Development of Inductive Coil Sensor based on Rogowski coil for Arcing Fault in Medium Voltage (MV) Measurement

by

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A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

Faculty of Electrical Engineering Technology
UNIVERSITI MALAYSIA PERLIS

2020

ACKNOWLEDGEMENT

This thesis would not have been possible without first and foremost, the blessing of Allah, and the support extended by all the people involved. First and foremost, I would like to thank my main research supervisor, Assoc Prof Dr. Muzamir Isa for his valuable guidance and advice. He inspired me greatly to work in this thesis. He was very supportive at all times.

I would also like to thank my co-supervisor of my research, Ts. Dr. Mohamad Nur Khairul Hafizi Bin Rohani who always provided his precious comments, guidance, ideas, advice, and encouragement throughout the development of this dissertation. I also would like to thank to Assoc. Prof Dr Haziah Abdul Hamid who is also my co-supervisor and Dean for always following up on the progress of my research and thesis.

My sincere appreciation goes out to Universiti Malaysia Perlis (UniMAP) for sponsoring my PhD scholarship under *Skim Latihan Akademik Bumiputra* (SLAB) and Ministry of Higher Education Malaysia as well.

A special thank you also goes out to Dr Nur Afifah Shuhada Rosmi for her guidance in developing the modeling sensor in FEM. Not forgetting my research members and friends who always give ideas and advice to me. I also would like to thanks to Mr Wan Mokhdzani Wan Nor Haimi for his idea and support during thesis writing. Not forgot to the laboratory Chargeman (technical staff), Mr Shukur Abdullah and Mr Azliman Musa for their advice during operating and handling high voltage equipment. They have always been flexible and supportive. Their valuable comments highly contributed to this study.

Last but not least, an honorable mention goes to my wife, Nurul Izza Mohd Nor, my son Muhammad Adam Izhan Bin Ayob Nazmy and also for my family especially to my mother, Z. Roaini Ismail, family in-law and siblings for their understanding and support in completing this thesis. With their kind help and patience, the thesis has been completed comfortably with less unwanted occasions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
AC	Alternating Current
ACD	Asymmetrical Conical Dipole
AFD	Arc Fault Detector
AFI	Arc Fault Interrupter
ANOVA	Analysis of Variance
BNC	Bayonet Neill-Concelman
CB	Circuit Breaker
CR	Circular
CVT	Capacitor Voltage Transformer
D-HFCT	Differential High-Frequency Current Transformer
DTOA	Difference Time of Arrival
EMF	Electromagnetic Field
EMTP-ATP	Electromagnetic Transient Program-Alternative Transient Program
FEM	Finite Element Method
FFF	Fused Filament Fabrication
FFO	Fast Front Overvoltages
FPD	Flush Plate Dipole
GHz	Gigahertz
GIS	Gas Insulated Switchgear
HF	High Frequency
HFCT	High-Frequency Current Transformer
HSD	Hollow Spherical Dipole
Hz	Hertz
IEC	International Electrotechnical Commission
IOPC	Integrator and Integrated-Optic Pockels Cell
kA	Kilo Ampere
kV	Kilo volt
LCC	Line Communicates Converter
LV	Low Voltage
MA	Mega Ampere
MATLAB	Matrix Laboratory

MHz	Mega-Hertz
ms	Milliseconds
MV	Medium Voltage
ns	Nanoseconds
OV	Oval
OV1	Oval cross-section 1
OV2	Oval cross-section 2
OV3	Oval cross-section 3
OV4	Oval cross-section 4
OV5	Oval cross-section 5
OV6	Oval cross-section 6
OV7	Oval cross-section 7
OV8	Oval cross-section 8
OV9	Oval cross-section 9
OV10	Oval cross-section 10
PCB	Printed Circuit Boards
PD	Partial Discharge
PE	Polyethylene
PLA	Poly Lactic Acid
PSIM	Power Simulator
PVC	Polyvinyl Chloride
R1	RC Rectangular 1
R2	RC Rectangular 2
R3	RC Rectangular 3
R4	RC Rectangular 4
R5	RC Rectangular 5
RC	Rogowski Coil
RC2A1	Rectangular RC sensor prototype with 20 turns
RC2A2	Rectangular RC sensor prototype with 30 turns
RC2A3	Rectangular RC sensor prototype with 50 turns
RC2A4	Rectangular RC sensor prototype with 90 turns
RC2A5	Rectangular RC sensor prototype with 100 turns
RC5A	Rectangular RC sensor prototype with 20 turns (good in term of mutual inductance)

RC5B	Rectangular RC sensor prototype with 30 turns (good in term of mutual inductance)
RT	Rectangular cross-section
RT1	Rectangular cross section 1
RT2	Rectangular cross section 2
RT3	Rectangular cross section 3
RT4	Rectangular cross section 4
RT5	Rectangular cross section 5
RT6	Rectangular cross section 6
RT7	Rectangular cross section 7
RT8	Rectangular cross section 8
RT9	Rectangular cross section 9
RT1A	Rectangular cross section 1A
RT2A	Rectangular cross section 2A
RT3A	Rectangular cross section 3A
RT4A	Rectangular cross section 4A
RT5A	Rectangular cross section 5A
RT6A	Rectangular cross section 6A
RT7A	Rectangular cross section 7A
RT8A	Rectangular cross section 8A
RT9A	Rectangular cross section 9A
SFO	Slow Front Overvoltages
SMA	Sub Miniature Version A
T1	Terminal 1
T2	Terminal 2
TNB	Tenaga Nasional Berhad
TOV	Temporary Overvoltages
USFA	United States Fire Administration
UHF	Ultra-High Frequency
VCB	Vacuum Circuit-Breakers
VFFO	Very Fast Front Overvoltages
VHF	Very High Frequency
XLPE	Cross-Linked Polyethylene

LIST OF SYMBOLS

B	Magnetic Flux Density
C_c	Self-coil Capacitance
C_p	Probe Capacitance
C_{ex}	External Capacitor
d	Radius of The Wire
d_{rc}	RC Core Diameter or width
d_w	Diameter of Conductor
fr	Resonance Frequency
g	Time-Varying Arc Conductance
G	Stationary Arc Conductance
h	Height
I	Current
i_{arc}	Instantaneous Arc Current
L_c	Self-coil inductance
l_w	Length of The Copper Wire
M_c	Mutual inductance
N	Number of Turn
ρ_c	Copper Resistivity
pF	Pico Farad
r	Resistive Component Per Arc Length
R_c	Self-coil resistance
R_{in}	Inner Radius
R_{out}	Outer Radius
R_T	Termination Resistance
T	Tesla
τ	Arc Time Constant
µH	Micro Henry
µs	Microsecond
μ_o	Air permeability
U_{arc}	Constant Arc Voltage
u_o	Characteristic Arc Voltage

Pembangunan Pengesan Gegelung Induktif berpandukan pada Gegelung Rogowski untuk Pengukuran Arka Rosak Voltan Sederhana

ABSTRAK

Voltan lampau arca rosak masalah biasa yang berlaku dalam sistem voltan rendah dan voltan sederhana. Walaubagaimanapun, voltan lampau arca rosak pada sistem voltan sederhana ialah paling berbahaya di mana ia mudah terdedah pada letupan komponen elektrikal seperti kabel, penggubah, peralatan suis dan kelengkapan lain. Punca Voltan lampau arca rosak adalah daripada kelonggaran penamatan kabel di terminal palang bas dan pengubah, penyambungan kabel dan sebagainya. Untuk mengurangkan risiko kesan arca rosak, teknologi litar penyampuk arka (AFSI) dan pengesan arca rosak (AFD) telah diperkenalkan. Walaubagaimanapun, alat ini hanya sesuai untuk di gunakan di voltan rendah atau penggunaan domestik sahaja.Untuk penggunaan di voltan sederhana (MV), penderia arca rosak yang baru perlu diperkenalkan untuk mengatasi masalah ini. Kekerapan voltan lampau arca rosak boleh sebabkan gangguan pada sistem elektrikal dimana mungkin menyebabkan kerosakan sistem. Maka, untuk mengatasi masalah ini penderia arca rosak telah dibangunkan dalam kajian ini. Gegelung Rogowski (RC) ialah salah satu di dalam kumpulan gegulung beraruhan telah dipilih sebagai penderia pengesanan arca rosak. Penyelakuan kaedah unsur terhingga (FEM) telah digunakan untuk analisa ketumpatan fluks electromagnet, B pada geometri dan bilangan lilitan pada RC dengan permodelan tiga jenis keratan rentas RC iaitu segiempat tepat, bujur dan bulat. Selain itu, pengiraan kearuhan saling terhadap keratan rentas segiempat juga dilakukan dan telah dibandingkan dengan keputusan penyelakuan FEM. Terdapat tujuh (7) contoh sulung penderia RC keratan rentas jenis segiempat yang dibuat menggunakan pencetak tiga dimensi (3D) dengan pelbagai bilangan lilitan antara 20 hingga 100 dan luas keratan rentas antara 200 mm^2 dan 1050 mm^2. Bahan *acrylonitrile butadiene styrene* (ABS) dipilih sebagai teras penderia RC kerana ia mempunyai kerana ia mempunyai keberaliran yang rendah, dikategorikan sebagai penebat, ketegaran yang mencukupi, kestabilan haba yang baik, mempamerkan keteguhan yang tinggi walaupun dalam keadaan sejuk, ketahanan kimia, retak tekanan persekitaran dan sifat mekanik yang baik Untuk mengesahkan prestasi penderia dari segi kepekaan dan jalur lebar, pengukuran eksperimen dilakukan di makmal voltan tinggi. Dari hasil eksperimen, RC2A5 (yang dibangunkan di dalam kajian ini) yang merupakan bilangan lilitan tertinggi (100 lilitan) menghasilkan sensitiviti yang sangat tinggi iaitu 0.56 kV / mA. Walau bagaimanapun, jalur lebar RC2A5 menurun kepada 3.51 MHz yang merupakan jalur lebar terendah Manakala, dengan mengurangkan bilangan lilitan pada 20, RC2A1(yang dibangunkan di dalam kajian ini) naik sehingga 7.93 MHz yang merupakan jalurlebar tertinggi akan tetapi kepekaannya jatuh dengan pesat pada 0.30 kV / mA. Dari hasil yang diperolehi, dapat disimpulkan bahwa jumlah lilitan yang lebih rendah menghasilkan jalur lebar yang lebih baik dari penderia RC tetapi mengurangkan kepekaan penderia dengan ketara Penderia RC terbaik yang dibangunkan dalam kerja ini dicadangkan untuk digunakan sebagai penderia pengukuran voltan lampau arca rosak pada masa akan hadapan.

Development of Inductive Coil Sensor Based on Rogowski coil for Arcing Fault in Medium Voltage (MV) Measurement

ABSTRACT

Arcing fault overvoltage is one of the most common problem that always occur in both low voltage (LV) and medium voltage (MV) systems. The arc fault overvoltage in high voltage system is the most dangerous which can easily cause explosion of electrical components such as cable, transformers, switchgears and other equipment. The cause of arc fault overvoltage is due to the loosen cable termination at bus bar and transformers terminal, cable jointing and others. In order to reduce the arc fault risk, the arc circuit interrupter (AFSI) technology and arc fault detectors (AFD) have been developed. However, these devices are more suited for LV or domestic application. For applications in medium voltage (MV), a new arc fault sensor is needed to overcome this problem. Frequent arcing fault overvoltage can cause an interruption of the electrical system which may breakdown the system. Thus, to overcome this matter, the arcing fault sensor was developed in this research. The Rogowski coil (RC) which is one of the inductive coil group was selected as the arc fault detection sensor. Finite Element Method (FEM) was used for electromagnetic flux density, B analysis on RC geometrical and number of turns effect by modelling three different types of RC which are the rectangular, oval and circular cross-section. Based on FEM simulation results, the rectangular cross-section of RC had the highest electromagnetic flux density among the circular and oval cross-section. The mutual inductance calculation of rectangular cross-section has also been performed and compared to the FEM simulation results. There were seven (7) rectangular cross-section RC sensor prototypes that were fabricated using three-dimensional (3D) printer with various number of turns ranging from 20 to 100 with the cross-sectional area ranging between 200 mm^2 and 1050 mm^2. The acrylonitrile butadiene styrene (ABS) material was selected as the RC sensor core because it has low conductivity, categorized as an insulator, adequate rigidity, good thermal stability, exhibit high toughness even in cold conditions, chemical resistance, environment stress cracking and excellent mechanical properties. The sensor performance verification in terms of sensitivity and bandwidth was conducted with an experimental measurement that was done in the high voltage lab. Based on the experimental results, the RC sensor prototype RC2A5 (fabricated in this research) which has the highest number of turns (100 turns) produced excellent sensitivity at 0.56 kV/mA. However, the bandwidth of RC2A5 descended to 3.51 MHz which is the lowest bandwidth. Whereas, by reducing the number of turns to 20, the RC sensor prototype RC2A1(fabricated in this research) ascended to 7.93 MHz which is the highest bandwidth, but its sensitivity drops rapidly to 0.30 kV / mA. From the obtained results, it can be concluded that that the lower number of turns produced better bandwidth for the RC sensor but reduces the sensor sensitivity significantly. The best RC sensor developed in this work was proposed to be used as an arc fault overvoltage measuring sensor for the future.

CHAPTER 1 : INTRODUCTION

1.1 Overview

In power systems, the overvoltage phenomenon always occurs, and it may increase the number of outages which interrupts the electric supply. Therefore, it is necessary for the electrical engineers to reduce the overvoltage phenomenon. Overvoltage occurs when voltage is raised higher than the upper design limit where it may be hazardous to the electrical equipment. The arc-faults or arc-flash is one of the overvoltage phenomena and this event always transpire in the electric power equipment and networks such as power cable, busbar, transformer and others. Arc fault is the result of current flowing through the air between conductors in phase-to-phase, single phase-to-ground, or multiple phase-to-ground configurations (i.e. a three-phase bolted fault). In other words, an arc fault is a high-power electricity discharge between two or more conductors. This discharge translates into heat that can break down the insulation of the wire and potentially cause an electrical fire (Choo & Sa'adon, 2016).

Arc faults can release large amounts of energy in a short amount of time in the form of radiant heat, intense light, and high-pressure waves. One of the major features of an arc fault is the progression of the fault and the effect of the build-up of ionised matter within the arc on other energised parts of the system. A line-to-ground arcing fault, for example, can quickly become a three-phase arcing fault because the ionised gas produced envelops the other energy-energized part of the device. In fact, arc faults are one of the most significant causes of electrical fires. In recent years, the dangers and impact of arc flash have been studied and are now better understood. However, the electrical industry