AN IMPROVED SWITCHING AND CONTROL TECHNIQUE IN POLARIZATION AND DEPOLARIZATION CURRENT MEASUREMENT APPLICATIONS

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AN IMPROVED SWITCHING AND CONTROL TECHNIQUE IN POLARIZATION AND DEPOLARIZATION CURRENT MEASUREMENT APPLICATIONS

NUR FAIZAL BIN KASRI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
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SEPTEMBER 2014

I declare that this thesis entitled "*An Improved Switching and Control Technique in Polarization and Depolarization Current Measurement Applications*" 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.

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A special dedication to,

My beloved mother, ***Sarwana Binti Shukor****,*

My brother, ***Nor Firdaus bin Kasri****,*

My younger brother,

Mohd Nor Wada bin Kasri*,*

And to My colleagues,

Fatin Liyana, Nor Akmal Jamail, Rabiatul Adawiah and Abu Bakar

Thanks for all your support

Also to all lecturers and colleagues,

For their kindness in education

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"In the name of ALLAH S.W.T, the most Merciful and the most Gracious"

الحمد لله ربّ العالَمين، والصّلاة والسّلامُ على أشْرَفِ الأنبياء والْمرسلين،

وعلى آله وصحبه أجمعين

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I was successful to complete my Master project and this thesis as the symbol of the idea, support and guidance that I get from all my lecturers, family members and colleagues.

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ABSTRACT

Polarization and Depolarization Current (PDC) measurement is one of the methods used to assess the insulation conditions of the High Voltage (HV) apparatus. PDC testing is a non-destructive dielectric diagnostic testing technique employed to determine the conductivity and moisture content of electric insulators. Due to rapid and advancing changes in insulation material technology, an improvement of the PDC measurement system is required to cope with new and emerging materials. Thus, the reliability of the PDC measuring system to accurately measure and record the charging and discharging currents is a crucial factor that cannot be overemphasized. Therefore, in this study, a PDC measurement switching circuit was designed and simulated using the Multisim 10 software and practically tested in order to obtain accurate and reliable results. The design included the reduction of HV relays from four to two, introduction of a safety feature to protect the electrometer and a LabVIEW software programme to control switching activity and data recording. A user friendly Graphic User Interface (GUI) was provided to make the programme user friendly. Furthermore, the study included the construction and testing of the simulated PDC switch. When the switch was tested on some insulation materials that included polymeric, cellulose and liquid insulators, the result shows that this system is able to accurately replicate the popularly known and accepted PDC pattern and also measure the polarization current (i_{dp}) and depolarization current (i_p) of some of these materials in Pico-amperes (x 10^{-12} A). The validity and reliability of this system were ratified after conduction of these tests. It is concluded that the experimental and theoretical PDC current response patterns are comparable and thus this system is reliable, and the results produced are valid for further analysis.

ABSTRAK

Pengukuran Arus Polarisasi dan Depolarisasi (PDC) adalah salah satu kaedah yang digunakan untuk menilai keadaan penebat radas Voltan Tinggi (HV). Ujian PDC adalah teknik ujian diagnostik dielektrik yang tidak memusnahkan digunakan untuk menentukan kekonduksian dan kandungan kelembapan penebat elektrik. Oleh kerana perubahan yang pesat dan maju dalam teknologi bahan penebat, penambahbaikan sistem pengukuran PDC diperlukan untuk meghadapi bahan-bahan penebat baru. Oleh itu, kebolehpercayaan sistem pengukuran PDC untuk mengukur secara tepat dan merekod arus mengecas dan menyahcas merupakan faktor penting yang tidak boleh diabaikan. Maka, dalam kajian ini, litar pensuisan pengukuran PDC telah direka bentuk dan disimulasi menggunakan perisian Multisim 10 dan diuji secara praktikal untuk mendapatkan keputusan yang tepat dan boleh dipercayai. Reka bentuk litar pensuisan ini berjaya mengurangkan bilangan geganti HV daripada empat kepada dua, pengenalan ciri keselamatan untuk melindungi electrometer dan program perisian LabVIEW bagi mengawal aktiviti pensuisan dan rakaman data. Antara Muka Pengguna Grafik (GUI) telah disediakan untuk membuat program ini mesra pengguna. Tambahan pula, kajian ini melibatkan pembangunan dan pengujian PDC suis simulasi. Apabila suis telah diuji ke atas bahan-bahan penebat termasuk polimer, selulosa dan penebat cecair, hasilnya menunjukkan bahawa sistem ini dapat meniru dengan tepat corak PDC yang dikenali dan diterima dan juga mengukur arus polarisasi (i_p) dan depolarisasi (i_{dp}) beberapa bahan ini dalam julat Pico-ampere (x 10^{-12} A). Kesahan dan kebolehpercayaan sistem ini telah diratifikasi selepas menjalankan ujian-ujian ini. Kesimpulanya bahawa corak tindak balas arus PDC ujikaji dan teori setanding dan dengan itu sistem ini boleh dipercayai, dan keputusan yang dihasilkan adalah sah untuk analisis lanjut.

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LIST OF ABBREVIATION

DAQ	-	Data Acquisition
DC	-	Direct Current
DGA	-	Dissolved Gas Analysis
DPDT	-	Double Pole Double Throw
FDS	-	Frequency Domain Spectroscopy
GPIB	-	General Purpose Interface Bus
HV	-	High Voltage
IGBT	-	Insulated Gate Bipolar Transistor
IPS	-	Interfacial Polarization Spectra
LabVIEW	-	Laboratory Virtual Instrumentation Engineering Workbench
LV	-	Low Voltage
NI	-	National Instrument
NPLC	-	Number of Power Line Cycles
PCB	-	Printed Circuit Board
PDC	-	Polarization and Depolarization Current
RVM	-	Return Voltage Measurement
SCPI	-	Standard Commands for Programmable Instruments
SPDT	-	Single Pole Double Throw
SPST	-	Single Pole Single Throw
TTL	-	Transistor-to-Transistor Logic
USB	-	Universal serial bus
TNBR	-	Tenaga Nasional Berhad Research

LIST OF SYMBOLS

$I_p(t)$	-	Polarization current
$I_{dp}(t)$	-	Depolarization current
U_0	-	Potential difference
C_0	-	Geometric capacitance
C_m	-	Measured capacitance
$f(t)$	-	Dielectric response function
σ	-	DC conductivity
ε_0	-	Dielectric constant
A	-	Area of overlap of the two plates
ε_r	-	Relative static permittivity
d	-	Separation between the plates
rdgs/s	-	Readings/seconds

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CHAPTER 1

INTRODUCTION

1.1 Background

The use of electric-powered equipment in a way that meets system requirements and maximizes the equipment beneficial life are a major challenge that faced the electric utilities' engineers today. One of the ways which can extend the useful life of electrical paraphernalia is by doing a proper monitoring and on-site diagnosis. So the improvement of diagnostic technique for determining the condition of the insulation materials is the reason to put an urge to direct priority attention of research in this field. Recent dielectric diagnosis complemented and supplemented with progressive modelling, and advanced analysis tools to assure precise and trustworthy methods for evaluating the insulation condition [1].

In the early 90s, the introduction of Polarization and Depolarization Current (PDC) measurement as one of a new dielectric diagnostic techniques gives a hope to improve the assessment of insulation condition. PDC testing is a non-destructive dielectric testing method to determine the conductivity and moisture content of high-voltage insulation materials. Among the non-destructive monitoring techniques, PDC measurement is achieved as an exceptional importance to the utility professionals [2-4]. It is due to the results from this technique that severely influenced by environmental factors, predominantly the temperature and practical measurement issues that need to be considered are addressed [5-7].

Several methods of insulation testing are available, and it comes in two types, which is destructive or non-destructive, and they comprise breakdown voltage, type testing, RVM (Return Voltage Measurement), DGA (Dissolved Gas Analysis), and FDS (Frequency Domain Spectroscopy). Nowadays, not much research has been done on those methods while the world now is focusing on PDC measurement [8, 9]. PDC is gaining immense popularity among the researchers today as it has a potential which confines all the information collected from FDS and RVM, and it is like having a result from these two methods in one single measurement [10-12].

1.2 Principle of PDC Measurement

The principle of measurement of polarization and depolarization current is based on application of a dc voltage, U_0 across a test object for a long time such as 10,000 s. During this time, t_p the current arising from the activation of the polarization process with distinctive time constants corresponding to different insulation materials, and due to the conductivity of the object is measured. This measured current is also known as polarization current, i_p [13, 14].

Then the voltage is removed, and the test object has been short-circuited also for a long time, t_{dp} (e.g. 10,000 s). The previous activated polarization process now gives rise to the discharging current in the opposite direction, where no contribution to the conductivity is present. In this state, the discharged current is measured and this type of current is also known as depolarization current, i_{dp}. Charging and discharging currents for polarization and depolarization currents are influenced by the properties of the insulating materials as well as by its geometrical structure system [14-16]. Figure 1.1 shows the basic PDC measurement circuit while Figure 1.2 shows the pattern of i_p and i_{dp} corresponding to time domain measurement.

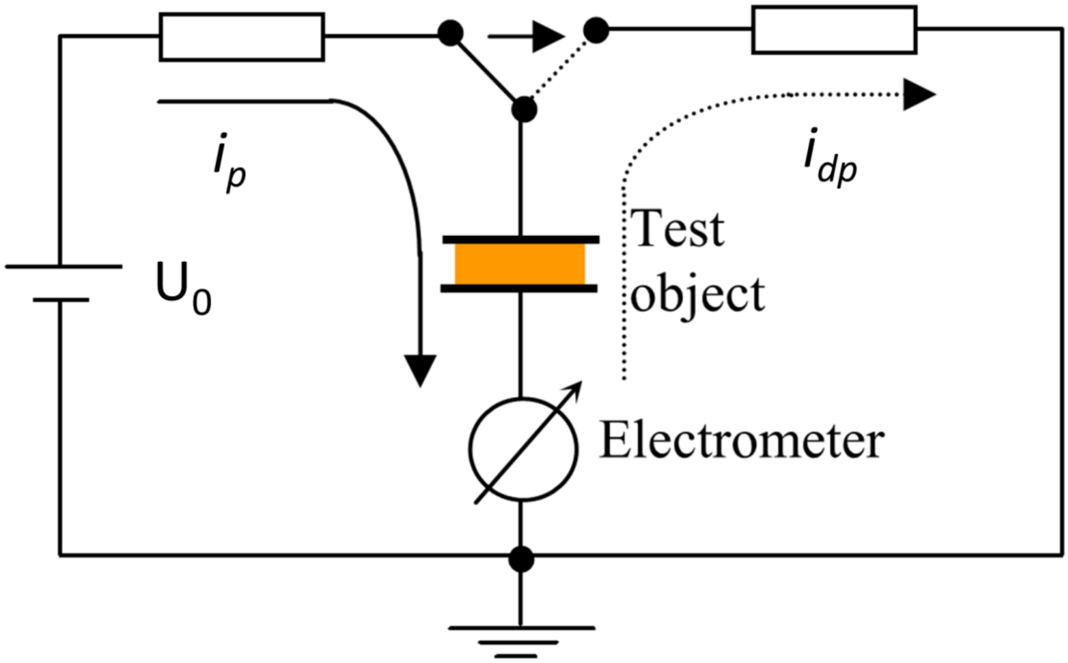

Figure 1.1: Basic PDC measurement circuit

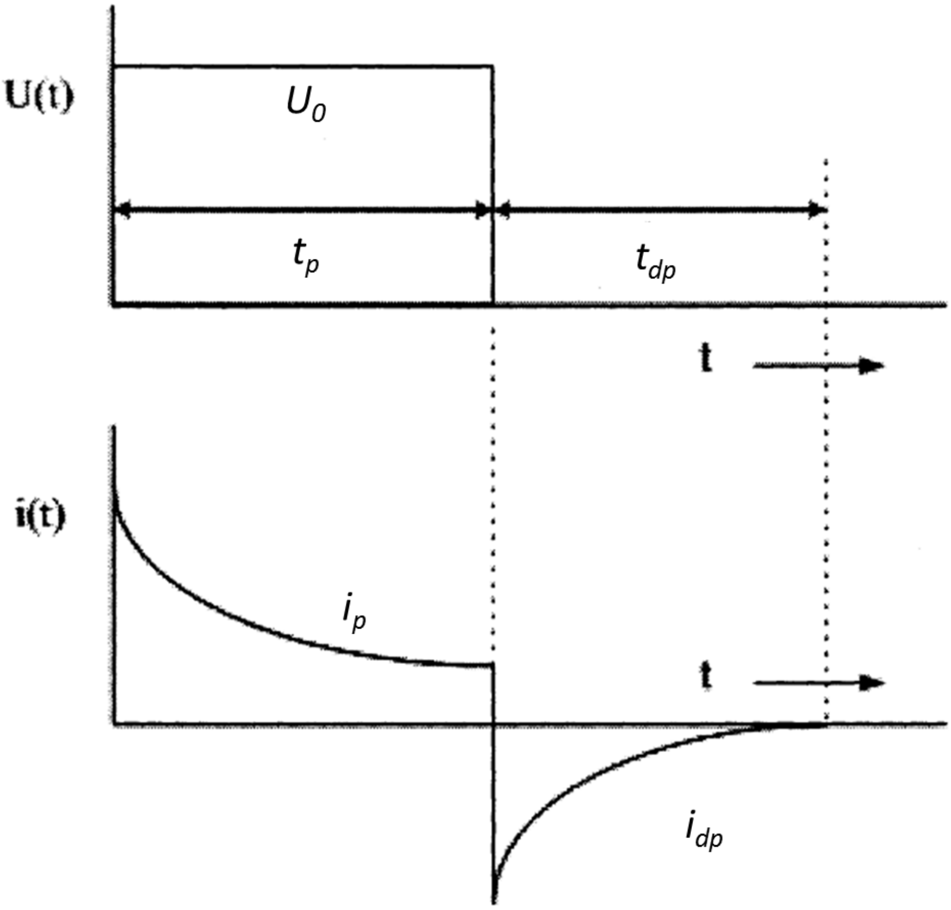

Figure 1.2: Typical pattern for i_p and i_{dp}

1.3 Problem Statement

The increasing demand for perfect insulating materials and the emergence of the technology to make such materials need to be matched with an accurate measuring instrument. The assessing device that needs accuracy is the PDC measurement system. The commercial PDC system has limitations of measuring currents only in the range of Pico-ampere (x 10^{-12} A) [17]. Furthermore, the measurement duration of this system does not go beyond 200,000 s at most [18]. However, it has been shown that emerging dielectric materials need to the tested for periods beyond 200,000 s at current values of Femto-ampere (x 10^{-15} A); thus, the PDC test needs longer charging and discharging time (more than 200,000 s) for system to perform the task maximally.

The important part in a PDC measurement system is its switching circuit. This part is used to determine PDC result as it is used to define the switching activity. In order to create safety features by using four units of HV relay in switching circuit without increased its performance and efficiency is a waste [19]. Four units of switching components in the circuit just make it look complicated. Besides, the price for one unit of HV relay is expensive. However, to diminish the development cost of the switching circuit, the circuits can be abridged by reducing the number of HV relay from four to two while perpetuates the safety features that protect the electrometer and user.

A specialized software needed to complete the PDC measurement system as it will be used to control the switching circuit and its activity. Moreover, the software should offer a user-friendly Graphical User Interface (GUI) so that it can be easily handled by the user. This software is necessary in order to overcome the handling problems faced by the user. The aim is to develop a GUI which can control, determine and adjust the parameters that correlate with PDC measurement such as voltage value, charging and discharging time and data capturing and storing. All of these can be accomplished by using a LabVIEW software.

1.4 Research Objectives

Objectives of the research should be clearly defined as it will determine whether this study is successful or vice versa. It should be achieved so that this research is valid and meet the goal. In this research, four main objectives are highlighted as follows:

a) To improve the existing PDC measurement system in terms of its specification so that it can cope with new and emerging materials.
b) To redesign, reconstruct and improve the existing switching circuit for PDC measurement system so that the number of HV relay used is reduced from four to two units while maintaining its safety features.
c) To design and develop user-friendly GUI that complete the PDC measurement system so that it can be easily handled by the user.
d) To integrate between PDC measurement switching circuit and the user-friendly GUI which will end up as a complete PDC measurement system that fulfil the requirement of dielectric diagnostic device.

1.5 Research Scopes

The project should be designed such that at the end of the project the objectives intended at the beginning of the project are achieved. The scopes of this project will be the guidelines throughout this project to ensure this project is conducted correctly within its intended objectives. The scopes are:

a) This research is focused on improving the existing PDC measurement system that concentrates on its specification, switching circuit, safety features and user-friendly GUI.
b) The experimental setup of this PDC measurement system is only done in a laboratory but can be used for outdoor testing due to its design that suit for both conditions.

c) The insulation materials used in the testing of this PDC measurement system are varied from solid to liquid. It shows the flexibility of the system.

1.6 Research Significance

The PDC measurement technique gives a better estimation of the condition of the electrical apparatus such as transformers, power cables, power capacitors and, etc. This technique is so popular among researchers in the late 90s, until now, because it involves the step response measurement and contains all information collected from RVM and FDS [10, 11]. It is like having both data from a single measurement.

This research is an extension of past studies on a PDC measurement system so that it can produce the best results that reflect the actual condition of insulator materials. Therefore, the improvement regarding to this system must be well planned. The switching circuit must operate properly and reliable as it might influence the PDC measurement result. When this project achieved its objectives, it can consider as a contribution to the diagnostic testing of insulation performance in HV applications.

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