EFFECTS OF ARTIFICIAL ACID RAIN ON WATER TREE IN CROSSLINKED POLYETHYLENE INSULATION MATERIAL

SHUDERMAWAN BIN JARUMAN

A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Power)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

MAY 2009

To my wife, Siti and my inspiration,
Nabilah, Aqilah and new born baby
To my beloved mother and late father

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the possibility to complete this project report. The preparation of this document would not have been possible without the support and endless efforts of a number of individuals. I would like to express my deep and sincere gratitude to my supervisor, Professor Dr. Hussein Ahmad, Director of The Institute of High Voltage and High Current, Universiti Teknologi Malaysia. His wide knowledge and his logical way of thinking have been of great value for me. His understanding, encouraging and personal guidance have provided a good basis for the present thesis. I owe my most sincere gratitude to Mr. Zainuddin Nawawi, the Director of Baliteks, Universitas Sriwijaya, Palembang. His ideas and concepts have had a remarkable influence on research. I warmly thank Mr. Muhammad Irfan Jambak for his valuable advice and friendly help.

I would to thank my ex-supervisor the late Associate Professor Tarmidi Tamsir (Al-Fatihah) which his supporting role in the beginning of this project. During this work I have collaborated with many colleagues for whom I have great regard, and I wish to extend my warmest thanks to all those who have helped me with my work in the Institute of High Voltage and High Current, Universiti Teknologi Malaysia. Lastly and most importantly I owe my loving thanks to my wife Siti Hairul Rashidah, my daughters Irdina Nabilah and Irdina Aqilah. My parents Poniah Hj Zainuri and Jaruman Birin (in memorial, Al-Fatihah), my brothers, my sisters and their families for their loving support. They have lost a lot due to my research. Without their encouragement and understanding it would have been impossible for me to finish this work.

ABSTRACT

Water tree was formed by applying an ac voltage of 15kV r.m.s. and 50Hz of frequency to the crosslinked polyethylene (XLPE). The experiment was accomplished with water tree test equipment using an artificial acid rain for different level of acidic. This experimental study focused on the effect of artificial acid rain on polymer for water trees phenomenon. The polymer used in this experiment is locally produced in the laboratory. All samples that exposed to the same electric field and different pH level were examined after a period of approximately 240 hours. The XLPE samples were then examined under the optical microscope. A numbers of water tree found in the aged XLPE sample. It was found that the propagation rate of water tree growth in acidic solution is proportional with the acid level. The conductivities in high acid level leads to large growth of water tree. The growth rate reduces in less acidic solution. The conductivity of the acid solution depends on the concentration of ions in the solution. Those that ionize the most are the most acidic; those that ionize the least are least acidic. The effect of temperature is also obtained from this experiment.

ABSTRAK

Pembentukan pepohon air di dalam polimer *Crosslinked Polyethylene* dilaksanakan dengan membekalkan voltan ulangalik sebanyak 15kV rms dengan frekuensi 50Hz keatas penebat tersebut. Perlaksanaan ujikaji ini dilakukan dengan menggunakan peralatan ujian untuk pepohon air dengan menggunakan larutan hujan asid buatan. Tujuan penyelidikan ini dilaksanakan adalah untuk melihat kesan-kesan dari hujan asid buatan ke atas polimer dengan pembentukan pepohon air. Ujikaji ini dilaksanakan selama 240 jam tanpa henti. Permerhatian terhadap semua sampel polimer yang telah terdedah kepada medan elektrik dan paras keasidan yang berbeza dijalankan dengan menggunakan mikroskop. Pepohon air telah didapati wujud di dalam semua sampel polimer. Kadar tumbesaran pepohon air di dalam larutan asid berkadaran dengan paras keasidan hujan buatan. Kekonduksian bagi paras asid yang tinggi menyebabkan pembentukan saiz yang besar bagi pepohon air. Saiz pepohon air pada larutan asid yang rendah adalah kecil. Kekonduksian bagi larutan asid bergantung kepada jumlah ion yang terkandung di dalam sesuatu larutan. Paras keasidan sesuatu acid ditentukan oleh jumlah ion di dalam larutan asid. Paras asid yang tinggi menunjukkan bahawa jumlah ion yang banyak di dalam larutan asid. Pengaruh suhu terhadap pembentukan pepohon air juga dapat dikesan.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiii
	LIST OF APPENDICES	xiv
1	**INTRODUCTION ON WATER TREE**	
	1.1 Introduction	1
	1.2 Objectives	2
	1.3 Scope of Work	3
	1.4 Methodology and Project Planning	3
2	**LITERATURE REVIEW**	
	2.1 Introduction	5
	2.2 Water Trees	6
	2.2.1 Water Tree Initiation and Growth Mechanism	7
	2.2.2 Ageing Conditions	8
	2.2.3 Characteristics of Water Tree	9

	2.3	Factors Affecting the Initiation and Growth of Water Trees	10
	2.4	Water Tree Test Consideration	12
		2.4.1 Correlation	13
		2.4.2 Time	13
		2.4.3 Accuracy	14
	2.5	Crosslinked Polyethylene (XLPE)	15
	2.6	Acid Rain	17
3	**EXPERIMENTAL SETUP**		
	3.1	Introduction	18
	3.2	XLPE Samples Preparation	19
	3.3	Test Apparatus	21
		3.3.1 Test Cell	21
	3.4	Artificial acid rain solution	25
	3.5	Ageing Test	25
4	**RESULT, ANALYSIS AND DISCUSSION**		
	4.1	Results	28
		4.1.1 Data Collected	28
		4.1.2 Measurement of Water Trees.	33
		4.1.2.1 Water Trees in *S1*	34
		4.1.2.2 Water Trees in *S2*	35
		4.1.2.3 Water Trees in *S3*	36
		4.1.2.4 Water Trees in *S4*	37
		4.1.2.5 Water Trees in *S5*	38
	4.2	Analysis and Discussion	39
		4.2.1 Comparison between *S1, S2 and S3*	40
		4.2.2 Comparison between *S4* and *S5*	43

5 CONCLUSION AND FUTURE WORK

5.1 Conclusion 45

5.2 Future Work 46

REFERENCES 48

Appendices A - B 51 - 52

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Three classes of ageing condition	9
3.1	Label for solution level	26
4.1	Temperature changes at test cup	30
4.2	Calculated electric field *Ep* for every needle	32
4.3	Length *l* and width *w* of water trees for *S1*	34
4.4	Length *l* and width *w* of water trees for *S2*	35
4.5	Length *l* and width *w* of water trees for *S3*	36
4.6	Length *l* and width *w* of water trees for *S4*	37
4.7	Length *l* and width *w* of water trees for *S5*	39
4.8	Summary of water tree measurement	39

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Types of Water Trees a) Bow tie b) Vented	7
2.2	Polyethylene molecular structure	15
2.3	Crosslinked Polyethylene molecular structure	16
3.1	Crosslinked Polyethylene Sample Preparation (a) XLPE pellet in a Moulding (b) Compression Moulding Machine (c) XLPE plaque (d) Drying oven	20
3.2	Sample Block Dimension	21
3.3	Test Cell	22
3.4	Dimensional drawing of test cell	22
3.5	Drawing of the test cell	24
3.6	Actual test equipment set	24
3.7	Test cell arrangement	26
3.8	Experimental setup	27
4.1	Temperature changes at test cup	29
4.2	Needle (after experiment) with rust and corrosion. (a) pH 1 (b)pH 2 (c) pH 3 (d) pH 4 (e) pH 5	31
4.3	Bow-tie water tree in *S1*	34
4.4	Bow-tie water tree in *S2*	35
4.5	Bow-tie water tree in *S3*	36
4.6	Bow-tie water tree in *S4*	37
4.7	Bow-tie water tree in *S5*	38
4.8	The growth of water tree in three level of artificial acid rain	40

4.9	Relationship between growths of water with electric field	42
4.10	The growth of water tree in *S4* and *S5* influence with temperature	43
4.11	Water tree growth over electric field at *S4* and *S5*	44

LIST OF SYMBOLS

d	-	Distance between tip of needle and XLPE sample
l	-	Length
w	-	Width
Ep	-	Electric field
r	-	Radius of curvature
U	-	Voltage applied
avg	-	Average

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Project Methodology	51
B	Project Planning	52

CHAPTER 1

INTRODUCTION ON WATER TREE

1.1 Introduction

Polymer insulated cables was first introduced in the 1960s. The used of it has led to a rise in the rate of cable failures resulting from water treeing which was first discovered in 1969[1]. This water treeing phenomenon is an important degradation process in polymeric insulation. Since the discovery, a great deal of research works has been devoted to this phenomenon. A water tree tends to growth and initiate in the presence of water under the ac field. Electric field, water and temperature are the parameter which can influences the growth of water tree.

Parameter involves in growth and initiation of water trees in a laboratory experiment is an important subject to be recognized. The electric field is a parameter which strongly influences the growth and initiation of water trees [2]. Another parameter involved is the liquid solution itself used in experiment. Researcher discovered that the ionic content in the liquid solution has a strong dependence for the growth of water trees which occur with ionized liquid [3]. The temperature dependence on water trees growth is another parameter involved. High temperature will produce large water trees [4]

The main focus for this project is the effect of artificial rain water on water trees in crosslinked polyethylene (XLPE) which is often used as an insulating material in cables. Acid rain phenomenon was first discovered in Manchester,

England. The term *acid rain* was introduced by Robert Agnus in 1872. Malaysia is beginning to experiences the effect of acid rain. The Malaysian watch acid rain project 1990 shows that all states in Malaysia are experiencing it except for Malacca, Kelantan, Terengganu and Sarawak. Emissions of waste gases from industries, vehicle exhausts and power generation are causes of rainwater acidity. Rain water of pH less than 5.6 is considered acidic.

In this study, ageing test were performed on crosslinked polyethylene (XLPE) using an artificial acid rain solution with different level of pH and conductivity. The insulators were exposed to different concentrated solution level in presence of electric field to examine the growth length of water trees. The insulators were subjected to same voltage to permit the growth values to be determined for the various pH levels.

1.2 Objectives

The objectives of this project are:

(i) To study and investigate the effect of artificial acid rain on growth rate of the water tree phenomenon.

(ii) To design and built a test set which are intended to assess the development of water trees in crosslinked polyethylene (XLPE) based insulating materials.

(iii) To analysis the characteristics of water treeing from the data collected on the experiment due to presence of acidic water.

(iv) To compare the growth of water tree between different liquid solution.

1.3 Scope of Work

This project is primarily intended to assess the effect of water trees in crosslinked polyethylene (XLPE) based insulating materials under the presence of artificial rain water. To understand the effects, all crosslinked polyethylene samples, test apparatus for experiment and ageing test procedure used in this experiment are made prior to the method suggested on PD IEC 61956:2001 by British Standard

The result of the laboratory experiment will be analyzed to determine the characteristics of the water tree. The comparison between growth length and shape of water tree under normal water and acid rain will be analyzed.

1.4 Methodology and Project Planning

Set of methods used in this study are shown in appendixes 1. The methodology covered a literature review of past researches, standard comparison, design and preparation of test apparatus, result obtained from the experiment and analysis. The literature review done in this study is important to understand the whole concept of water trees and the previous finding by the researcher. The knowledge of water trees morphology, characteristics, parameter involved and ageing condition are useful for the analysis of this project. The understanding of polymer itself and acid rain also contribute to the strong analysis made.

The reliability of the result obtained also dependence on the equipment test set, polymer samples and liquid solutions. The reference of the design and built of the equipment test set and polymer samples is according to the British Standard PD IEC 61956:2001. The preparation for polymer samples and artificial acid rain are made at the polymer laboratory at Faculty of Chemical and Natural Resources Engineering.

The ageing test is performed in a laboratory for 240 hours. Voltage applied to the equipment test set is 15kV r.m.s and 50 kHz frequencies. The water trees exist in the sample is seen through the optical microscope connected to the camera. The picture of water tree is then being analysis using the software supplied for the Motic Camera. The project planning shown in appendixes 2 covered two section of the project.