RETURN VOLTAGE MEASUREMENTS TO INVESTIGATE THE DEGRADATION OF ZINC OXIDE VARISTOR

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Dedicated to my beloved parents

Ahmad Noorden and Rohaya

And my family

For their supports and blessings

To all my friends especially Siti Aisyah

For the emotional support throughout my ups and downs

All your kindness would not be forgotten

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ABSTRACT

Due to their reliability and accuracy, many modern diagnostics based on dielectric voltage response, such as polarization/depolarization current (PDC), voltage decay (VD) and return voltage (RV) measurements, have been used in monitoring ageing processes of metal oxide (MO) varistors. Among these diagnostics, recently, RV measurement (RVM) seems to be an increasingly popular method as it has high sensitivity to the condition of varistors and low sensitivity to disturbances in vicinity of the field measurements. Nonetheless, the basic interpretation based on the RVM essential parameters – peak RV, time-to-peak RV and initial slope of RV - provides insufficient information of the MO varistors condition since they are inevitably dependent on the measuring parameters such as the charging and discharging times as well as the test object temperature. Hence, this project focuses on a new way in interpreting the RVM parameters based on dielectric time constants analysis using an equivalent circuit of varistor microstructure, namely the Maxwell-Model. In order to investigate the ageing processes of MO varistors, two types of accelerated degradation techniques – impulse and heat degradations – are systematically conducted on test samples. Experimental results are presented and discussed in detail according to the underlying physical mechanism. On the basis of this concept, a sensible ageing parameter, *p-factor*, is used for better characterization of the ageing status of varistors.

ABSTRAK

Disebabkan oleh keboleharapan dan ketepatannya, banyak diagnostik moden berdasarkan pada respon voltan dalam dielektrik, seperti pengukuran pengutuban/penyahkutuban arus (PDC), voltan penyusutan (VD) dan voltan balikan (RV), telah digunakan dalam proses pemantauan penuaan varistor oksida logam (MO). Di antara diagnostic-diagnostik ini, kini, pengukuran RV (RVM) semakin meningkat digunakan kerana mempunyai kepekaan yang tinggi terhadap keadaan varistor dan sensitiviti rendah terhadap gangguan persekitaran proses pengukuran. Walaubagaimanapun, penguraian asas berdasarkan pembolehubah penting RVM - puncak RV, masa-ke-puncak RV dan kecerunan awal RV - tidak memberi maklumat yang cukup tentang keadaan varistor MO kerana ia bergantung pada parameter pengukuran seperti tempoh pengecasan and penyahcasan serta suhu objek. Oleh kerana itu, projek ini fokus pada cara baru dalam mengurai pembolehubah RVM berdasarkan analisis pemalar dielektrik masa dengan menggunakan litar yang sesuai untuk varistor mikrostruktur - Maxwell-Model. Dalam proses untuk menyiasat penuaan varistor MO, dua jenis teknik penuaan – secara aplikasi dedenyut dan pemanasan - dilakukan secara sistematik pada sampel. Keputusan eksperimen tersebut dilaporkan dan dibincangkan secara terperinci sesuai dengan mekanisma fizikal yang memdalam. Atas dasar konsep ini, pembolehubah yang sesuai, *p-faktor*, digunakan untuk menggambarkan dengan lebih baik status penuaan varistor.

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LIST OF SYMBOLS

R_{IG}	-	Resistance of intergranular layers
C_{IG}	-	Capacitance of intergranular layers
R_{GRAIN}	-	Resistance of grains
I	-	Current
K	-	Ceramic constant
V	-	Voltage
α	-	Non-linearity exponent
$S1$	-	Switch 1
$S2$	-	Switch 2
U_p	-	Charging voltage
t_c	-	Charging time
t_d	-	Discharging time
U_m	-	Peak return voltage
t_m	-	Time to reach return voltage
s	-	Initial slope of return voltage
R_o	-	Geometric resistance
C_o	-	Geometric Capacitance
R_{ns}	-	Resistance of n-th parallel branches
C_{ns}	-	Capacitance of n-th parallel branches
ε_r	-	Relative permittivity
ρ	-	Specific resistance
τ_1	-	Dielectric time constant of material 1
τ_2	-	Dielectric time constant of material 2
C_1	-	Capacitance of material 1
C_2	-	Capacitance of material 2
ε_1	-	Permittivity of material 1
ε_2	-	Permittivity of material 2

R_1	-	Resistance of material 1
R_2	-	Resistance of material 2
ρ_1	-	Specific resistance of material 1
ρ_2	-	Specific resistance of material 2
R_L	-	Resistor of current limiter
V_{HV}	-	Voltage on high voltage arm
V_{LV}	-	Voltage on low voltage arm
^oC	-	Degree Celsius
τ	-	Dielectric time constant
U_r	-	Return voltage
U_s	-	Voltage after short circuit period
p-factor	-	New ageing parameter

LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
IVAT	-	Institute of High Voltage and High Current
ZnO	-	Zinc oxide
MOV	-	Metal oxide varistor
MO	-	Metal oxide
MOSA	-	Metal oxide surge arrester
VD	-	Voltage decay
PDC	-	Polarization/Depolarization current
RV	-	Return voltage
RVM	-	Return voltage measurement
V-I	-	Voltage-current
DC	-	Direct current
MCOV	-	Maximum continuous operating voltage
rms	-	Root mean square
Hz	-	Hertz
mm	-	Millimeter
kA	-	Kilo amperes
kV	-	Kilo volts
µs	-	Micro second
pF	-	Pico farad
J	-	Joule

CHAPTER 1

INTRODUCTION

1.1 Project Background

Surge protection devices are often used to protect power and electronic equipment from the destructive transient overvoltage from lightning or other large-magnitude surge. These devices are used to limit the overvoltage to a level which is sufficiently safe for the equipment being protected by diverting the large current to ground. The non-linearity characteristics of these devices depend on their material composition. One type of non-linear devices is known as metal oxide varistor (MOV). MOV is a ceramic device with highly non-linear electrical characteristics; similar to those of a back-to-back diode, and has been used for low voltage application (below 1 kV). For higher voltage application that is above 1 kV the protection device is usually known as metal oxide surge arrester (MOSA) which may consists of several MOV blocks. Due to its high nonlinear characteristics, these devices have high energy absorption capability which is a good characteristic for an overvoltage suppressor.

However, these nonlinear characteristics can be degraded by the effects of electrical and thermal stresses as well as chemical reactions with the surrounding material. Usually, the thermal stress is considered as effect due to the temperature rise of the metal oxide materials subsequent to the discharge of high energy surges. While, the electrical stress may be the effects of voltage stress by its own operating voltage at ambient temperature or by high current stress due to overvoltages occurrence.

In the past, many investigations of several non-destructive diagnostic techniques have been conducted for reliable condition assessment of the ageing of MOSA. These diagnostic techniques include the standard 1mA reference voltage, lightning impulse discharge residual voltage, voltage decay (VD), polarization or depolarization current (PDC) and Return Voltage (RV) measurements. The modern diagnostic techniques based on dielectric response such as VD, PDC and RV measurements, have also been used to evaluate insulating materials such as cables and transformers [1-4].

Among these modern diagnostic techniques, recently, the return voltage measurement (RVM) seems to be increasingly used as a reliable diagnostic method in monitoring the ageing process of the metal oxide materials due to its high sensitivity to smaller degrees of degradation [5]. In addition, RVM has low sensitivity to disturbances by external noise, a situation that is auspicious for in-field measurements [6].

1.2 Problem Statement

RVM method is a good approach to attain the information of insulating components condition for devices such as ZnO varistor (under normal operating mode). Due to less sensitive to disturbances, the measurements are reliable and also reproducible, at least with regard to the collection of the data. Unfortunately, in the past, not all RVM interpretation methods suggest correct insulation components condition information because of unreliable diagnosis parameters and inaccurate RVM data interpretation approach. Hence, this project focus on investigation of an accurate and correct way to interpret RVM data of ZnO varistor in order to obtain real physical condition of the ZnO insulation.

1.3 Objective of Project

There are two main objectives that have been achieved in this project:

- To model the equivalent circuit of ZnO varistor according to RVM phenomenon using Maxwell multilayer dielectric circuit.
- To investigate reliable interpretation of ZnO degradation process using RVM method.

1.4 Scope of Project

The main scope of this project is to study the diagnostic tecnique of ZnO varistor based on RVM method which includes:

- Study of behaviour and characteristics of metal oxide material;
- Study of theory, principles and interpretation of RVM;
- Evaluation of metal oxide material using multilayer dielectric approach – Maxwell-Model;
- Experimental works of ageing investigation on MOV using RVM method; and
- Results validation by comparison with total leakage current and 1 mA reference voltage measurements.

1.5 Thesis Outline

This thesis is divided into five chapters. Generally, some basic principles, theories, equations, previous researches' references, experimental result and discussions are discussed included in these chapters based on the contents requirements of each chapter.

In chapter 1, the author has included the project overview and the main objectives of conducting this project. Chapter 2 presents some background information of the project, such as the description of ZnO varistor as overvoltage protective device, and RVM as ZnO varistor diagnostic technique. This chapter briefly explains the ZnO varistor structure, common equivalent circuit and electrical characteristics as well as the importance of conducting a research on its diagnostic technique. At the end of the chapter, the author summarizes the current research works done by other researchers and of course their valuable recommendations.

Chapter 3 presents the methodologies of modeling ZnO varistor as well as the experimental procedures of carrying out the RV measurements. These are presented in a flow chart form together with a brief explanation. The RVM interpretation methods are discussed at the end of this chapter. Then, results and discussion are covered in Chapter 4.

Finally, Chapter 5 summarizes all the works and studies that had been presented in the previous four chapters. Besides, some future works are recommended at the end of the chapter.