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Faculty of Electrical Engineering

HIGH VOLTAGE INSULATION SURFACE CONDITION ANALYSIS USING TIME FREQUENCY DISTRIBUTIONS

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NURBAHIRAH BINTI NORDDIN

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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2014

DECLARATION

I declare that this thesis entitle “High Voltage Insulation Surface Condition Analysis using Time Frequency Distributions” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Nurbahirah Binti Norddin

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for award of Master of Science in Electrical Engineering.

Signature	:	....
Supervisor Name	:	Dr. Abdul Rahim Bin Abdullah
Date	:	....

DEDICATION

A million praise towards my family, my respectful supervisor, examiners and lecturers and to all my friends for their support and cooperation in helping me to complete this thesis.

Thanks to the Ministry of Education (MOE) and Universiti Teknikal Malaysia Melaka (UTeM) for the financial support for my study.

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ABSTRACT

In high voltage engineering, insulation is the most important part to prevent the flow of current to undesired paths. Currently, polymeric type of insulation is widely used because of its advantages which are light, easy to fabricate, and have good dielectric properties compared to traditional ceramic or non polymeric insulation. In previous researches, leakage current frequency component is mainly used to analyze surface condition of polymeric insulation and it is, normally, analyzed by using fast Fourier transform (FFT). However, the technique only presents spectral information and is not suitable for the leakage current signal that consists of magnitude and frequency variations. Thus, time-frequency analysis technique needs to be employed to provide spectral and temporal information of the signal. This research presents the analysis of leakage current using time-frequency distributions (TFDs). Time-frequency distributions (TFDs) such as spectrogram and S-transform are applied to represent the leakage current (LC) in time-frequency representation (TFR). These techniques extract relevant information from TFR include root mean square current (RMS), total harmonic distortion (THD), total non harmonic distortion (TnHD) and total current waveform distortion (TWD). Tracking and erosion test via Incline Plane Test complying with BS EN60587-2007 is conducted to collect different leakage current patterns on polymeric and non polymeric material. Furthermore, the performance of the TFDs is evaluated based on their TFRs accuracy and the results shows that S-transform outperforms spectrogram in term of frequency and time resolution. Thus, the classification of leakage current using parameters from S-transform can be implemented to determine material state and severity instantaneously.

ABSTRAK

Di dalam kejuruteraan voltan tinggi, penebat merupakan bahagian yang penting untuk mengelakkan pengaliran arus ke tempat yang tidak diingini. Pada masa ini, penebat jenis polimer digunakan secara meluas kerana kelebihannya berbanding penebat seramik tradisional atau bukan polimer yang mana lebih ringan, mudah untuk di fabrikasi dan mempunyai sifat dielektrik yang baik. Dalam penyelidikan sebelum ini, komponen frekuensi arus bocor selalunya digunakan untuk menganalisis keadaan permukaan penebat dan kebiasaanya, dianalisis dengan menggunakan fast Fourier transform (FFT). Walaubagaimanapun, teknik ini hanya memaparkan maklumat spektral dan tidak sesuai untuk isyarat arus bocor yang mengandungi perubahan magnitud dan frekuensi. Oleh itu, teknik pengagihan masa-frekuensi (TFDs) perlu digunakan untuk memberikan maklumat tentang spektral dan temporal daripada isyarat tersebut. Penyelidikan ini mempersembahkan analisis arus bocor dengan menggunakan pengagihan masa-frekuensi (TFDs). Pengagihan masa-frekuensi (TFDs) seperti spectrogram dan S-transform digunakan untuk mewakilkan arus bocor dalam perwakilan masa-frekuensi (TFR). Teknik ini mengekstrak maklumat yang berkaitan daripada TFR termasuklah root mean square current (IRMS), total harmonic distortion (THD), total non harmonic distortion (TnHD) dan total current waveform distortion (TWD). Pengujian traking dan hakisan melalui Incline Plane Test mematuhi BS EN60587-2007 dijalankan untuk mengumpul pelbagai pola arus bocor pada bahan polimer dan bukan polimer. Tambahan lagi, prestasi daripada TFDs dinilai berdasarkan ketepatan TFRs mereka dan keputusan menunjukkan S-transform menunjukkan prestasi lebih baik daripada spectrogram dari segi resolusi frekuensi dan masa. Oleh itu, klasifikasi arus bocor menggunakan parameter daripada S-transform boleh dilaksanakan untuk menentukan keadaan bahan dan tahap keterukan pada permukaan sesuatu penebat secara serta-merta.

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LIST OF SYMBOLS

A	-	Ampere
ASTM	-	American Society for Testing and Materials
IEC	-	International Electro technical Commission
cm	-	centimeter
t	-	Time
f	-	Frequency
f_r	-	Frequency resolution
T_r	-	Time resolution
IPT	-	Incline plane test
LC	-	Leakage Current
FFT	-	Fast Fourier transform
TFD	-	Time frequency distribution
TFR	-	Time frequency representation
STFT	-	Short time Fourier transform
WT	-	Wavelet transform
S/m	-	Siemens/meter (Electric Conductivity)
kV	-	Kilovolts
N_w	-	Window size
pu	-	per unit
$h(\tau)$	-	Input signal in continuous
$w(t)$	-	Observation window in continuous

$x(n)$	-	Input signal in discrete
$g(m-n)$	-	Window function
$\sigma(f)$	-	Control the position of the Gaussian window
$I_{rms}(t)$	-	Instantaneous root means square current
$I_{1rms}(t)$	-	Instantaneous root means square fundamental current
$I_{TnHD}(t)$	-	Instantaneous Total non harmonic distortion current
$I_{THD}(t)$	-	Instantaneous Total harmonic distortion current
$I_{TWD}(t)$	-	Instantaneous Total waveform distortion current
IRMS	-	Root means square current
THD	-	Total harmonic distortion
TnHD	-	Total non harmonic distortion
TWD	-	Total waveform distortion
DAQ	-	Data Acquisition
NH_4Cl	-	Ammonium chloride
MAPE	-	Mean absolute percentage error

LIST OF PUBLICATIONS

A. Journal

1) N. Norddin, A. R. Abdullah, N. Q. Z. Abidin, and A. Aman, "Automated Classification System for Polymeric Insulation Surface Conditions" Engineering Letters, 2013 (Accepted with revision)
2) N. Norddin, A. R. Abdullah, N. Q. Z. Abidin, and A. Aman, "High Voltage Insulation Surface Condition Analysis using Time Frequency Distribution," Aust. J. Basic Appl. Sci., vol. 7, pp. 833-841, 2013.
3) N. Q. Z. Abidin, A. R. Abdullah, N. Norddin, and A. Aman, "Online Surface Condition Monitoring System using Time Frequency Distribution on High Voltage Insulator," Aust. J. Basic Appl. Sci., 2013.

B. Conference

1) A. Sulaiman, A. R. Abdullah, A. Aman, N. Norddin, and N. Q. Zainal Abidin, "Performance analysis of high voltage insulators surface condition using Time-Frequency Distribution," in Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International, 2013, pp. 603-607.

2) N. Norddin, A. R. Abdullah, N. Q. Z. Abidin, A. Aman, and A. N. Ramani, "Polymeric insulation surface condition analysis using linear time frequency distributions," in Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International, 2013, pp. 558-563.

3) N. Q. Z. Abidin, A. R. Abdullah, N. H. Rahim, N. Norddin, and A. Aman, "Online surface condition monitoring system using time-frequency analysis technique on high voltage insulators," in Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International, 2013, pp. 513-517.

4) A.R. Abdullah, N. Norddin, N.Q.Z. Abidin, A. Aman, M. H. Jopri, Leakage Current Analysis on Polymeric and Non-Polymeric Insulating Materials Using Time-Frequency Distribution, in: IEEE International Conference on Power and Energy (PECON) Sabah, Malaysia, 2012, IEEE International, 2012, pp. 979-984

5) N. Norddin, A.R. Abdullah, N.Q.Z. Abidin, A. Aman, Leakage Current Analysis Of Polymeric Insulation Using Linear Time Frequency Distribution, in: Power and Energy Conversion Symposium (PECS 2012) Malacca, 2012.

6) N.Q.Z. Abidin, A.R. Abdullah, N. Norddin, A. Aman, K.A. Ibrahim, Leakage current analysis on polymeric surface condition using time-frequency distribution, in: Power Engineering and Optimization Conference (PEOCO) Melaka, Malaysia, 2012 IEEE International, 2012, pp. 171-175.

C. Exhibition

1) Awarded PECIPTA 2013 silver medal for the invention “Online High Voltage Insulator Surface Condition Monitoring System” at International Conference and Exposition on Invention of Institutions of Higher Learning 7-9th Nov 2013

2) Awarded ITEX bronze medal for the invention “Online High Voltage Insulator Surface Condition Monitoring System” at the 24th International Invention, Innovation & Technology Exhibition ITEX 2013 Kuala Lumpur, Malaysia from 9-11th May 2013

CHAPTER 1

INTRODUCTION

1.1. Introduction

In high voltage engineering, insulation is the most important part to prevent the flow of current to undesired paths. Insulation technology is still undergoing continuous development and improvement from time to time, from non polymeric type since the early 1900s, until the development of polymeric composite insulation materials. Polymeric or polymeric composite insulation is widely accepted (M.H. Ahmad et al. 2011) compared to conventional ceramic or non polymeric insulation due to its several advantages as mentioned by Hackam (1999). It is broadly used because they are light weight, tough and have excellent dielectric properties.

Polymeric insulation confronts a problem that is ageing cause by erosion and tracking in the presence of severe contamination and sustained moisture on its surface. Different methods and analytical techniques are used to analyze the ageing effect on polymeric insulating materials. Hydrophobicity measurement techniques are mostly studied on material surface characterization and chemical investigation. The methods to determine the loss of hydrophobicity are surface morphology by scanning electron microscope (SEM), Swedish transmission research institute (STRI) hydrophobicity classification, measuring the bead angle using a Goniometer, the equivalent salt deposit density (ESDD), total salt deposit density (TSDD) and non soluble salt deposit density (NSDD). Besides that, one of the key indicators widely accepted to determine performance of polymeric insulation either in service or accelerated ageing laboratory test is by investigating the leakage current (LC) signal. Incline plane test (IPT) tracking and erosion test complying with BS EN 60587-2007 are conducted to select different patterns of leakage current, then leakage current frequency components is used as a diagnostic tool for their surface condition monitoring and degradation severity. leakage current (LC) signal provides information of polymeric insulation surface condition and the pollution severity (N. Bashir and H. Ahmad 2009a).

Leakage current (LC) harmonic component analysis will give better information on insulation surface (M.A.R.M. Fernando and S.M. Gubanski 2010; S. Chandrasekar et al. 2009; M.A.R.M. Fernando and S.M. Gubanski 1999b; S. Kumagai et al. 2006). A lot of studies have been done based on leakage current (LC) investigation especially into their harmonics characteristics as well as leakage current (LC) lower harmonic content and their ratios. Most of the researchers analyze the harmonic component using fast Fourier transform (FFT) but it is known for their limitation to analyze non stationary signals.

In this research work, time frequency distributions (TFDs) is employed to analyze leakage current (LC) components of material insulators to classify insulation material surface condition state and its severity. From the time-frequency representation using spectrogram and S-transform, the parameters of the leakage current (LC) is estimated such as total harmonic, total non harmonic, total waveform distortion and RMS value. Furthermore, the comparison between these two methods is made to identify their accuracy. From the results, it shows that S-transform outperforms spectrogram in term of frequency and time resolution based on their accuracy obtained by mean absolute percentage error (MAPE). Then, the characteristics of the leakage current (LC) are identified from leakage current (LC) parameters to determine the material state and severity instantaneously.

1.2. Problem Statements

Polymeric insulation has been used for many years but it still has certain limitations such as difficulty in detecting defective insulation while being used in high voltage system. The knowledge about it long term reliability and loss of hydrophobicity that leads to tracking and erosion as well as to flashover under contaminated condition still lacking. It is found that harmonic component from leakage current can be used to determine the severity of insulator surface condition.

Most of researches use fast Fourier transform (FFT) to analyze the leakage current signal (M.A.R.M. Fernando and S.M. Gubanski 1999a; N. Bashir and H. Ahmad 2010) . However, FFT does not provide temporal information and is not appropriate for non-stationary signal (O. Rioul and M. Vetterli 1991). The short time Fourier transforms (STFT) which provide temporal and spectral information that represent signal with time-frequency representation (TFR) can overcome the FFT limitation. The spectrogram is the square of the absolute value of the STFT of a signal. However, because of the fixed window width this method cannot track the non stationary dynamic properly.

Besides that, there are some researchers using wavelet transform to analyze leakage current (S. Chandrasekar 2010; M.A. Douar, A. Mekhaldi and M.C. Bouzidi 2010). However, S. Zhang et al. (2009) found that wavelet is sensitive to noise and suitable selection of mother wavelet and the level of decomposition need to be chosen based on the disturbance. Furthermore, the features extracted from the wavelet multi resolution analysis required neural network and this procedure need high computational (P.K. Dash, B.K. Panigrahi and G. Panda 2003). Therefore, the time frequency representation that is S-transform is used in this research that it allows high time resolution for high frequency component and high frequency resolution for low frequency component. It also has the ability to detect the disturbance correctly in the presence of noise (S. Zhang et al. 2009).

The method that has been used in this research that is S-transform can overcome the deficiency from FFT, STFT, spectrogram and Wavelet. The exchange and maintenance of insulator can be made easily by determine surface condition deterioration through development of practical monitoring and reliability methods using measurement of leakage current.

1.3. Objectives of the Research

The objectives of this research are:

1. To conduct a leakage current (LC) measurements of polypropylene (polymeric) and glass (non polymeric) insulator using IPT test according to BS EN60587.
2. To analyze the leakage current (LC) signal using time frequency distributions (TFDs) which are spectrogram and S-transform. The best time frequency distribution (TFD) for the leakage current analysis is selected in terms of the accuracy of the analysis.
3. To identify and classify the surface condition of polymeric and non polymeric based on the parameters of the leakage current (LC) signal.

1.4. Scope of Works

Polypropylene and glass have been cut according to British standards size of 50x120 mm with a thickness of 6mm. The leakage current is collected using inclined plane test based on BS EN60587 standard. The data for leakage current is stored using Labview software to enable offline data analysis using Matlab. The main focus of this research is to concentrate on signal analysis using linear time frequency distributions which are spectrogram and S-transform. The classification of the state of the insulator surface condition using parameters obtained from TFDs where it is based on the four patterns for polypropylene and three patterns for glass of leakage current.

1.5. Thesis Contributions

The significant contributions of this research are as follow:

1. The leakage current (LC) patterns are identified and presented for polypropylene (polymeric) and glass (non polymeric) insulator. There are no research carried out that present the leakage current patterns for polypropylene and glass.
2. The leakage current (LC) analysis is demonstrated using time-frequency distributions (TFDs) which are spectrogram and S-transform. In addition, the selection, evaluation and verification are also presented to determine best time frequency distributions (TFDs) for leakage current analysis based on their time frequency representation (TFR) accuracy.
3. The classification system is established for leakage current (LC) signals by using the best time frequency distribution (TFD). It can be implemented for surface condition deterioration monitoring system of insulating material.

1.6. Thesis Outline

The thesis has been divided into several chapters as followed:

Chapter 1 is an overview of the research project in whole. The problem statement, objectives and scope of research project are described. The research works has been conducted based on the objectives and scopes stated earlier.

Chapter 2 consists of literature review about the polymeric insulation, leakage current (LC) pattern and signal processing. It also contains a review of ageing mechanism and leakage current (LC) studies in the field and laboratory. The studies about surface condition determination with leakage current (LC) also reported.

Chapter 3 discussed about research methodology which contained incline plane test and analysis techniques which are time frequency distributions (TFDs). In addition, the detail about leakage current (LC) measurement and storage is also explained.

Chapter 4 consists of result and discussion which explained about the performance comparison analysis which used mean absolute percentage error (MAPE) and the classification of leakage current (LC) for polypropylene and glass insulation.

Chapter 5 contained the conclusion and recommendation for future work for this research because there are some improvement and potential to be developed.