PARTIAL DISCHARGE RECOGNITION USING ARTIFICIAL NEURAL NETWORK

by

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TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 RESEARCH METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
CWT	Continuous Wavelet Transform
DC	Direct Current
DGA	Dissolved Gas Analysis
DSI	Discrete Spectral Interference
DSP	Digital Signal Processing
DWT	Discrete Wavelet Transform
EMTP-ATP	Electromagnetic Transient Program-Alternative Transient Program
FN	False Negative
FP	False Positive
FT	Fourier Transform
FFT	Fast Fourier Transform
FPR	False Positive Rate
GIS	Gas Insulated Switchgear
HL	Hidden Layer
HPF	High Pass Filter
HV	High Voltage
HFCT	High Frequency Current Transformer
IDWT	Inverse Discrete Wavelet Transform
IEEE	Institute of Electrical & Electronic Engineering
LPF	Low Pass Filter
MATLAB	Matrix Laboratory
MLP	Multi-layer Perceptron
MLPFNN	Multi-layer Perceptron Feed Forward Neural Network
MSE	Mean Square Error

PD	Partial Discharge
pps	Pulse per Second
PVC	Polyvinyl Chloride
PILC	Paper Insulated Lead Sheathed Cable
ROC	Receiver Operating Curve
SNR	Signal to Noise Ratio
STFT	Short Time Fourier Transform
TP	True Positive
TN	True Negative
TACS	Transient Analysis Control System
THR	Threshold
TNB	Tenaga Nasional Berhad
TPR	True Positive Rate
UHFT	Ultra High Frequency Technique
XLPE	Cross Linked Polyethylene

LIST OF SYMBOLS

A	Amplitude
C	Capacitance
d	Thickness of the Insulation Cable
E	Electric Stress Equation
f	Frequency
I	Inductance
N	Number of Data Points
n	Number of Pulse Rate
q	Pulse Magnitude
R	Resistance
t	Partial Discharge Duration
t_0	Time of Partial Discharge Occurrence
$X(t)$	Time Domain
$X(\omega)$	Frequency Domain
$\hat{y}_i$	The Predicted Value for Case i
y_i	The Expected Value for Case i
Z_{out}	Terminating Impedance
ΔV	Electrical Potential across the Cavity
ϕ	Phase
τ	Damping Factor of Partial Discharge Pulse

Partial Discharge Recognition Using Artificial Neural Network

ABSTRACT

Partial discharge (PD) seriously affects the reliability of the distribution system due to electrical stress and the duration of the installation. Recent technology advance brings the analysis of the PD act as the guideline and maintenance strategy can be carried out when a parameter exceeding the predefined level. This thesis presents an artificial neural network (ANN) modeling in recognizing the PD signal. PD signals are generated from experimental measurement and simulation by using electromagnetic transient program-alternative transient program (EMTP-ATP). There are two analyses are carried out; classification and de-noising of PD signal. The first analysis is aim to discriminate between PD and noise signals. Multilayer perceptron with back propagation algorithm is used to perform this task. The result shows that the number of nodes in hidden layer affects the accuracy of classification. Second analysis presents the de-noising performance of PD signal using three different techniques; ANN, fast Fourier transforms (FFT) and discrete wavelet transform (DWT). The objective of this analysis is to yield the PD signal from the measured signal which is the combination of PD and noise signals. Only PD signals generated from EMTP-ATP simulation environment is considered. The de-noising algorithm is implemented to discover a clean PD signal from disrupted signal. The performance of the de-nosing techniques was evaluated by comparing the signal to noise ratio (SNR). In order to de-noise the disturbed PD signal, the knowledge of interference peak needs to take into account. The result of this analysis shows ANN is the best de-noising technique as all the other techniques produce a peak higher than PD signal peak.

Pengesanan Discas Separa Menggunakan Rangkaian Neuron Tiruan (ANN)

ABSTRAK

Discas separa (PD) memberi kesan yang serius terhadap kebolehpercayaan kepada sistem pengagihan disebabkan oleh tekanan elektrik dan tempoh pemasangan. Kemajuan teknologi terkini menjadikan analisis PD sebagai garis panduan dan strategi penyelenggaraan boleh dilakukan apabila parameter melebihi tahap yang telah ditetapkan. Tesis ini membentangkan model rangkaian neuron tiruan (ANN) dalam mengenalpasti kehadiran isyarat PD. Isyarat PD dihasilkan melalui eksperimen pengukuran dan simulasi menggunakan aplikasi *electromagnetic transient program-alternative transient program* (EMTP-ATP). Terdapat dua jenis analisis yang dijalankan; pengkelasan dan penyingkiran gangguan pada isyarat PD. Analisis pertama disasarkan untuk pengkelasan antara isyarat PD dan isyarat gangguan. Pelbagai lapisan neuron tiruan dengan algoritma rembatan balik digunakan untuk melaksanakan tugas ini. Hasil keputusan menunjukkan bilangan nod dalam lapisan tersembunyi memberi kesan kepada ketepatan klasifikasi ini. Analisis kedua menunjukkan prestasi penyingkiran gangguan pada isyarat PD menggunakan tiga kaedah berbeza; ANN, FFT dan DWT. Objektif analisis ini adalah untuk menghasilkan isyarat PD daripada isyarat yang diukur yang merupakan gabungan antara isyarat PD dan isyarat gangguan. Hanya isyarat PD yang dihasilkan daripada simulasi menggunakan EMTP-ATP dipertimbangkan. Algoritma penyingkiran gangguan di implimentasikan untuk mencapai isyarat PD yang tulen daripada isyarat yang terganggu. Prestasi teknik penyingkiran gangguan dinilai dengan membandingkan nisbah isyarat kepada gangguan (SNR). Pengetahuan mengenai puncak gangguan haruslah diambil kira dalam proses penyingkiran gangguan daripada isyarat PD. Keputusan analisis ini menunjukkan ANN adalah teknik penyingkiran gangguan yang terbaik kerana teknik yang lain menghasilkan puncak isyarat lebih tinggi daripada puncak isyarat PD.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Partial Discharge (PD) can be described as small electrical pulse that moderately channel part of insulation material in high voltage (HV) cable or equipment. Typically PD has a short and sharp rise time, about 1 ns whereas its width take up to few ns and several hundreds of MHz of frequency domain bandwidth. The condition around the faults generates development of electrical field which lead to production of PD (N. H. Ahmed & Srinivas, 1998).

PD can arise as the source and indicator of the insulation system deterioration (Ayub et al., 2008). The existence of different kinds of stresses in HV cable influence the insulation system, thus contributes to the PD generation. These stresses are thermal stress, mechanical stress and electric stress. Many studies have been carried out to identify the health of insulation system and its state of operation. Increasing activity of PD is widely regarded as the early warning of the insulation failure. Early PD detection provides statistics of safe and reliable operation, maintenance and replacement strategy long before unexpected failure happen.

PD is recognized by the pattern of charge produce during the PD test which is carried out frequently by electrical energy utilities companies such as Tenaga Nasional Berhad (TNB) which is the main Malaysia energy provider. Main cause that contributes to the PD occurrence is aging and jointing equipment. Utility route such as swampy area

and the area that receives more rain lead to less soil resistivity. Less soil resistivity increase the tear of insulation system. In order to reduce PD phenomena, TNB is upgrading the old cable use; paper insulated lead sheathed cable (PILC) to Cross-linked polyethylene cable (XLPE).

There are several techniques available in detecting PD such as dissolved gas analysis (DGA) (Aida et al, 2012), acoustic emission technique (Tian et al., 2000 and Tian et al., 1999) and high frequency technique (HFCT)(Liu Hui et al., 2014). Meanwhile, different types of sensor favorable by the research which are radio frequency sensor (Antenna) (Sarkar et al., 2013 and Shurrab et al., 2012), spectrum analyzer (N. H. Ahmed & Srinivas, 1998) and Rogowski coil (Rohani et al., 2016). Each sensor performs at suitable environment and had its own capacity. Current PD signal analysis tool for classification and pattern recognition is fuzzy logic (Contin et al., 2002 and Salama and Bartnikas, 2000) and ANN (Swedan et al., 2011, Lee et al., 2000 and Chang & Su, 2001).

Nowadays, the relationship between PD occurrences and the insulation system failure, PD pattern characteristic and pattern recognition method of HV insulation system become the main focus among the researchers. Ability to learn, process and solve problems involving non-linear and complex data makes artificial neural network (ANN) an interesting tool to learn. ANN is capable to make its own outcome prediction based on new independent input data after the correlated pattern between input data and corresponding target output.

1.2 Problem statement/Significance of study

Nowadays, the increasing demand of HV electricity may leads to increasing number of electrical accident caused by the insulation failure. The danger of rapid development with extra high voltage and massive capacity generates electrical stress to the system. It is well known that electrical stress creates PD.

Based on literature, there are numerous types of interferences appear in PD signal, thus the improvement in signal processing technique are very helpful in recognizing PD signal. Time taken in recognizing PD signal is very crucial in every recommended technique. PD signal may produce a redundant signal at a time, which makes certain detection algorithm unable to recognize the presence of PD signal at the early stage with better accuracy. Conventional technique in recognizing PD signal have the disadvantage in preserving the information in both time domain and frequency domain during the process, either one of the information will be lost (Vigneshwaran et al., 2013). Since PD is a non-stationary signal, fast Fourier transform (FFT) have failed to perform the detection and de-noising of PD signal accurately (Vigneshwaran et al., 2013). Besides that, short time Fourier transform (STFT) is implemented due to inability of FFT to afford time resolution of the frequency components (Phukan & Karmakar, 2013).

1.3 Research Objectives

The objective of this research is to model the PD detection and recognition using ANN technique to discriminate PD signal and noise signal. In order to achieve this objective, the works are divided into several components and carried out systematically with associated research objectives that have been identified as follows:

- To formulate an efficient technique which can expedite the identification of the significant PD occurrence.
- To employ ANN in new application which can detect and recognize the presence of PD in HV insulation material.

1.4 Research Scope

This research scope is limited to:

- PD measurement is carried out using experiment and EMTP-ATP Simulation
- ANN is used to classify and pattern recognition in PD detection
- The system is developed using MATLAB version 2012a and 2015a

1.5 Thesis organization

This thesis consists of five chapters all together. The content of each chapter is briefed as follows:

Chapter 2 focused on the literature review of the research. In this chapter, a brief explanation of numerous sensors suitable in detecting PD occurrence and the application of ANN as classifier between PD signal and noise signal. There is a short description of theories that related to this project.

Chapter 3 explains the research methodology in developing this research. This chapter includes the flow chart in completing this research. Experimental measurement and simulation data is collected for the classification. It is then followed by theories of intelligent technique proposed, ANN. The theories of mean squares error, confusion

matrix, receiver operating characteristic (ROC) and classification theory were explained.

Chapter 4 presents the findings achieved and discussion produced from the results. Graphs and tables obtained from the ANN is illustrated and tabulated respectively. The analysis of the ANN performance is discussed.

Chapter 5 concludes the research. The conclusion is made to indicate the successful of this research by referring to the result produced from the analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter contains a deeper discussion about partial discharge (PD) and overview of the other methods of PD detection system. Besides that, literature review section gives more knowledge regarding this research. This chapter is divided into five sections.

Section 2.2 is going deeper about PD, PD characteristics, importance in detecting PD and types of sensor used in PD detection. Exclusive review on artificial neural network (ANN) is explained in section 2.3 includes the advantages of ANN, ANN topology and training algorithm of ANN.

Section 2.4 reviews on the signal de-noising techniques which are ANN, fast Fourier transform (FFT) and discrete wavelet transforms (DWT). Lastly is a brief explanation of signal to noise ratio to measure the performance of each de-noising technique.

2.2 Partial Discharge

PD is a short electrical pulse resulting from the electromagnetic emission with the sharp rise time less than 1μs and width of its pulse of several ns (J R Lucas et al., 2001, Ayub et al., 2008 and Denissov et al., 2007). PD also defined as the flow of ions and electrons in gaseous state in a small amount over the total insulation system.

Referring to IEC60270, PD is defined as small electrical arc that connect the insulation and conduction in a cable. PD occurs due to the electrical stress either in the insulation system or at the surface of the insulation system. Structural damage and surface pollution of the insulator lead to failure of insulator, initiates PD. Inhomogeneous electrical fields such the occurrence of voids, bubbles or defects in insulating material can yield the PD (Ghulam Murtaza Hashmi, 2008).

PD can occur at the surface and within the insulation system. There are three types of PD phenomena; corona discharge, surface discharge and internal discharge. Cavity discharge and treeing channel is another branch of the internal discharge. The corona and localization arching might occur if there is any presence of air pockets at the insulation material. Water treeing can occur with the presence of water and electrical stress, also known as a chemical degradation of polymeric insulation. Internal discharge is indicated by the PD measurement. PD amplitude distribution is based on the different types of PD phenomena.

Figure 2.1 illustrate the PD phenomena pattern of internal discharge, surface discharge and corona discharge in a 360° phase. Generally, internal discharge and surface discharge usually exist in first and third phase. Meanwhile corona discharge normally appear symmetric to 90° (Qi et al., 2014) .

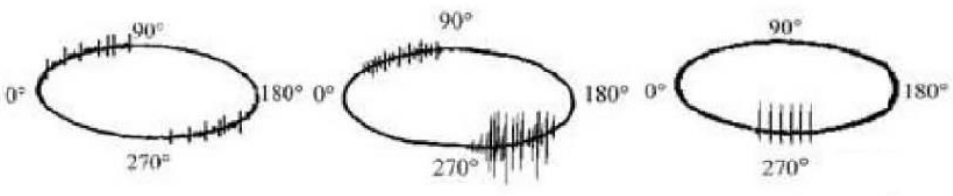

Figure 2.1 : PD pattern of internal discharge, surface discharge and corona discharge (Qi et al., 2014)

Figure 2.2 depicted the sinusoidal wave of PD signal. This signal is captured from the XLPE cable that suffers from the cracked cable, indicates that it facing the surface discharge. Referring to Figure 2.1 above, it proves that surface discharge happens in first and third phase of the phase revolved partial discharge pattern, 0°-90° and 180°-270°.

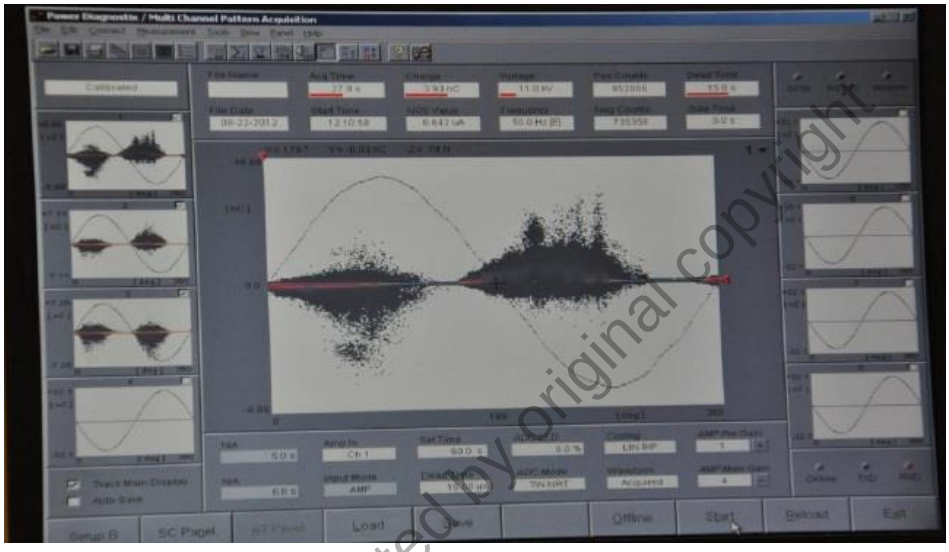

Figure 2.2 : Sinusoidal Wave of PD Signal (Isa, 2013)

The insulation system weakens as some void or bubbles might occur in the impure insulation system. Figure 2.3 illustrate the stages of electrical tracking or known as electrical treeing forms in the insulation. There are three stages in the electrical treeing which is initiation, propagation and breaking down. At the initiation stage, only minor presence of void in the insulation, so it is consider as minor partial discharge. Due to electrical stress, treeing begin to propagate along the insulation with more occurrence of voids. Due to long time being exposed to electrical stress, the conducting channel between voids in insulation form a conducting path across the surface and this phenomena leads to spark formation. The spark blows up as the conducting path formed in the insulation bridge the applied voltage and ground.

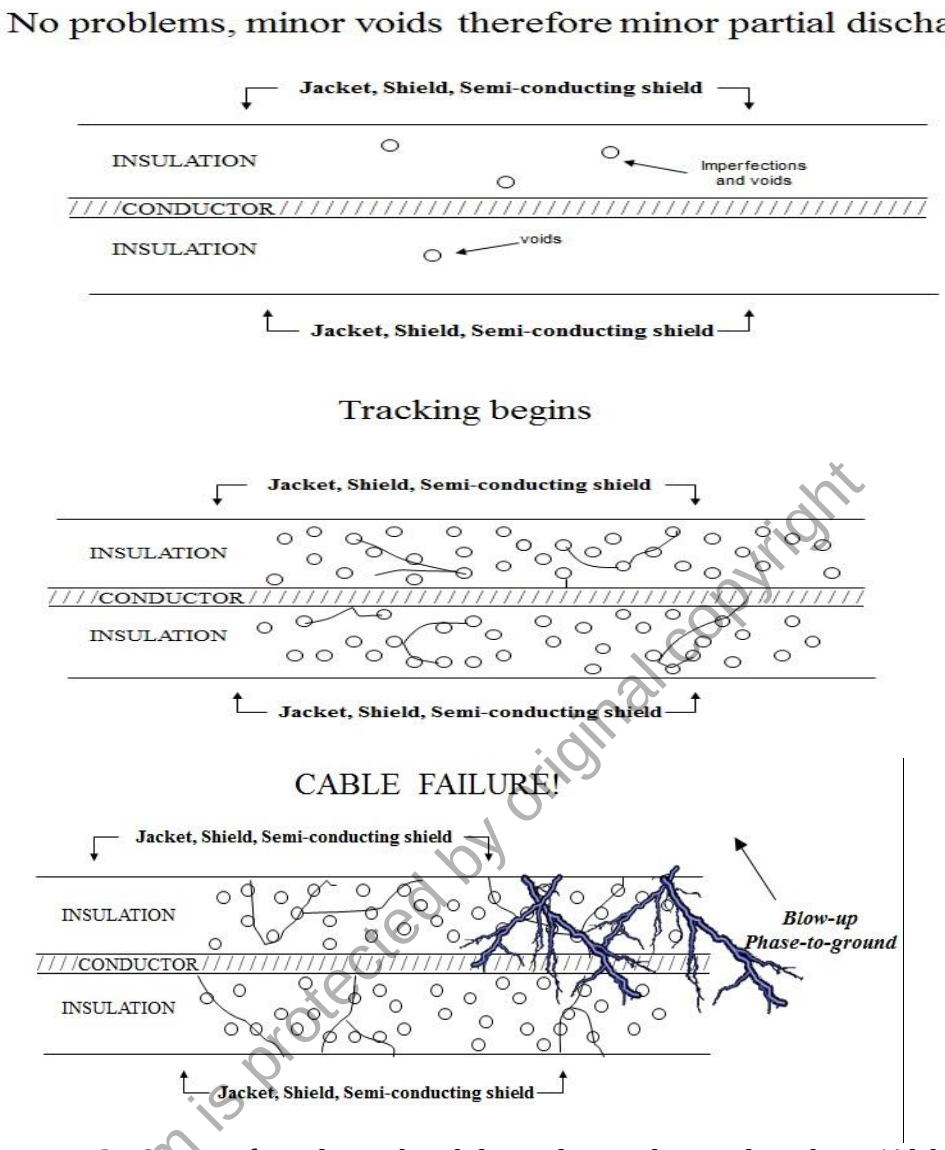

Figure 2.3 : Stages of insulation breakdown due to electrical tracking (Alsharif et al., 2009)

PD discharges are captured, known as discharge pattern. Characteristic of each pattern depends on its aging. The loading condition of the cable system contributes to the different PD discharge pattern. Repetition rate and the value of magnitude do have an effect on the PD distribution pattern (Alsharif et al., 2009).

Recently, increase of electricity demand with extra HV and massive capacity lead to rapid development of electric cable and electric transfer machine to meet the customer need. This phenomenon can lead to the dangers of electrical accident of the

insulator failure caused by the electric stress and insulation degradation, which can be initiated by PD. After being put in service for a long time period, the performance of dielectric strength can be affected by the wear and tear of the insulator. This event will lead to the existence of PD where the current from the conductor will temporarily bridge the insulator to the supporting structure pole. Cracked insulators and highly polluted insulators are example of the faults in the overhead cable that lead to the PD existence (Khor, 2010). The polluted insulation surface will bridge the current from the conductor to the power pole if the conductive element is present. This incident is dependent to the current ambient temperature condition. The pollutant starts to act like a conductor when there is a presence of mist produces the moist surface at the polluted insulator surface.

The cable connections play an important role in determining of exact propagation properties and load impedances (Ayub et al., 2008). Most of the progressive degradation of the cable occurs at the joints and termination along the underground cable. The presence of PD is most likely at the point which has the human intervention during the cable installation (Alsharif et al., 2009).

Underground cables are known to exhibit incipient fault, self-clearing arcing faults prior to failing permanently. A high fault current of the essential frequency is created when the insulating layer is broken. The resulting wave from the discharge propagate towards the end of the cable and its duration is very short, merely less than 1 ns. High frequency losses are dependent on the conductivity of the semiconductor layers and the dielectric constant.

It has been suggested based on operational experience that it is important to isolate the underground cable that shown the symptoms of the existence of PD. This action can limit the overall energy at the fault point. At the same time, it can reduce the rate of repeated voltage transient in the system. The disadvantages of this type of