A SIGNAL PROCESSING TECHNIQUE FOR PD DETECTION AND LOCALIZATION IN POWER TRANSFORMER

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I would like to dedicate this thesis to my parents, my wife and my son

for their endless love and guidance which always helps me

to choose the right path

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ABSTRACT

The activity of partial discharge (PD) is major problem that causes degradation to the insulation system. Due to continuous stresses of high voltage it may lead to complete breakdown of insulation system. Due to the high cost of transformer windings, especially in the case of high kVA capacity, it is necessary to find a way to localize the PD along the winding length so that only faulty part is replaced instead of the whole winding. In this project a new technique of a digital signal processing method based on the Fast Fourier Transformation (FFT) is applied to locate the PD. The transformer winding was modelled in Matlab using an equivalent lumped transformer circuit for each winding section. The PD source is injected at different section, each section represent a different PD location. The output current was then analysed using FFT. For validation, comparisons had been made with the results of an experimental work on the same transformer winding configuration as well as with theoretical equations. The work has shown that the frequency spectra of the simulated output current have the same characteristic as that for the measured signal as well as for the theoretically derived transfer function. It is also shown that the crests and troughs in the frequency spectra could be used for locating the source of the discharge activity in the power transformer winding. The frequency of the zero in the simulated spectra increases as the discharge moves away from the measuring terminal. The poles are however not affected by the position of the PD source. An Artificial Neural Network (ANN) was successfully used to determine the section number where PD occurs based on just the frequency response of the output current. Further studies on the effects of the modelling parameters such as variations in the capacitance and inductance values due to factors such as ageing on the PD localization show that the capacitance is the most sensitive parameter in the model. In addition, it is also shown that the effect of noise on the PD localization can be eliminated using the Free Induction Decay (FID) technique.

ABSTRAK

Aktiviti nyahcas separa (PD) adalah satu masalah besar yang menyebabkan keburukan kepada sistem penebat. Kerosakan penuh pada sistem penebat boleh berlaku disebabkan oleh tekanan berterusan voltan tinggi. Disebabkan harga lilitan pengubah yang tinggi, terutama apabila melibatkan kapasiti kVA yang besar, satu kaedah untuk menentukan lokasi PD sepanjang lilitan adalah sangat penting agar hanya bahagian yang rosak sahaja perlu digantikan berbanding keseluruhan lilitan. Projek ini memperkenalkan satu kaedah baru yang menggunakan pemprosesan isyarat digital berasaskan 'Fast Fourier Transformation' (FFT) bagi menentukan lokasi PD. Lilitan pengubah dimodelkan dalam Matlab menggunakan litar setara tergumpal bagi setiap seksyen lilitan. Sumber PD dikenakan pada setiap seksyen, setiap seksyen mewakili satu lokasi PD. Arus keluaran kemudiannya dianalisis menggunakan FFT. Untuk pengesahan, perbandingan telah dibuat dengan hasil pengukuran dari pengubah yang mempunyai konfigurasi sama dan juga persamaan teori. Didapati spektra frekuensi arus keluaran yang disimulasi mempuyai ciri yang sama dengan ciri isyarat dari eksperimen dan dari rangkap pindah yang diterbitkan secara teori. Puncak dan paluh spektra frekuensi boleh digunakan untuk menentukan lokasi nyahcas separa di dalam lilitan pengubah kuasa. Frekuensi sifar pada spektra frekuensi bertambah berkadar dengan lokasi PD menjauhi terminal pengukuran. Walaubagaimanapun, frekuensi kutub tidak dipengaruhi oleh sumber PD. 'Artifical Neural Network' (ANN) telah digunakan dengan jayanya untuk menentukan nombor seksyen lilitan di mana berlakunya PD berasaskan hanya sambutan frekuensi arus keluaran. Kajian lanjutan ke atas kesan parameter model seperti perubahan kapasitan dan keraruhan disebabkan oleh faktor seperti penuaan ke atas lokasi PD menunjukkan kapasitan merupakan parameter model yang paling sensitif. Telah ditunjukkan juga bahawa kesan hingar ke atas penentuan lokasi PD boleh dihapuskan dengan menggunakan kaedah 'Free Induction Decay' (FID).

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LIST OF SYMBOLS AND ABBREVIATIONS

Vref	-	Reference signal of PD
si(t)	-	Reference signals of the responses of winding si(t)
rx(t)	-	Test signals of the responses of winding rx(t)
tref	-	Reference pulse width in μs
ttest	-	Test PD pulse in μs
Pix	-	Correlation coefficient
α	-	Winding distribution factor
H(w)	-	Gain of the two end voltages in dB
v_x	-	Voltage variation from the neutral to the distance x
K	-	Capacitance of inter-turn and inter-disc transformer winding
C	-	Capacitance to ground including the capacitance of the core and tan
L	-	Inductive branch of each turn conductor
R	-	Resistance branch of each turn conductor
CB	-	Bushing capacitance
l	-	Total length of winding
Cc	-	Capacitance of cylindrical void
Cb	-	capacitance of the remaining series insulation with void
Ca	-	capacitance of the remaining discharge-free insulation of the rest of the solid insulator
N	-	The number of samples
fs	-	Sampling frequency
N	-	The number of samples
fs	-	Sampling frequency
UL	-	Voltage at line end
IL	-	Current at line end

UN	-	Voltage at neutral end
IN	-	Current at neutral end
CL	-	The line end capacitance
CN	-	The neutral end capacitance
a,b	-	Designed separable FIR filter coefficient vectors
η_k	-	learning rate η_k
$\partial E/\partial w$	-	Partial derivatives of the error function with respect to the weights
W_0	-	The weight on the output connection
$W_{1,}$ W2. . . W_n	-	The weight on the input connection
$X_{1,}$ X2. . . X_n	-	n outside stimuli
$y_{1,}$ y2. . . y_n	-	Output from the n neurons
IFFT	-	Invers Fourier Transform
TFL	-	Transfer Functions between the PD source and the Line- End
TFN	-	The transfer Functions between the PD source and the Neutral-End
FIR	-	Finite Impulse Response Digital Filter
IIR	-	Infinite Impulse Response Digital Filter
WGN	-	White Gaussian Noise
A/D	-	Analogue to Digital Convertor
Zoh	-	Zero Hold error
FID	-	Free Induction Decay
ANN	-	Artificial Neural Network
f()	-	a function
E	-	Error function
SSE	-	Sum of Squared Errors
MLP	-	Multi-Layer Perceptrons
BP	-	Back Propagation Algorithim

CHAPTER 1

INTRODUCTION

1.1 Introduction

There are many assets in electric power system, which are very expensive, and the most significant and an expensive component in the grid station is the power transformer. It is considered to be one of the essential and costly equipment that operate like heart of the power system. Its insulation is very important and detection of insulation faults is the best possible preventive measurements to avoid irreparable damages. The life of Power transformer could be extended by insulation monitoring through PD measurements. It is not only economically valuable, but also saves lots of revenues. The PD activity is one of the most common phenomenon's that become cause of insulation faults. Other sources are mechanical deformations, which leads to defects in power transformers that can cause insulation failure [1]. Considering the fact that early detection of PD can prevent complete failure of the transformer insulation and breakdown, a precise modelling of partial discharge associated with transformer winding in high frequencies mode has been performed. To reduce the maintenance time and cost the exact detection of PD activity in the insulating structure near the transformer windings has a great importance [2].

1.2 Background

Partial discharge (PD) is defined as localized electrical discharge within only a part of the insulation between two separated conductors. In the real applications, PD is caused by the existence of voids in the insulation. Even if the local electrical field in the void exceeds a threshold and a dicharge occurs, it is limited within the void due to the strong surrounding insulation, enough to avoid a complete breakdown. PD in voids is considered harmful, especially in high-voltage systems from the engineering viewpoint as they cause energy loss and gradually degrade the insulation [1].

PD may occur in solid, liquid and gaseous insulation media and are generally initiated by an excessive localized electric field. The PD induced current in an external circuit depends on the nature of the discharge and the geometry of the system [2]. In many cases, where there are electrically weak areas in solid dielectric materials (most often gaseous or liquid inclusions), PD can be measured when enough voltage is applied. PD phenomenon causes degradation in insulated materials[3]. The investigation of insulated material behaviour under electrical stress and the data obtained from PD measurements, provide the possibility to predict dielectric breakdown. There are three main types of PD: (i) micro discharges in small voids, which always exist both at the surface of electrodes and in the volume of insulators; (ii) breakdowns along the boundaries between two insulators (typically along the solid insulator–gas interface); and (iii) PD in the channels of branched structures (streamers) propagating in the volume of a dielectric medium. The second and third PD types can be considered as incomplete breakdown, since the insulating properties of a dielectric are not violated[4,5].

Consequently, on-line PD measurement is a powerful condition monitoring technique that is now being devcloped for use with power transformers. Techniques for the location of a PD are of major importance in on-site maintenance and repair. The PD pulse suffers distortion and attenuation as it travels from the site-of-origin to the measuring terminal. Consequently, the measured signal is a highly distorted representation of the original PD pulse, but it does contain useful information about the location and nature of the discharge. If this information can he extracted and analysed, the PD source may he located[6,7]. The different frequency ranges that describe the spectra of the measured PD signal, the modes of propagation in the transformer winding have different characteristics. In the lower frequency range (e.g. 0 to 0.0IMHz) the component of a PD pulse that propagates in the, winding is predominantly an electromagnetic wave that travels along the galvanic path. In the intermediate frequency range (e.g. 0.01 to 0.1MHz) the propagation is dominated by the characteristic resonances of the winding. In the higher frequency range (e.g. 0.1 to 10 MHz) the propagation is mainly through the capacitive elements of the winding[8,9].

The PD signals detected at the terminals of a transformer will have different waveshapes due to the different propagation paths from the discharge source to the terminals, even if the same type of discharge generates them.

In this project Matlab/Simulink simulation software would be used for the detection and localization of PD phenomenon. The simulation studies have suggested that the PD signals at the measurement terminals their propagation paths and the transfer functions from the source of the discharge to the measuring terminal have unique characteristics. The measurements conducted using PD calibrators on several plain-disc-type windings A frequency spectrum representation was used during those measurements. Studies carried out on the transfer function based PD location techniques indicated the importance of developing these techniques into practical applications.

1.3 Problem Statement

Some of transformer winding reaches to many thousand dollars specially in the case of high KVA capacity. The popular test had been done by detecting the fault like partial discharge without localizing the PD in the winding, and the problem solved by replacing the whole winding and hence expensive cost. To overcome this economical issue it is necessary to find a way to localize PD along the winding length so that only faulty part is replaced instead of the whole winding. This concept is very useful especially in a disk type transformer winding, when replacing a portion of the winding instead of the whole winding.

Voluminous digital PD data are nowadays readily available with constant improvement in PD measurement techniques. Power engineer may be able to detect prominent PDs using oscilloscope and existing couplers. But identification of the types of developing and random occurring PD is a real challenge to any practicing engineer. In this thesis a new technique of a digital signal processing method such as fast fourier transformation (FFT) is applied to analyse PD detection and localization in transformer winding.

PD activities may cause deviation of the transformer winding parameters. The deviation of the transformer parameters are due to many reasons like for example heating during operation aging and deterioration of the winding insulation. Hence reduces the sensitivity of the measurements and the uncertainties in the estimation of transformer parameters.

When the winding was energised there was significant audible and electrical noise due to core vibration. The result was an increase in the noise level in the time domain signals. For the corresponding frequency spectra, the noise only affects the spectra in the lower frequency range, i.e. below 50kHz. Various time and frequency domain de-noising techniques are adopted for the extraction of PD signal. Signal processing methods to post process the measurements have been utilised, resulting to a rejection of the noise and improvement of the sensitivity.

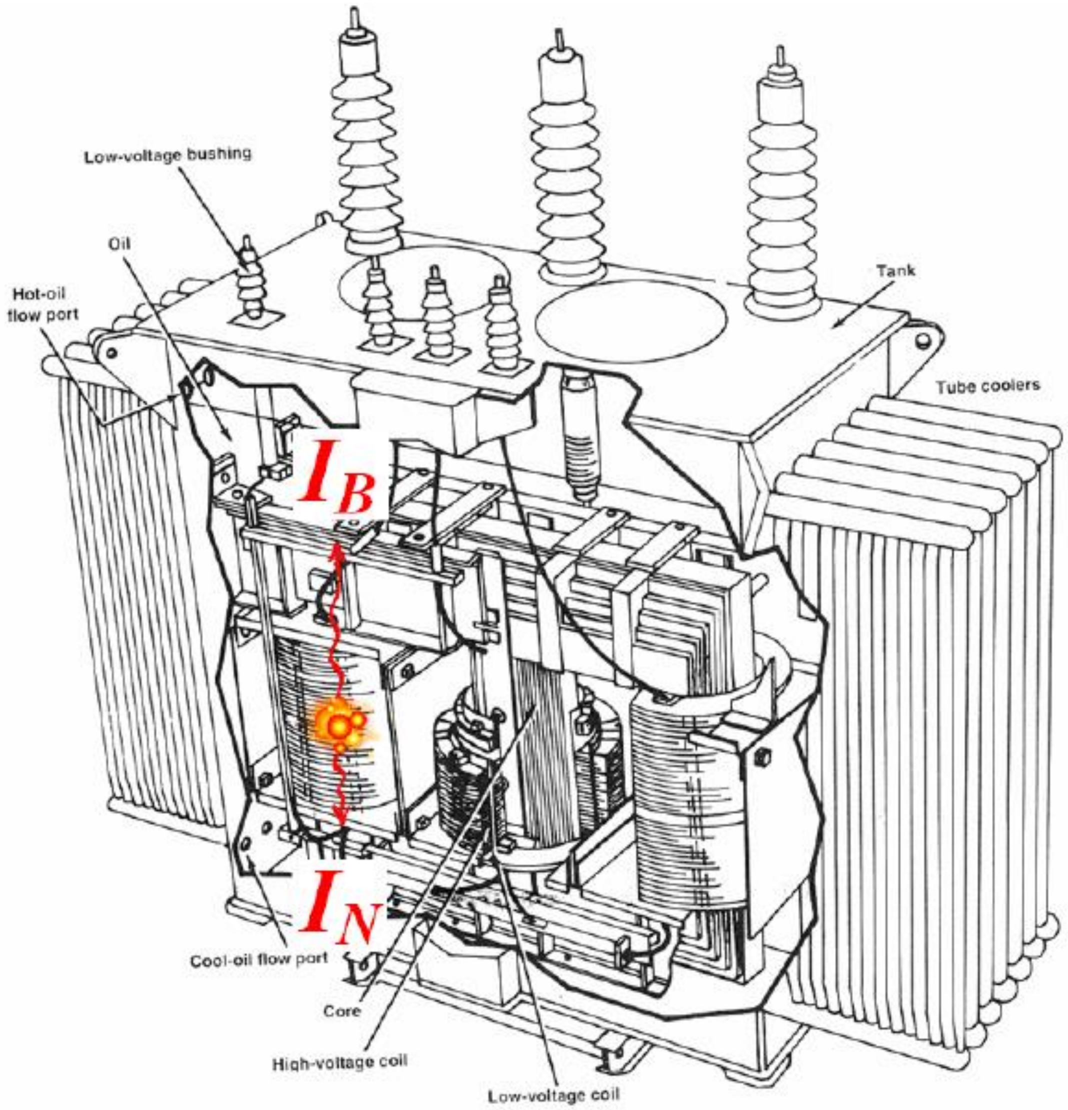

Figure 1.1 PD on high voltage transformer

1.4 Objective of the study

i- Modelling the power transformer circuit winding parameters with partial discharge (PD) injection.
ii- Demonstrate the concept of the detection and localization using FFT transfer function. And classify the location using ANN.
iii- Studying the dynamic behaviour of winding parameters deviation.
iv- De noising the audible noise in transformer core using FID filtering technique.

1.5 Scope of the study

i- Simulate a model for the transformer winding by a lumped circuit model and PD pulses using Simulink/Matlab software.
ii- Analyse the PD location by FFT to the measured current responses from the bushing and neutral terminals. After injecting a PD pulse into different sections along the winding, then classify by ANN.
iii- Change the value of R,L and C to study the behaviour of winding parameters deviation.
iv- De noising the noise in transformer core using FID filtering technique After modelling the noise.

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