CHARACTERISTICS OF MULTI-MODE SENSOR FOR PARTIAL DISCHARGE SIGNAL MONITORING IN OIL INSULATION

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This thesis dedicated to:-

My mother who has been a source of warm-heartedness, love and inspiration to me throughout my life.

My father who has been a constant source of support and encouragement during the challenges of graduate school and life.

My brothers and sister and for my future wife , for their endless love ,supports and encouragement

I am truly thankful for having all of you in my life

God bless you all

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OSAMAH

ABSTRACT

Partial Discharge (PD) is a term used to describe electrical discharge activity which is normally accompanied by sparks. PD can occur when electric field difference across the void exceeds the minimum breakdown field strength. Therefore, PD measurement and diagnosis is an important nondestructive technique for assessing the quality and integrity of high voltage transformer. In practice, PD measurements suffer from noise interference due to low sensitivity of available sensors. Noisy signal at the output of the sensors cause inaccuracy in the detection of PD. In this work a multimode optical fiber sensor would be used to detect PD in transformer because it has the advantages such as: small size and weight, enormous potential bandwidth, immunity to interference and crosstalk, and compare it with electrical(capacitive) sensor. PD was detected at atmospheric pressure in voltage range (0-20 kV), the output from these two detection processes and the source wave form fed into separate channels of the multichannel digital oscilloscope. The gained data has been analyzed in time and frequency domain by using (OrginPro8) software. These results show that the appearance of PD caused a ripple in the shape of source wave form and it is being more clear in high voltage rang where in time domain these results show that signal generated by PD contains a sinusoidal pulses. The shapes and peaks of the signal output of both sensors follow the same oscillatory pattern at the same time with the ripple in the source wave form. Although these shapes and peaks of the signal output of both sensors are not much clear in voltage range below (20 KVp-p) but in voltage range above (20 KVp-p) the optical sensor shows good sensitivity where it shows up clear peaks and more than the capacitive sensor and this conclusion approved by the Frequency Domain Analysis the Fast Fourier Transform (FFT) where optical shows good resolution in range of voltage above (20 KVp-p).

ABSTRAK

Nyahcas separa (PD) adalah istilah yang digunakan untuk menggambarkan aktiviti pelepasan elektrik yang biasanya diiringi oleh percikan api. PD boleh berlaku apabila perbezaan medan elektrik merentasi kekosongan melebihi kerosakan minimum kekuatan medan. Oleh itu, pengukuran dan diagnosis PD adalah satu teknik tanpa musnah yang penting untuk menilai kualiti dan integriti transformer voltan tinggi. Pada praktiknya, pengukuran PD mengalami gangguan hingar kerana sensitiviti rendah sensor yang ada. Syarat hingar pada output sensor menyebabkan ketidaktepatan dalam pengesanan PD. Dalam kajian ini, sensor gentian optik multimod digunakan untuk mengesan PD dalam transformer kerana mempunyai kelebihan seperti kecil dan ringan, potensi jalur lebar yang besar, rintang/imuniti terhadap gangguan dan cakap silang (*crosstalk*) berbanding sensor elektrik (kapasitif). PD dikesan pada tekanan atmosfera dalam julat voltan (0-20 kV), output daripada kedua-dua proses pengesanan dan bentuk gelombang sumber disuap ke dalam saluran berasingan osiloskop digital berbilang saluran. Data yang diperolehi dianalisis dalam domain masa dan frekuensi menggunakan perisian (OrginPro8). Keputusan ini menunjukkan bahawa kemunculan PD menyebabkan riak dalam bentuk gelombang sumber dan ianya menjadi lebih jelas dalam gegelang voltan tinggi yang mana dalam domain masa keputusan ini menunjukkan bahawa isyarat yang dihasilkan oleh PD mengandungi denyutan sinus. Bentuk dan puncak output isyarat kedua-dua sensor mengikut corak ayunan yang sama pada masa yang sama dengan riak dalam bentuk gelombang sumber. Walaupun bentuk dan puncak output isyarat kedua-dua sensor tidak banyak jelas dalam julat voltan bawah (20kVp-p) tetapi dalam julat voltan di atas (20 KVP-p), sensor optik menunjukkan sensitiviti yang baik yang mana ia menunjukkan puncak jelas dan lebih daripada sensor kapasitif dan kesimpulan ini diluluskan oleh Kekerapan Analisis Domain Fourier pantas (FFT) yang menunjukkan optik resolusi yang baik dalam julat voltan di atas (20 KVP-p).

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LIST OF ABBREVIATIONS

AC	-	Alternative voltage
AE	-	Acoustic emissions
Cm	-	Centimetre
dB	-	Decibel
DBD	-	Dielectric Barrier Discharge
DC	-	Direct current
EHV	-	Extra high-voltage
EMI	-	Electro-magnetic interference
F	-	Frequency
FFT	-	Fast Fourier transform
FOS	-	Fibre Optic Sensor
GHz	-	Giga hertz
GIS	-	Gas insulated switcher
HF	-	High frequency
HV	-	High Voltage
kHz	-	Kilo hertz
kV	-	kilo volt
LED	-	Light emit diode
LLD	-	Low Level Discriminator
M	-	Meter
MHz	-	Mega hertz
mm	-	Millimeter
MMF	-	Multimode fiber
mS	-	Milli second
mW	-	milli watt

Nm	-	Nanometer
Pc	-	Pico Column
PZT	-	Piezoelectric
PD	-	Partial discharge
SI	-	Step index
SNR	-	Signal to noise ratio
µm	-	Micro meter
UHF	-	Ultra high frequency
V	-	Voltage
VHF	-	Very High Frequency

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CHAPTER 1

INTRODUCTION

1.1 Introduction of Research

High voltage equipment's are considered as one of the essential elements in electrical network. Any failure in these equipment's directly reduces network reliability and increases maintenance costs. In a power system failure of major elements can cause disruptions and result in very expensive losses. An on-line continuous insulation monitoring diagnostic system helps prevent power interruptions and costly damage caused by insulation failure. Most insulation failures are caused by partial discharges (PD) that are localized electrical discharges within a void of an insulation system. Although only a small amount of energy is involved, the PD can cause the progressive deterioration of the insulation that may lead to a disruptive breakdown [16]. Therefore, it is necessary to detect and monitoring and assess the PD for high voltage equipment insulation. In such applications, an understanding of PD mechanisms, characteristics and development processes is important. The insulation system has high risk for dielectric stability when PD occurs. Therefore, measurement of PD is important to prevent high-voltage equipment from damage [17].

PD can occur in a gaseous, liquid or solid insulating medium. It often starts within gas voids, such as voids in solid epoxy insulation or bubbles in transformer oil. Protracted partial discharge can erode solid insulation and eventually lead to breakdown of insulation. Insulation breakdown is the main type of power transformer breakdown. PD is a main cause of insulation breakdown. PD in transformer can lead to corrosion in solid insulating materials and thus cause a breakdown of concerned operating component in the long term. PD is electrical discharges that do not completely bridge; they are localized to small area within insulation medium. PD can occur when electric field strength exceed the breakdown strength of insulation after that the insulation is unable to withstand the electrical stress and lead to flashover. Studying and monitoring of PD are done to detect insulation problems [18]. Traditional PD detection methods include electrical measurements, acoustical measurements, etc. However these methods have the disadvantage that the measurements can be influenced by interference and as well it is bard to ascertain the discharge location. The light detection method which is discussed in this study can overcome the above disadvantages to some extent. Typical PD signals and associated light emissions are studied. The PD light emission is not only related to the discharge quantity, but also to the discharge energy. Discharge counts do not affect the magnitude of the emitted light, but are related to the number of light pulses. Optical fiber has unique features that can be used as the light receiving system. These features include good optical transmission properties (light wave loss is a few tens of dB/km), good insulation and anti-jamming properties. The transmission frequency band is wide. The fiber is light in weight and has good flexibility. It can be employed without disturbance in special working environments [19]. Optical method that uses optical fiber sensor which is small in size, highly sensitive and light weight, and possesses high frequency response and significant immunity against electromagnetic interference, can measure a wide range of chemical and physical parameters at ease. This features made the optical method more suitable than the others methods especially for the power transformer.

The measuring techniques of PD detection are using different physical properties of phenomena such as electromagnetic emission (in form of radio wave,

light and heat), acoustic emission (in audible and ultra-sonic rages), ozone and nitrous oxide gases.

Optical detection is based on fractional changes on optical parameters such as wavelength, intensity, polarization and phase. Hence, it is possible to get four types of optical sensors; namely spectrum based sensor, intensity based sensor, polarization based sensor and interferometric based sensor. Fiber optic acoustic sensor includes optical fiber intrinsic sensor such as Michelson interferometers, Mach– Zehnder interferometers, multimode fiber and fiber optic extrinsic such as Fabry–Perot interferometric sensors. The fiber optic acoustic sensor combines the acoustic and optical method. The detection process of this method is based on photo elastic effect of silica fiber. The acoustic wave that is incident on the optical fiber will cause distortion of optical fiber structure. This distortion will change fiber length and fiber refractive index. This change can create a modulation effect on a laser beam which passes through the fiber. Due to the low photo elastic effect of the silica fiber, the sensitivity needs to be increased [20, 31].

Currently, the most popular method for detecting PD in high voltage transformer and other equipment such as GIS is the optical detection method which uses fiber intrinsic sensor coil. When a PD occurs inside the transformer, the oil that acts as insulation becomes degraded and the result can be unexpected catastrophic failure of the power transformer. The optical sensor mounted inside transformers can help warn of the occurrence of PDs, thus helping to prevent transformer failures by measuring PD acoustic signals [20].

The most possible reason for a failure of a transformer is insulation breakdown .oil-impregnated paper is used to cover winding conductors and pressboard is placed around transformer windings. Small oil channels are formed between multiple pressboard layers and it represents its insulation. Mineral oil, synthetic esters and silicon oil are traditionally used for transformer insulations. Polychlorinated Biphenyl (PCB) owing to their low flammability and good dielectric

properties was initially used as insulating oil. Conversely due to their negative environmental impact, they are no more used in many countries including Sri Lanka. Silicon also has a very low flammability but it is the most expensive oil of all types. Currently, scientists are looking for alternatives for these nonrenewable sources, which are also environmental friendly.

Mineral oil has been used for a long time as insulating oil for large power transformers. Recently, on the issues of depletion of resources and environmental damage at leakage, demand on environment-friendly insulating oil is increasing. Various vegetable oils have been investigated especially the palm oil due to it is advantages of productivity, good biodegradability, excellent insulating performance, high cooling ability and good oxidation stability, therefor in this study oil palm will be used.

Recently, vegetable oil based insulating liquid has been studied as a substitute of mineral insulating oil, because it is almost fully biodegradable and its flash point exceeds 300 c and it is cheap price and availability in the market.

Recent developments that have improved the electrical properties of vegetable insulating oil have led to more research interests in the application of vegetable oil paper insulation. The development of vegetable oil leads to many problems of oil paper insulation. The dielectric properties of the vegetable oils need to be further studied so this new type of insulating oil can be used in power transformers [21].

In this work will study the characteristic of multi-mode optical sensor for partial discharge signal monitoring in high voltage transformer with natural oil (palm oil), data obtained and analyzed in form of time and frequency domain and compare with conventional sensor

1.2 Background of Research

Partial discharges are the result of local enhancements of the electric field in non-homogenous areas, either in gaseous, liquid or solid media. They produce quick transfers of charge in localized areas and, consequently, create a high-frequency electric impulse that propagates through the electric circuit. For a short time have partial discharges usually no effects to the insulating material but the long time influence shows a destructive effect predominantly on organic insulation systems, which degrade the electrical characteristics of the insulation or the insulation systems. The result is a further degradation of the insulation system and may therefore lead to a failure of the device.

Fiber optics, though used extensively in the modern world, is a fairly simple, and relatively old, technology. Guiding of light by refraction, the principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s.

In the 1840s, physicists Daniel Collodon and Jacques Babinet showed that light could be directed along jets of water for fountain displays. In 1854, John Tyndall, a British physicist, demonstrated that light could travel through a curved stream of water thereby proving that a light signal could be bent. He proved this by setting up a tank of water with a pipe that ran out of one side. As water flowed from the pipe, he shone a light into the tank into the stream of water. As the water fell, an arc of light followed the water down.

Alexander Graham Bell patented an optical telephone system called the photophone in 1880. The laser was introduced in 1958 as a efficient source of light. The concept was introduced by Charles Townes and Arthur Schawlow to show that masers could be made to operate in optical and infrared regions. In 1961, Elias Snitzer of American Optical published a theoretical description of single mode fibers

whose core would be so small it could carry light with only one wave-guide mode. Snitzer was able to demonstrate a laser directed through a thin glass fiber which was sufficient for medical applications. In 1970, the goal of making single mode fibers with attenuation less then 20dB/km was reached by scientists at Corning Glass Works. This was achieved through doping silica glass with titanium. Also in 1970, Morton Panish and Izuo Hayashi of Bell Laboratories, along with a group from the Ioffe Physical Institute in Leningrad, demonstrated a semiconductor diode laser capable of emitting continuous waves at room temperature. In 1991, Desurvire and Payne demonstrated optical amplifiers that were built into the fiber-optic cable itself. The all-optic system could carry 100 times more information than cable with electronic amplifiers. Also in 1991, photonic crystal fiber was developed. This fiber guides light by means of diffraction from a periodic structure rather then total internal reflection which allows power to be carried more efficiently then with conventional fibers therefore improving performance.

Acoustic detection with fiber 0ptic based sensors is possible if an acoustic wave is able to transfer energy to a fiber. The first successful application of optical-fiber sensors to PD detection was reported in 1996 by Zargari and Blackburn. They developed an intrinsic fiber sensor based on a Michelson interferometric configuration.

In 1998, the same authors worked out another non-intrusive fiber-optic sensor for PD detection that is mounted externally on brushing of a current transformer.

The optical detection method based on the acoustic waves that produced by the partial discharge inside the oil tank in power transformer. The interaction of acoustic waves at sonic and ultrasonic frequencies with the optical fiber produces a pressure on the optical fiber. For the range of ultrasonic frequencies, the acoustic pressure on the fiber is axisymmetric and uniform along the fiber, and hence producing a uniform radial pressure on the fiber. The pressure sensitivity of fibers is

governed by the elastic and elasto-optic coefficients of the glass fiber and the elastic coefficients of the fiber coatings.

The light in the fibre may be modulated in different ways, hence the fibre optic sensors can be classified as polarimetric, interferometric, intensiometric, and modalmetric. In the interferometric method that is used in our application, the optical beam propagating through the fibre is phase modulated by the perturbation from the ultrasonic pressure waves produced by the partial discharges. The index of modulation depends on different parameters eg. refractive index of the fiber and change in the fiber length[16].

1.3 Problem Statement

In electrical engineering, partial discharge (PD) is a localized dielectric breakdown of a small portion of a solid or fluid electrical insulation system under high voltage stress, which does not bridge the space between two conductors and cause gradual deterioration. Therefore it is necessary to detect the PD in early time.

Insulation breakdown is the main type of power transformer breakdown. PD is a main cause of insulation breakdown. PD in transformer can lead to corrosion in solid insulating materials and thus cause a breakdown of concerned operating component in the long term. Traditional PD detection methods include electrical measurements, acoustical measurements, etc. However these methods have the disadvantage that the measurements can be influenced by interference and as well it is bard to ascertain the discharge location.

The light detection method which is discussed in this study can overcome the above disadvantages to some extent. Optical method that uses optical fiber sensor which is small in size, highly sensitive and light weight, and possesses high frequency response and significant immunity against electromagnetic interference, can measure a wide range of chemical and physical parameters at ease. This features made the optical method more suitable than the others methods especially for the power transformer.

Mineral oil, synthetic esters and silicon oil are traditionally used for transformer insulations because their low flammability and good dielectric properties but due to their negative environmental impact, they are no more used. Silicon also has a very low flammability but it is the most expensive oil of all types. Currently, scientists are looking for alternatives for these nonrenewable sources, which are also environmental friendly.

Recently, vegetable oil based insulating liquid has been studied as a substitute of mineral insulating oil, because it is almost fully biodegradable and its flash point exceeds 300 c and it is cheap price and availability in the market. The development of vegetable oil leads to many problems of oil paper insulation. The dielectric properties of the vegetable oils need to be further studied so this new type of insulating oil can be used in power transformers.

1.4 Objectives of Research

1- To detect and analysis the partial discharge phenomena using multi-mode fiber optical sensor in natural oil-palm

2- To compare the result and the data gained from this experiment with electrical (capacitive) Sensor detection data and waveform result.

1.5 Scope of Research

The scope of this work is described below:

In this work a multimode optical fiber sensor would be used to detect PD in transformer because it has the advantages such as: small size and weight, enormous potential bandwidth, immunity to interference and crosstalk, electrical isolation, signal security, low transmission loss.

This study would confind in the high voltage range upto 1-20 kV applied to the electrode of the discharge reactor. This study would confined in the comparison of two sensors; optical fiber sensor and capacitve sensor. Also in this study the oil that used in this expermental work is a palm oil because it is so cheap and environmental friendly.

1.6 Significance of the Study

As mentioned above, the convention techniques of detection for partial discharges are expensive and have drawbacks in accuracy. The optical fiber sensor technique can also be used as an inexpensive alternative for the detection of PD in heavy transformers to monitor the efficiency and working of the transformer. The

optical fiber sensor technique is inexpensive and more reliable than conventioonal sensors and provide safty due to total isolation from the line high voltage.

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