beside that, the duration for the complete measurement on one transformer which can last for several hours has concerned the power utilities which limit the measurement on basic routine testing and applied on the selected critical transformer due to difficulties of long hour outages. In some situations, due to system overloading the outage of power transformer is not permitted and caused the insulation ageing is not being assessed and determined.

Even though, the chemical analyses on transformer oil insulation provide direct information on parameters like oil moisture content, sludge, acidity, Degree of Polymerization (DP) and DGA [12-14], however, most of the chemical analyses are conducted under laboratory condition where sample sampling, storage and transportation cause significant variance due to different practices and location of the site. All these will incurred high cost to the power utilities as part of their condition based maintenance activities.

In order to avoid any unwanted circumstances, accurate assessment of transformer condition is crucial so that replacement or refurbishment of the assets can be taken before failures take place. Thus, a cost effective measuring technique, simpler but can provide an accurate measurement results is highly required.

In this paper, the PDC was investigated to be used as an alternative diagnostic technique to determine the incipient fault occurs in power transformers. The oil samples was taken from various transformers and tested for its condition. The analysis of PDC pattern for transformers with normal, partial discharge, overheating and arcing faults conditions are presented in this paper. An Artificial Neural Network (ANN) was used to identify each spectrum characteristic for faults identification and the results was compared with other established diagnostic interpretation techniques.

## 2. POLARIZATION AND DEPOLARIZATION CURRENT MEASUREMENT

This section covers the details of experimental test set-up and the testing procedure of PDC measurement.

### 2.1. Measuring Test Circuit

The polarization and depolarization current are measured using the commercial PDC known as Analyzer-1MOD manufactured by Alff Engineering Switzerland. The analyzer can supply the excitation voltage up to 2kV DC and measure the dielectric response in time domain up to 10000s [15]. The analyzer is then connected to the test cell with electrode gap of 1.5mm and capacitance of 60pF. Two electrodes circuit were 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 were carried out at 1000V and polarization and depolarization times of 10,000s each.

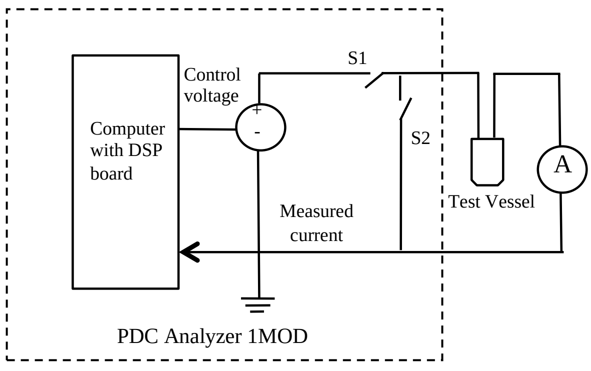



Figure 1. Laboratory Experimental Test Set-Up [15]

**2.2. Oil Test Sample**

The oil samples used in this experiment are hydrocarbon based mineral oil obtained from in-service transformers operating at Malaysia power distribution network. The operating conditions of these transformers had previously been identified based on DGA data of their respective oil samples. The test samples were classified into four conditions; normal, partial discharge, overheating and arcing. Prior to PDC measurement, the DGA was performed again on the oil samples to confirm the presence of combustible gases and its nature of faults.

In each condition, the oil samples were taken from 10 units of power transformers and every unit has 3 samples; i.e. there are 30 oil samples for each condition. Each PDC assessment was repeated for five times on all oil samples. The aim of having such a large number of the same samples and repetition of PDC assessment process was to ascertain the reproducibility of the test results.

To avoid the effect of moisture on polarization and depolarization current measurement, it was crucial that the oil samples were dry. Thus, the selection of transformers are limited to the units with moisture content less than 30ppm; considered dry according to IEC 60422-2013 [12].

**2.3. Testing Procedure**

The consistency of experimental test results is highly dependent on the PDC test procedure used. The test vessel must be cleaned prior to each measurement process as contamination from previous oil samples could affect the next test results. The residual charges can also affect the polarization current results, thus before the excitation voltage is applied to the test sample, the test object was discharged for 500s. For safety purposes, the test sample was placed in the shielded case. Figure 2 shows the flow chart of experimental works.

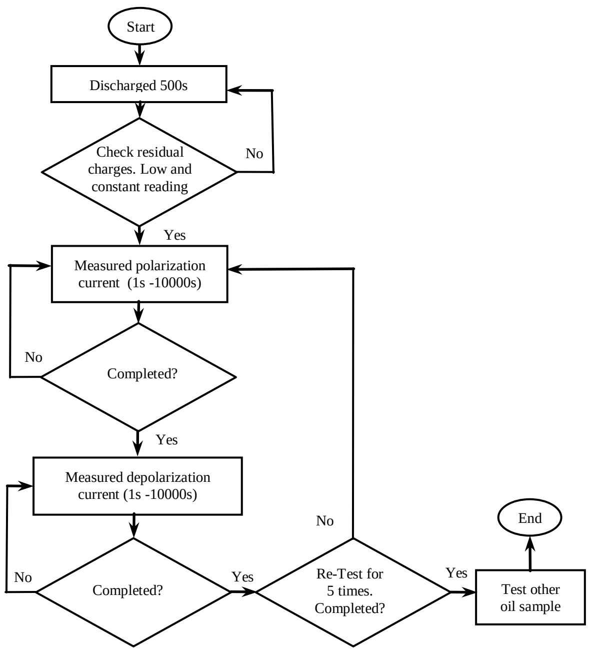


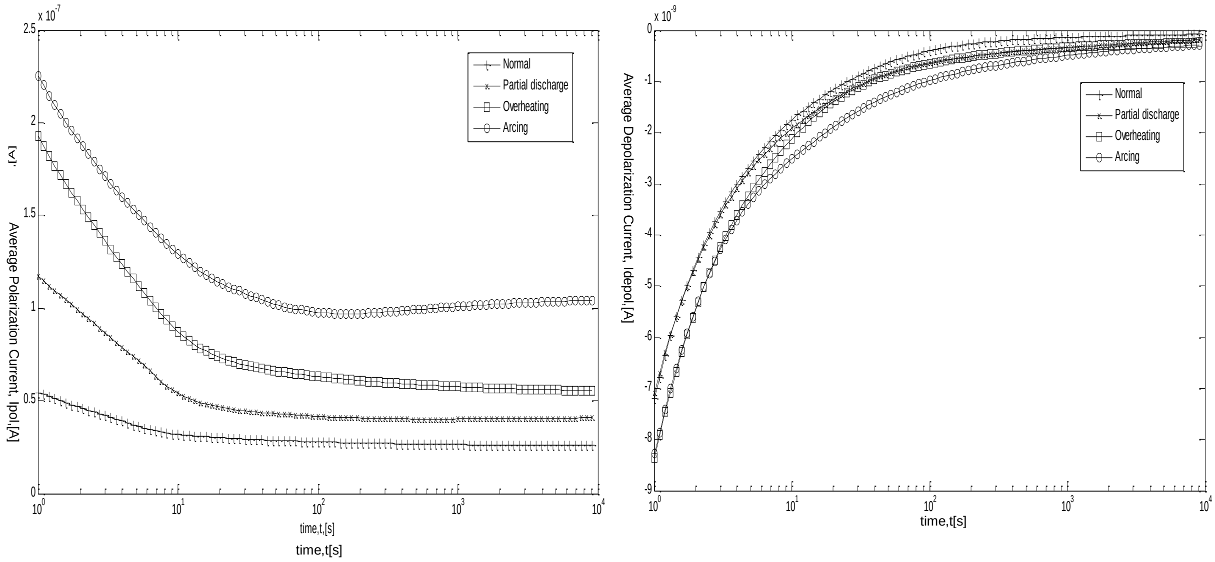

Figure 2. Flow Chart of Experimental Works

**3. RESULTS AND DISCUSSIONS**

The polarization and depolarization current of oil with different fault conditions in this research are analyzed based on its graphical pattern obtained from the experiments. Artificial Neutral Network (ANN) was used to further analyze the measured currents for transformer fault identification.

**3.1. Analysis of Polarization and Depolarization Current**

Since oil was the only insulation tested in this research, it would be expected that the changes of measured current is attributed to changes at the initial time response [16]. Figure 3(a) and (b) shows the average of polarization and depolarization current on oil samples with normal, partial discharge, overheating and arcing condition. The analysis of polarization current demonstrated that the measured current starts to stabilize and saturated almost after 100s of being charged until the completion of polarization process. Meanwhile, the depolarization current takes a longer time and only after 1000s the measured currents are starts to stabilize until the end of discharging process.




(a) Polarization current (b) Depolarization current

Figure 3. Polarization and depolarization current pattern of normal, partial discharge, overheating and arcing oil samples

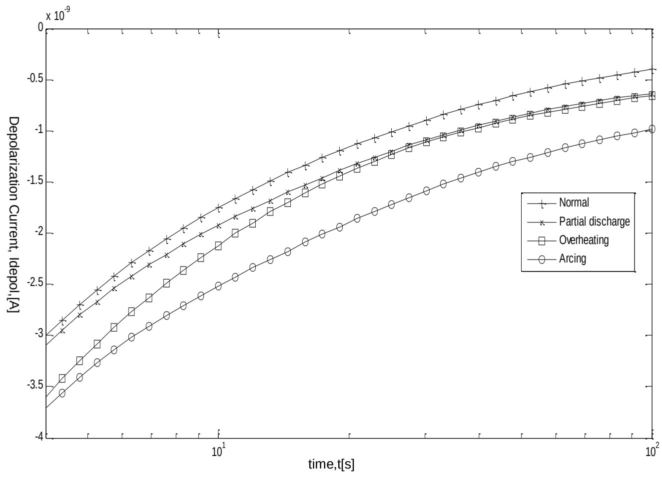



Figure 4. Depolarization current pattern of oil samples at duration of 4 seconds to 100 seconds

The curves have shown that the oil with normal condition had the least value of polarization current, while the values were progressively higher in partial discharge, overheating and arcing fault conditions. The average magnitude of maximum polarization current recorded on normal oil sample is 50.23nA, partial discharge is 118.33nA, overheating is 184.96nA and arcing is 226.45nA. The high polarization current of oil samples with fault conditions can be attributed to the fact that faults in power transformer 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. In addition, it can be seen that the polarization current pattern seemingly correspond to degree of fault; the initial slopes of the oil samples with fault conditions are steeper than the oil with normal condition.

The plot of depolarization current on oil samples with normal, partial discharge, overheating and arcing fault conditions shows that the depolarization curves are almost identical. The average magnitude of maximum depolarization current recorded is -7.12nA for normal oil samples, -7.06nA for partial discharge, -8.31nA for overheating and -8.28nA for arcing samples.

An interesting point was observed on depolarization current pattern at duration of 4 seconds to 100 seconds as the responses are changes with different transformer conditions, as shown in Figure 4 It can be seen that the normal oil condition has low current pattern and as the energy of the fault increases the current pattern of oil samples with fault conditions are also increases.

### 3.2. Selection of Current for Fault Identification

According to [17], the polarization current is the combination of the absorption current due to polarization and the conduction current. On the other hand, the depolarization current consists only of the absorption current because conduction current exists only when the voltage is applied to the dielectric. From the results, both polarization and depolarization currents were found to have correlation with faults in power transformer. Nevertheless, it is important to identify and classify the currents that are effectively used to characterize incipient faults in power transformers.

In this research, an Artificial Neural Network (ANN) was used to further analyze the currents for transformer fault identification. The design and simulation of the ANN was done using Neural Network Toolbox provided in MATLAB.

Initially, the input data was normalized with the objective of ensuring a uniform statistical distribution of each input value. In this research, the maximum and minimum values of a group of data are used to normalize each single input using the following equation

$$\mathrm{I} = \mathrm{I_{min}} + (\mathrm{I_{max}} - \mathrm{I_{min}})\left[\frac{\mathrm{D} - \mathrm{D_{min}}}{\mathrm{D_{max}} - \mathrm{D_{min}}}\right] \tag{1}$$

where $I$ is the normalized value of a single data. $I_{min}$ and $I_{max}$ are the input range of the ANN and the typical range is -1 to 1 or 0 to 1. $D$ is the input value for each data while $D_{min}$ and $D_{max}$ are the minimum and maximum values of the input data.

The ANN is a 3 layered structure comprised of input, hidden and output layer. In order to increase the prediction capability of the network, the ANN utilized 2 hidden layers with 100 neurons on each layer. Initially, the learning algorithm employed to train the ANN is Back Propagation (BP). However, the algorithm is too slow for practical problem due to the fact that multilayer networks use sigmoid transfer functions in the hidden layers. These functions, known as ‘squashing’, compress infinite input range into a finite output range. Sigmoid function is characterized by the fact that their slope must approach zero as the input gets large. This causes a problem when using steepest descent to train a multilayer network with sigmoid function because the gradient can have a very small magnitude; therefore causing small changes in the weights and biases, even though the weights and biases are far from their optimal values. Thus, a faster Back Propagation (BP) algorithm known as Resilient Back Propagation (Rprop) was used as learning algorithm to train the ANN.

This algorithm eliminates the harmful effects of the magnitudes of the partial derivatives. Only the sign of the derivative determines the direction of the weight update. The size of the weight change is determined by a separate update value. The update value for each weight and bias is increased by a factor that depends on the derivative of the performance function with respect to weight changes sign from the previous iteration. If the derivative is zero, the update value remains the same. Whenever the weights are oscillating, the weight change is reduced. If the weight continues to change in the same direction for several iterations, the magnitude of the weight change increases.

Table 1. Relationship of ANN output value and type of fault

| Output Neuron Value | Type of Fault |
|---|---|
| 1000 | Normal |
| 0100 | Partial discharge |
| 0010 | Overheating |
| 0001 | Arcing |

A PDC sample with a total of 21,900 input data were used to train the ANN and later was tested with another PDC sample data that is separated from the earlier training data. The output will then refer to different types of faults as shown in Table 1. The training procedure and the ANN structure with 2 hidden layers are shown in Figure 5 and Figure 6 respectively.

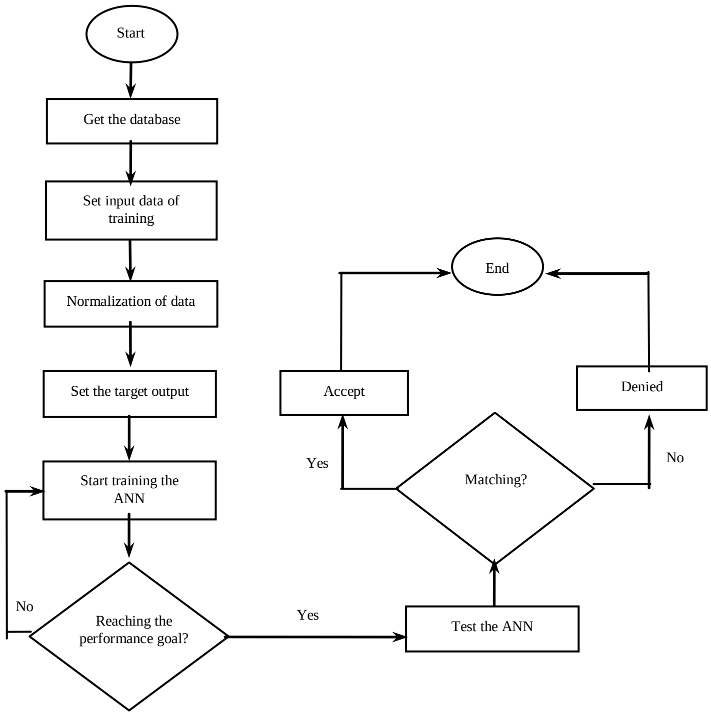



Figure 5. ANN training procedure

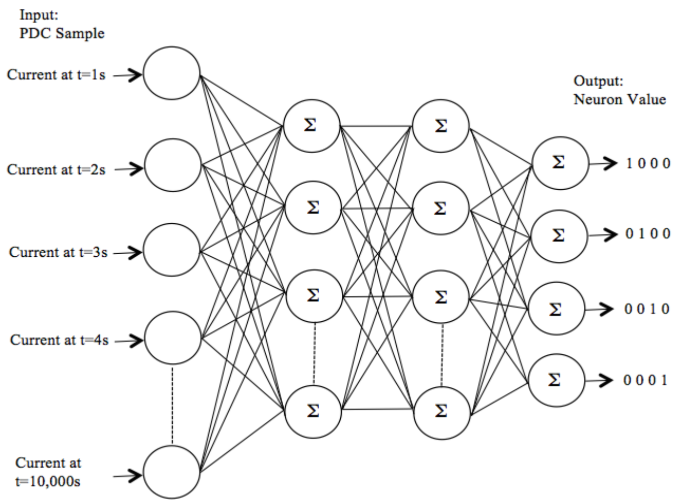



Figure 6. Schematic diagram of the ANN

Finally, the accuracy and performance of the ANN output is determined by the following equation,

$$\frac{\text{Number of correct fault recognised}}{\text{Total number of fault tested}} \text{x}100\% \quad (2)$$

The results of ANN analysis on polarization and depolarization current are shown in Table 2.0 and Table 3.0 respectively.

Table 2. ANN result of polarization current

| Condition | Correct output recognised | Wrong output recognised | % ANN Accuracy |
|---|---|---|---|
| Normal | 87 | 3 | 97 |
| Partial discharge | 58 | 7 | 80 |
| Overheating | 15 | 5 | 75 |
| Arcing | 36 | 9 | 90 |

Table 3. ANN result of depolarization current

| Condition | Correct output recognised | Wrong output recognised | % ANN Accuracy |
|---|---|---|---|
| Normal | 86 | 4 | 96 |
| Partial discharge | 60 | 5 | 92 |
| Overheating | 19 | 1 | 95 |
| Arcing | 43 | 2 | 96 |

The ANN analysis of polarization current demonstrated that higher accuracy of more than 90% was observed for oil samples on transformer with normal and arcing fault conditions. On the other hand, lower accuracy was observed for identification and classification of partial discharge and thermal overheating faults as the accuracy recorded is only 80% and 75% respectively.

Meanwhile, higher accuracy of more than 90% was recorded for depolarization current on all conditions. Both normal and arcing condition has ANN accuracy of 96%, whereas thermal overheating fault has accuracy of 95%. The partial discharge fault was observed slightly lower with ANN accuracy of 92%. Based on this ANN simulation results, depolarization current yielded a better accuracy in identifying and classifying different transformer conditions as compared to polarization current and identified as the current of main interest that can be uniquely used for fault identification of in-service power transformer.

The results has confirmed the initial research done by Bhumiwat [18] on overheating of transformer solid insulation stated that the condition can be identified by the prominently crooked shape of the depolarization current.

## 4. CONCLUSION

In this paper, the extended application of PDC measurement for characterization of different faults conditions of in-service power transformer was investigated. The oil sample with normal, partial discharge, overheating and arcing condition were taken from respective units and tested for its combustible fault gases, polarization and depolarization current.

The changes of the molecular properties of the insulating oil material due to different fault conditions was found influences the initial time response of both measured currents. The sensitivity analysis using Artificial Neural Network (ANN) shows that depolarization current gives a better accuracy in identifying and classifying different transformer conditions as compared to polarization current. Thus, depolarization current measurements provide a new alternative in identifying incipient faults and such knowledge can be used to avoid catastrophic failures of power transformers.

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