MODIFIED TEST ASSEMBLY FOR WATER TREE STUDY ON POLYMERIC INSULATING MATERIALS

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To my beloved father,

Che Mohd Shukri bin Che Musa

To my beloved mother,

Nik Zaleha binti Nik Abdul Rahman

To my brothers and sisters

Che Nurul Saadatina, Che Ahmad Nazimuddin, Che Ahmad Najmi and Che Ahmad Najwan

lecturers and friends

for their encouragement, inspiration and support

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ABSTRACT

Water tree is a process that causes degradation of insulation performance and ageing of Cross-Linked Polyethylene (XLPE) underground cables. It is known as one of the major causes of premature ageing and failure of polymeric cables. Previous research has shown that there are different effects of ageing time on water tree growth in different types of polymeric insulating materials where nickel and platinum have been used as electrodes and were found to cause corrosion and reduce efficiency. Thus, in this research, a modified test assembly using tungsten needle as an electrode to avoid corrosion and increase efficiency was introduced. This research investigated the effects of ageing time on water tree growth in two different types of polymeric sample namely (XLPE) and Low-Density Polyethylene (LDPE) under high voltage stress. Using computational simulation, the effect of voltage application and angle of tip radius against electric field using COMSOL 4.2a was studied. In this study, the polymeric samples were prepared using a new method known as “leaf-like” specimen method. The experiment was based on BS IEC 61956 2001, “Methods of test for the evaluation of water treeing in insulating materials” and BS EN 60243-1 : 1998, “Electrical strength of insulating materials-Test methods”. Samples were exposed to high voltage injection for 150 hours and 470 hours. The simulation results show that when voltage application increases, the electric field will increase. Besides that, a lower angle of tip radius in polymeric sample, will result in higher electric field being produced. Experimental results show that water tree growth is proportional to ageing time of the two polymeric samples. However, XLPE has better water treeing resistance than LDPE because the average length of water tree growth for LDPE is higher as compared to XLPE. This study has shown that ageing time as the cause of water tree growth that causes degradation in insulation performance has different effects on different types of polymers.

ABSTRAK

Pepohon air ialah satu proses yang menyebabkan degradasi prestasi penebat dan penuaan Polietilen Hubung-Silang (XLPE) kabel bawah tanah. Proses ini menjadi salah satu punca utama penuaan pramatang dan kegagalan kabel polimer. Kajian terdahulu menunjukkan terdapat kesan yang berlainan terhadap masa penuaan kepada pertumbuhan pepohon air dalam pelbagai jenis bahan penebat polimer dengan nikel dan platinum digunakan sebagai elektrod didapati menyebabkan hakisan dan mengurangkan kecekapan. Dalam kajian ini, pemasangan ujian diubah suai menggunakan tungsten sebagai elektrod untuk mengelakkan hakisan dan meningkatkan kecekapan. Kajian ini mengkaji kesan masa penuaan terhadap pertumbuhan pepohon air dalam dua jenis sampel polimer iaitu (XLPE) dan Polietilen Berketumpatan-Rendah (LDPE) di bawah tekanan voltan tinggi. Kesan aplikasi voltan dan sudut jejari hujung terhadap medan elektrik menggunakan COMSOL 4.2a telah dikaji menggunakan simulasi pengiraan. Dalam kajian ini, sampel polimer telah disediakan dengan kaedah spesimen "jenis dedaun". Eksperimen ini berdasarkan BS IEC 61956 2001, "Kaedah ujian untuk penilaian pepohon air dalam bahan-bahan penebat" dan BS EN 60243-1: 1998, "Kekuatan elektrik bahan penebat – Kaedah ujian”. Sampel telah didedahkan kepada suntikan voltan tinggi selama 150 jam dan 470 jam. Keputusan simulasi menunjukkan apabila aplikasi voltan bertambah medan elektrik akan bertambah. Selain itu, jejari hujung di dalam polimer yang bersudut lebih rendah akan menghasilkan medan elektrik yang lebih tinggi. Keputusan eksperimen menunjukkan pertumbuhan pepohon air berkadar terus dengan masa penuaan kedua-dua sampel polimer. Walau bagaimanapun XLPE mempunyai rintangan pepohon air yang lebih baik daripada LDPE kerana purata tempoh pertumbuhan pepohon air untuk LDPE adalah lebih tinggi berbanding dengan XLPE. Kajian ini menunjukkan bahawa masa penuaan merupakan punca pertumbuhan pepohon air yang menyebabkan kemerosotan dalam prestasi penebat yang mempunyai kesan berbeza kepada jenis polimer yang digunakan.

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LIST OF ABBREVIATIONS AND SYMBOLS

XLPE - Cross-linked Polyethylene
AC - Alternating Current
DC - Direct Current
HDPE - High Density Polyethylene
RF - Radio Frequency
PE - Polyethylene
PS - Polystyrene
PVC - Polyvinyl Chloride
LDPE - Low-density Polyethylene
TEM - Transmission Electron Microscopy
SEM - Scanning Electron Microscopy
PIXE - Particle Induced X-ray Emission
FTIR - Fourier Transform Infrared Spectroscopy
PEA - Pulse Electro Acoustic
RC - Resistance Capacitance
TSC - Thermally Stimulated Current
OSW - Oscillating Wave
VLF - Very Low Frequency Wave
RVM - Return Voltage Measurement
DR - Dielectric Response
PD - Partial Discharge
TDR - Time Domain Reflectometry
NaCl - Sodium Chloride

PT - Platinum
Cu - Copper
Al - Aluminium
Fe - Ferum
Pb - Plumbum
NaOH - Sodium Hydroxide
Ep - Electric field in the axis of the point
U - Voltage applied
r - Radius of curvature of needle tip
d - Distance between needle tip and sample
t - time
t_o - Parameters
m - Parameters in the range 0.2-0.9
M_w - molecular weight
P (L) - probability of finding a tree length
T - temperature
exp - exponent
L - length
L_c (t) - Characteristic tree length to the function of time
α - Shape parameter of the distribution
L (t) - Average length water tree
kV - kilo volt
cm - centimeter
mm - milimeter
h - hour
kHz - kilo hertz
Hz - hertz
MHz - mega hertz
μm - micrometer
% - percent
kV/mm - kilo volt per milimeter
^{o}C - degree Celsius
^{0} degrees
β - beta

mol/l	-	moles per litre
kVA	-	kilo volt ampere
Ω	-	ohm
V/m	-	volt per meter
g/cm^3	-	grams per cubic centimeter

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Water tree is a process that causes degradation of insulation performance as well as the ageing of cross-linked polyethylene (XLPE) cables. It is also one of the major causes of premature ageing and failure of polymeric cables [1-3]. The reduction in cable life due to water treeing has been identified as a major problem and the way to overcome this problem is needed [4]. This phenomenon is known as the growth and initiation of voids and microchannels filled with water [5]. They are two main types of water trees, namely bow-tie trees and vented trees [6]. Water trees occur between the insulation and another substance. They are many factors that can cause the growth of water trees. Some of them are the material variables such as additives and different kinds of polymeric materials, mechanical stress, environmental factors include temperature, electrical variables such as ac, dc, frequency, and contaminations ions in water [7].

Water tree is one of the major causes of premature ageing and failure of extruded medium voltage of polymeric cables which do not have water-impervious barriers. It has been a challenge until now to overcome such failures.

Figure 1.1 shows a failure category diagram of underground cable (medium voltage 6.6kV) reported by Tenaga Nasional Berhad (TNB) Selangor for the date of 1 Sept 2010 to 31 Aug 2011. It can be seen that the majority of the cable failures is due to water tree, which is about 16.5%. In Malaysia, according to national power utility, Tenaga Nasional Berhad (TNB), the main cause of power cable breakdown is suspected due to water tree in underground polymeric cable. The inconsistent and unreliable nature comes out with the importance of research in water tree observation in polymeric materials.

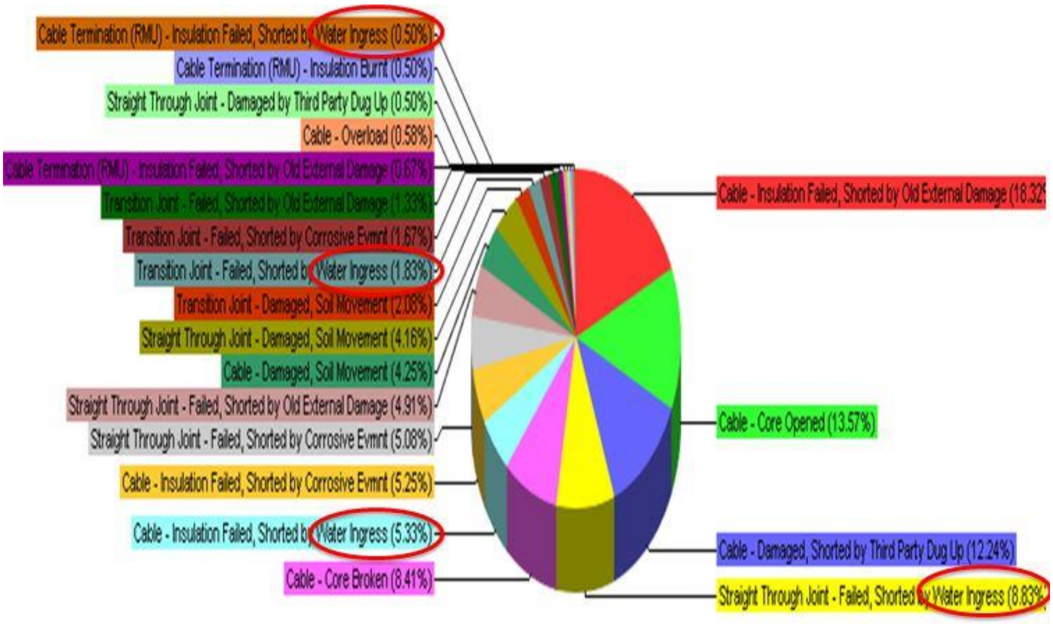

Figure 1.1 Failure category diagram of underground cable (medium voltage 6.6 kV) reported by Tenaga Nasional Berhad (TNB) Selangor for the data of 1 Sept 2010 – 31 Aug 2011

Currently, there are some techniques for water tree detection such as a residual charge method, return voltage method, low frequency dielectric losses measurement, time domain reflectometry method, very low frequency voltage withstand test, dc current method, and RF technique [1, 8-11]. Polymeric cables are widely used in power system application as cable insulation. From economical perspective, there is significantly reduced demand of paper-type cable and increase of polymeric ones. The maintenance routines of cables are improved to minimize the cost and the diagnostic testing of installed cross-linked polyethylene (XLPE) power cable is high of interest because of the high probability of failure caused by water treeing. For the detection of water trees in XLPE cables, various types of electrical testing have been done as reported in [8].

Many previous studies concentrated on the mechanism of water treeing process as there are questions that are still unanswered, such as the formulation of tree-resistant materials and the factors that cause the tree growth. Many observations have been made to explain the propagation of water trees which include chemical, electrical and mechanical aspects. It is believed that there are a lot of factors that can contribute to the growth of water trees and not only depend on single mechanism. In the treeing process, the ionic materials in the water play the significant role [7].

Water trees are hydrophilic dendritic, tree-like features (specifically, they appear initially to be chains of water-filled cavities which later become bushes of microscopic channels with hydrophilic surfaces), which grow typically under wet and electrical operating conditions and may reach lengths of the order of 1 mm within several years. A typical feature of water tree is shown in Figure 1.2. It shows the typical vented trees are observed in water needle electrode of XLPE cable insulation.

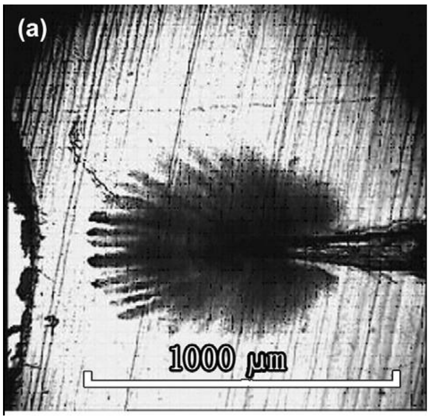

Figure 1.2 Typical vented trees observed in the water needle electrode of XLPE cable insulation [12]

1.2 Problem Statement

The use of high water treeing resistance underground cable is important in order to ensure the reliability of power supply. Water tree observation in polymeric insulating materials is important to investigate the water tree occurrence mechanism. There are different effects of ageing time on water tree growth in different types of polymeric insulating materials. From the previous researches, the types of needle that have been used are nickel and platinum. It is found that the use of these needles has weaknesses such as corrosion and corona discharge. They may hinder the clarity of water tree observation by introducing noise in the result. In addition, it was shown that the time taken is longer using the previous method to observe the water tree.

Thus, a modified test assembly for water tree study on polymeric insulating materials was introduced in this research. From the modified test assembly, a tungsten needle was used as an electrode in this research because it has a very high electrical resistance and is the most refractory metal. Tungsten needle can avoid corrosion and increase efficiency during experimental work. The modified test assembly tests samples in parallel condition reducing the time taken to observe water tree since more samples can be tested simultaneously at equal applied voltage. This research using modified test assembly, the effect of ageing time on water tree growth in two different types of polymeric sample namely cross-linked polyethylene (XLPE) and low-density polyethylene (LDPE) were investigated.

1.3 Objective of Research

The objectives of the research are as follows:

1. To study the effect of voltage application and different angle of tip radius against electric field using COMSOL 4.2a.

2. To investigate the effect of ageing time on water tree growth in two different types of polymeric sample namely cross-linked polyethylene (XLPE) and low-density polyethylene (LDPE).

1.4 Scope of Research

In order to achieve the direction of research and objectives, there are several scopes that must be outlined and these include:

- Analyze previous researches regarding the water tree observation method and application to the polymeric sample materials.
- Research focuses only on two thermoplastic materials such as cross linked polyethylene (XLPE) and low-density polyethylene (LDPE).
- The conducted experiments are based on BS IEC 61956 : 2001, “Methods of test for the evaluation of water treeing in insulating materials” and BS EN 60243-1 : 1998, “Electrical strength of insulating materials-Test methods”.
- Computational simulation and analysis using COMSOL 4.2a.

1.5 Significance of Research

- In this research, a new method of water tree observation by improved methods of water tree study so called “leaf-like” method was successfully proposed.
- From computational simulation studies using COMSOL 4.2a of the improved investigation method, it is clearly describe the voltage application is directly proportional to the electric field and the angle of tip radius in polymeric sample is inversely proportional to the electric field.
- The use of tungsten needle can avoid corrosion and losses during the experiment.

- Experimental data from the improved investigation method clearly shows XLPE has better water treeing resistance than LDPE.
- Experimental data clearly shows the ageing time is directly proportional to the water tree growth.

1.6 Thesis Organization

Chapter 1: Introduction

This chapter describes the overview of this project. Besides that, the first chapter discusses the introduction that includes the research background, problem definition, direction of research and objective, the significance of the research and research flowchart as well as the summary of work that has been undertaken.

Chapter 2 : Literature Review

Additional information and literature reviews related to this research, such as the background of water tree, basic of water tree, types of water tree, diagnostic and testing of water tree and factors affecting the growth of water tree are discussed and highlighted in this chapter.

Chapter 3 : Research Methodology

In Chapter 3, this chapter describes about the operation and methodology used in this project. The main content of this chapter is a detailed discussion on computational analysis using COMSOL 4.2a, the sample production process and test kit assembly. This chapter also gives detailed information on how the test and analysis will be conducted in this project, including the experimental setup and parameter used.

Chapter 4 : Results and Discussion

The analysis of water tree using COMSOL 4.2a software will also be presented. The experimental results of water treeing tests will be discussed thoroughly in this chapter. After that, the water tree analysis and discussion of laboratory experiment will be highlighted in this chapter.

Chapter 5 : Conclusion and Recommendations

Chapter 5 concludes the work based on the results and discussion obtained from this research and suggestions on some recommendations for the future work that can be done to improve the research in this field.

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