ZINC OXIDE SURGE ARRESTER CONDITION MONITORING USING THERMAL IMAGE AND THIRD HARMONIC LEAKAGE CURRENT CORRELATION

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Special dedication to my beloved husband Muhammad Khair Noordin, mother Latifah Ahmad, father Abdul Ghafar Haji Tahir, mil Kamsiah Sumiran, fil Noordin Atan, son Muhammad Aryan Amsyar and Mukhlis 'Afy , brothers and sisters who have encouraged, guide and inspired me throughout my journey in education

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ABSTRACT

Arrester is used to protect high voltage equipment or electric power lines from permanent or temporary overvoltage. It is imperative to perform a frequent monitoring on the condition of the arrester as this device will prevent damage to the power system. When there is an AC operating voltage applied across the arrester body, there is a small leakage current flowing to the ground terminal of the arrester. Currently, the third harmonic component of the leakage current has been used to identify the condition of the arrester whether it is still safe to be used. However, measurements of the leakage current and its harmonic components pose some difficulties. Moreover, the usage of a new technique based on thermal condition in monitoring the performance of arrester has been studied widely. The thermal condition of an arrester can be used to support the efficiency of the monitoring process. This research proposes to investigate the correlation between two variables, namely the third harmonic leakage current, and the arrester housing surface temperature (representing the thermal condition of the arrester) using a Radial Basis Function (RBF) Neural Network analysis. In addition, this research also studies the effect of ambient temperature on the correlation between the two variables. The leakage current values were measured using a current shunt and a digital storage oscilloscope, and then analyzed using Fast Fourier Transform to obtain its harmonic component. The surface thermal profile of the arrester body was captured using a thermal camera and then further analyzed to obtain several key representative parameters including the maximum, minimum, average, and standard deviation temperatures. These temperature parameters, together with the ambient temperature, were used as input variables while the third harmonic leakage current magnitude as a target to the proposed radial basis function neural network. The ambient temperature was then omitted in a repeated computation. From the radial basis function analyses, the two mentioned variables are positively correlated. Also, the ambient temperature has an effect on this correlation, whereby it is advisable also include the ambient temperature in the ANN computation to minimize the error. The results from all experimental data (500 training, 61 testing) show that a 97% accuracy in categorizing the arrester condition (either good or bad) is successfully achieved. Thus, it can be concluded that there is a good correlation between the third harmonic leakage current and the thermal image of an arrester which means the thermal image can be used as an alternative technique for zinc oxide surge arrester monitoring without the need to measure the leakage current.

ABSTRAK

Penangkap digunakan untuk melindungi peralatan voltan tinggi atau talian kuasa elektrik daripada terlebih voltan kekal atau sementara. Pemantauan yang kerap ke atas keadaan penangkap adalah penting kerana penangkap akan menghalang kerosakan kepada sistem kuasa. Apabila voltan operasi AC dikenakan ke seluruh badan penangkap, terdapat arus bocor kecil mengalir ke terminal bumi penangkap. Pada masa ini, komponen harmonik ketiga arus bocor telah digunakan untuk mengenal pasti keadaan penangkap sama ada ia masih selamat untuk digunakan. Walau bagaimanapun, pengukuran arus bocor dan komponen harmonik menimbulkan beberapa kesukaran. Selain itu, penggunaan keadaan terma dalam memantau prestasi penangkap telah dikaji secara meluas. Keadaan terma penangkap boleh digunakan untuk menyokong keberkesanan proses pemantauan. Kajian ini mencadangkan untuk menyiasat hubungan antara dua pembolehubah: harmonik ketiga arus bocor dan suhu permukaan perumah penangkap (mewakili keadaan terma penangkap) menggunakan analisis Rangkaian Neural Fungsi Asas Radial (RBF). Di samping itu, kajian ini juga mengkaji kesan suhu persekitaran kepada hubungan antara kedua-dua pembolehubah. Nilai arus bocor diukur dengan menggunakan pemirau arus dan osiloskop digital dan kemudian dianalisis dengan menggunakan Jelmaan Fourier Pantas untuk mendapatkan komponen harmonik. Profil suhu permukaan perumah penangkap diambil menggunakan kamera terma dan kemudian dianalisis untuk mendapatkan beberapa wakil parameter utama termasuk suhu maksimum, minimum, purata dan sisihan piawai. Parameter suhu bersama-sama dengan suhu persekitaran telah digunakan sebagai pembolehubah masukan manakala harmonik ketiga arus bocor sebagai sasaran kepada Fungsi Asas Radial yang dicadangkan. Analisis diulang dengan mengeluarkan suhu persekitaran. Fungsi Asas Radial menunjukkan bahawa kedua-dua pembolehubah yang dinyatakan telah berhubung secara positif. Suhu persekitaran juga mempunyai kesan kepada hubungan ini. Keputusan daripada semua data eksperimen (500 latihan, 61 ujian) menunjukkan bahawa ketepatan sebanyak 97% dalam mengkategorikan keadaan penangkap (sama ada baik atau buruk) telah berjaya dicapai. Oleh itu, dapat disimpulkan bahawa terdapat hubungan yang baik antara harmonik ketiga arus bocor dan imej terma penangkap dimana imej terma boleh digunakan sebagai teknik alternatif untuk pemantauan penangkap pusuan logam oksida tanpa perlu mengukur arus bocor.

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LIST OF SYMBOLS

i_t	-	total leakage current
i_r	-	resistive leakage current
i_c	-	capacitive leakage current
$I_{tshifted}$	-	shifted leakage current
I_{sum}	-	summation of total and shifted leakage current
v_{sh}	-	applied voltage

LIST OF ABBREVIATIONS

AC	-	Alternating Current
ANN	-	Artificial Neural Network
Ave	-	Average
Bi	-	bismuth
Co	-	cobalt
CM	-	Compensation Method
FFT	-	Fast Fourier Transform
Mn	-	manganese
Max	-	Maximum
Min	-	Minimum
MO	-	Metal Oxide
MOSA	-	Metal Oxide Surge Arrester
p.u	-	per unit
RBF	-	Radial Basis Function
rms	-	root mean square
Sb	-	antimony
SCM	-	Shifted Current Method
Std Dev.	-	Standard Deviation
T_d	-	delay time
Temp	-	Temperature
T_p	-	peak time
V-I	-	Voltage Current
ZnO	-	Zinc Oxide

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electric power system in power station is a system or network of electrical equipment that is used to generate, transmit and distribute electrical power to the consumer. High voltage equipment such as generator, transformer, transmission line, insulator, circuit breaker and arrester are examples of electrical equipment in the power station. These equipment operate simultaneously to provide a continuous electricity. Protection system is one of the important systems that must operates efficiently. Its failure could lead to several damages in the power system which might affect the whole operation system.

Metal oxide (MO) surge arrester is one of protection device that is generally used to protect the equipment in the power system from damaging effect of overvoltage. It is installed near the equipment being protected to minimize the inductive effects of the leads while discharging large surge current. MO surge arrester is connected between the phase and ground terminals of arrester. Basically, surge arrester has two main functions regarding to the operating system condition (Durbak, 2001). Apparently, surge arrester does nothing during normal operating voltages as there are approximately no current flows through the arrester due to a very high resistance. On the other hand, surge arrester must have the ability to conduct high current during overvoltage without causing any fault to the system. Overvoltage can be divided into three types, these are lightning strokes, temporary overvoltage and switching surge. Temporary overvoltage may occur due to fault condition while switching surge may occur due to opening and closing of the circuit breakers in the system.

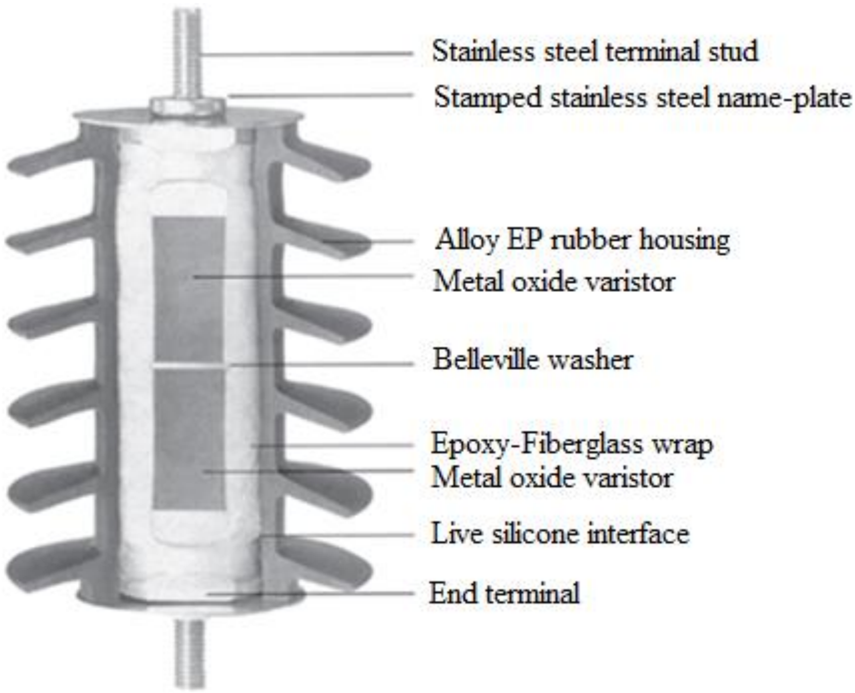

Figure 1.1 Cross-section view of polymeric MO surge arrester (http://www.hubbellpowersystems.com/arresters/trans/basics/)

Figure 1.1 shows the cross sectional view of a polymeric MO surge arrester of Ohio Brass brand. MO surge arrester has a very simple structure that consists of two parts. Outer part is an insulating housing which is made of porcelain or polymeric material while inner part or inner active column contains metal oxide varistors and thermal dissipating elements. The main component of surge arrester is the varistor as it provides the desired nonlinear characteristics and presents a strong relation with the temperature (low current range). Nowadays, zinc oxide (ZnO) varistor is the choice of many as it gives the best performance in energy dissipating ability (Neto *et al*., 2004) and has a highly nonlinear voltage current characteristic (Castro *et al*., 1993).

Figure 1.2 shows the graph of voltage magnitude of equipment with and without the arrester device in per unit. The time axis is divided into the range of lightning overvoltage in microsecond, switching overvoltage in milisecond and temporary overvoltage in second. The blue line represents the withstand voltage of high voltage equipment. It is clarifies that by using an arrester as a protection device, the voltages of equipment are limited below the withstand voltage. However, if the equipment is not protected by arrester device, the magnitude of overvoltage can reach until several per unit. This phenomenon clearly shows the importance of arrester for overvoltage protection.

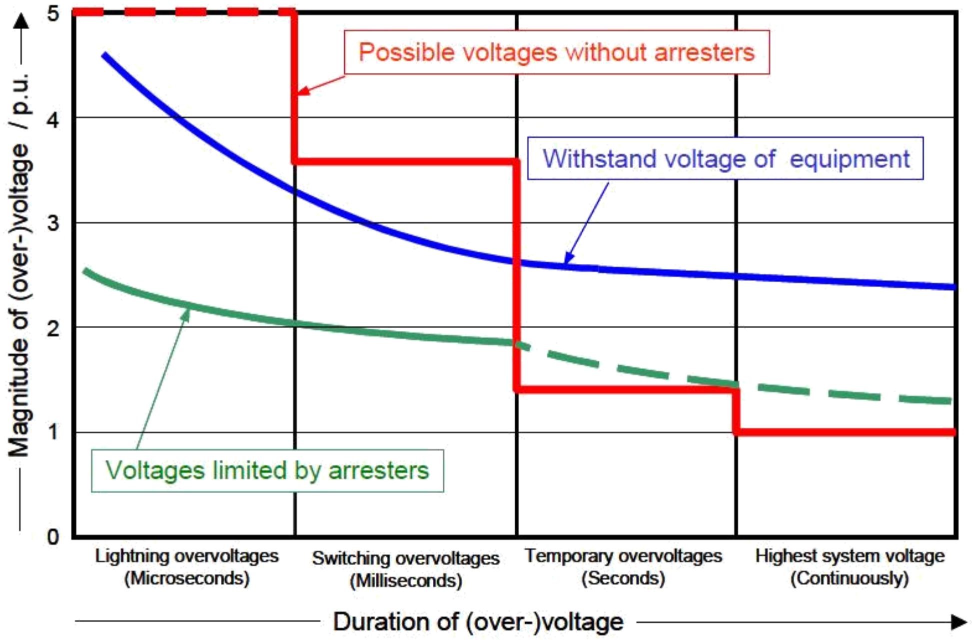

Figure 1.2 Schematic representation of the magnitude of overvoltage (Heinrich and Hinrichsen, 2001)

A good zinc oxide arrester should recover to its initial condition after its voltage limiting operation. Nonetheless, the voltage current characteristic of ZnO arrester will changes due to degradation and will affects the performance of arrester.

1.2 Zinc Oxide Surge Arrester Monitoring

Zinc oxide surge arrester is a protection device that protects power system equipment from undesired damage or breakdown caused by overvoltages. It is important to maintain the arrester in a good condition during its service in order to ensure a reliable and safe power system. The condition of arrester that is in service must be regularly monitored even though it has no serviceable part that requires a regular maintenance. One of the purposes of a regular monitoring is to detect the presence of an abnormal ageing and degradation of the arrester itself, as the ageing condition at a given time can basically be related to the performance of the arrester.

There are few methods to monitor the condition of an arrester in service that have been presented in the past. These include the ultrasonic and radio interference detections, partial discharge and electromagnetic radiation measurements, thermo vision methods, and the leakage current measurement (Christodoulou *et al*., 2009). In the leakage current method, most researchers use the total leakage current measured, usually using a clamp at the ground-end terminal of an arrester, to extract the arrester ageing condition (Lundquist *et al.*, 1990; Heinrich and Hinrichsen, 2001; Neto *et al.*, 2004; Karawita and Raghuveer, 2005; Karawita and Raghuveer, 2006; Neto *et al.*, 2006; Lee and Kang, 2005; Abdul-Malek *et al.*, 2008; Huijia and Hanmei, 2010). The total leakage current of an arrester consists of two components, namely the resistive component and the capacitive component. The resistive component needs to be extracted from the total leakage current signal since it is the magnitude of the resistive current that is usually used as the arrester ageing indicator. The increase in the magnitude of the resistive current is mainly caused by a deteriorated zinc oxide element within the arrester (Shirakawa *et al*., 1988).

Many years later, researchers had found out that the magnitude of the third harmonic component of the resistive leakage current was more accurate to be used in determining the ageing condition of the arrester. Subsequently, the increase in the third harmonic component magnitude had to be analysed. Lundquist *et al.* (1990) has stated that the amplitude of the harmonic current increases with the increment of resistive component of the leakage current. The authors used the harmonic content in the resistive leakage current as an ageing indicator. Nevertheless, Heinrich and Hinrichsen (2001) found out that the third harmonic of the resistive leakage current can be used to detect specific kinds of degradation only as the third harmonic component cannot be used to detect the degradation caused by moisture ingress. Since an arrester in service is energised by the system voltage, the harmonics present in the system voltage may be measured together with the harmonic component generated by the ageing surge arrester itself. Some differentiations between the different sources of harmonics are therefore needed. Lundquist *et al.* (1990) has proven that for a method that is based on the compensation technique, the harmonic analysis of the leakage current is not affected by the presence of harmonics in the system voltage.

There are several difficulties in measuring the third harmonic of the resistive leakage current of an arrester. Until now, the simplest device that can measure the leakage current of an arrester is a current probe. The current probe can only measure the total leakage current while the resistive and harmonic components have to be determined by a further processing of the measured leakage current signal. The current probe which is connected to a display device is clamped in the ground-end terminal of the arrester. The current probe and display device may suffer from many disturbances due to the surrounding high electromagnetic field which may then lead to inaccurate readings (Abdul-Malek *et al*., 2010a).

1.3 Problem Statement

In the past years, several researchers (Mizuno *et al*., 1981; Andoh *et al*., 2000; Heinrich and Hinrichsen, 2001; Xianglian *et al*., 2002; Jinliang *et al*., 2003; Neto *et al.*, 2004; Neto *et al.*, 2006; Miyakawa *et al*., 2008, Abdul-Malek *et al*., 2008) have reported on the usage of arrester housing thermal images for monitoring the ageing condition of an arrester. The housing of an arrester is usually made from materials that are durable and heat resistant so that it can withstand high temperatures for a long-term duration. Neto *et al*. (2006) has confirmed the usage of thermal analysis as an adequate methodology to monitor the performance of a zinc oxide arrester. The surface temperature of an arrester can indicate the characteristic of the arrester as the presence of hot spots can be due to its ageing condition. It is noted that the arrester surface temperature is not only dependent on the ageing related internal leakage current, but also the ambient temperature. Therefore, when measurements are made, the ambient temperature can also be used as an additional parameter for a better accuracy in deciding the ageing condition of the arrester. The effects of the ambient temperature on the ageing analysis of surge arresters are mentioned in (Zahedi, 1994). The author has stated that as the ambient temperature increases, the temperature of the arrester valve element also increases which will cause an additional heating to the element and may lead to a thermal runaway condition.

A thermography camera is a well-known device that can capture the thermal image of an object together with details such as the hot spots, maximum and minimum temperatures, and etcetera. Several researchers (Neto *et al*., 2004; Neto *et al*., 2006) have used thermography cameras in monitoring the arrester temperature for signs of ageing and degradation. This camera can be used to capture the surface temperatures of an arrester while it is in service without being influenced by the surrounding high electromagnetic field. A sudden appearance of hot spots or rise in the maximum temperature in the captured thermal image may indicate arrester degradation, and depending on the ageing level, may require an immediate replacement. Neto *et al*. (2009) and Lira *et al*. (2010) have captured thermal images of defective arresters while in service, and then have analysed the images using a simple Artificial Neural Network. In particular, they have adopted the resilient propagation and the self-organizing maps techniques to correlate between the thermal images and the failure condition of the arrester.

The technique proposed by Neto *et al*. (2009) and Lira *et al.* (2010) were used to classify the arrester according to the current condition status either defective or not and they have a correlation or decision error of about 0.6% and 4.17%. Later, Neto *et al*. (2009) proposed the Radial Basis Function (RBF) technique for obtaining a lower decision error in classifying the arrester condition using a thermal profile. However, both authors do not include the measurement of leakage current as an indicator to the ageing condition of arrester as a supportive data. Meanwhile, Mizuno *et al*. (1981) has includes the effect of ambient temperature on the thermal runaway monitoring condition on the zinc oxide valve elements. Even though many studies had been carried out with respect to the use of thermal images and artificial intelligence in determining the arrester condition, more work still need to be done to relate the ambient temperature to the two factors and improve the accuracy of artificial intelligence. Thus, this research aims to use a Radial Basis Function Neural Network in correlating the third harmonic leakage current with arrester housing surface temperature with taking the ambient temperature into consideration to monitor the ageing condition of arrester.

1.4 Objectives of the Research

The objective of this study is to obtain the algorithm of Radial Basis Function in order to correlate third harmonic leakage current and housing surface temperature of arrester. Specifically, the objectives of study are:

1. To obtain and analyze the experimental data on leakage currents and thermal images of zinc oxide surge arresters. The housing surface temperatures are to be statistically analysed and summarised into several key parameters.

2. To obtain a correlation between the third harmonic leakage current and the arrester housing surface temperature (represented by several statistical parameters) using the Radial Basis Function Neural Network and determine the effect of the ambient temperature to the correlation.

1.5 Research Scope

There are several scopes needed to achieve the objectives of this research. This research is focusing on determining the leakage current and thermal images of six 120kV rated gapless polymeric arresters. The leakage current is measured using a high digital oscilloscope and analyzes using MatLab software to get the third harmonic leakage current. Whereas, the thermal images of arrester housing surface is captured using a high resolution thermography camera and analyze using InfReC Analyzer Thermography Studio software to get the arrester housing surface thermal profile. The thermal profile used in this analysis is a line profile that is taken at the center of the arrester body. The line profile is further analyzed to get the temperature parameters that are maximum, minimum, average and standard deviation temperature. Radial basis function neural network is then used in correlating the obtained third harmonic leakage current values with the arrester housing surface temperature using a MatLab software application. The basis function that is used in the analysis is a newrb function with setting the mean square error to 0.002. The ambient temperature is also recorded and used in the analysis to see the effects towards the correlation.

1.6 Contribution

The contributions of this research are outlined below:

i. A technique to represent the arrester housing surface temperature from its thermal image had been proposed. The arrester housing surface temperature can be adequately represented by these key parameters – the maximum temperature, minimum temperature, average temperature and standard deviation temperature.

ii. A new finding on the effects of the ambient temperature on the correlation between the third harmonic leakage current and the arrester housing surface temperature had been obtained. The effect of ambient temperature is in terms of improving the accuracy of the artificial intelligence.

iii. A new algorithm using a radial basis function in correlating the third harmonic leakage current with the arrester housing surface temperature had been obtained.

1.7 Summary

Chapter 1 describes the background of study, zinc oxide surge arrester monitoring, problem statement, objectives, research scope and contribution of this research. This chapter is a research proposal or preparations that need to be followed throughout this research.

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