MODELING OF WATER TREE DEGRADATION IN UNDERGROUND POLYMERIC POWER CABLE USING TIME DOMAIN REFLECTOMETRY METHOD

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Dedicated to my beloved parents

Ahmad bin Mahmood & Robiah binti Rojali

Siblings

Azizah binti Ahmad

Nazri bin Ahmad

Azida binti Ahmad

Nasir bin Ahmad

and

All my friends

for their support and encouragement

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With the name of ALLAH, Most Generous and Most Merciful

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ABSTRACT

Cross-linked polyethylene (XLPE) is a one of the insulation materials in polymeric power cable. They are usually used in underground medium voltage cables. These cables are exposed to a significant risk of premature ageing and failure of polymeric cable. One of that phenomenons is water treeing. In this project, water tree has been modeled using MATLAB simulation while PSpice software was regarded as an experimental model. Time domain reflectomerty (TDR) is applied as a method to investigate the degradation and location due to the water tree. Five different geometries of cables with varied in two different length will be measured in this study. The simulation results show the wave propagation characteristics such as attenuation and velocity are important parameters as a benchmark to analyze the signals generated from PSpice software. Moreover, in experimental model shows that the water tree can be defined by implemented the TDR method. It was found that the error percentage of simulation results and calculations is 9.06%.

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ABSTRAK

Polietilen Hubung-Silang (XLPE) adalah salah satu daripada bahan penebat dalam polimer kabel. Ianya biasa digunakan dalam kabel bawah tanah bagi voltan sederhana. Kabel ini terdedah kepada risiko penumbuhan pra-matang dan kegagalan kabel polimer. Pepohon air merupakan salah satu fenomena ini. Dalam kajian ini, pepohon air dimodelkan dengan menggunakan simulasi MATLAB manakala perisian Pspice sebagai eksperiment kajian. Oleh itu, 'Time Domain Reflectomerty'(TDR) adalah kaedah untuk menyiasat degradasi dan lokasi pepohon air itu. Kajian ini diukur dengan menguji lima perbezaan geometri serta dua ukuran yang berbeza. Hasil simulasi, menunjukkan ciri-ciri perambatan gelombang seperti pengecilan dan halaju adalah parameter adalah penting sebagai penanda aras untuk menganalisis isyarat yang dihasilkan dari perisian Pspice. Selain itu, keputusan eksperimen menunjukkan, pepohon air boleh dilaksanakan dengan kaedah TDR. Peratusan kesilapan bagi hasil simulasi eksperiment dan pengiran ialah 9.06 %.

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LIST OF ABBREVIATIONS

XLPE	-	Crosslink polyethylene
PE	-	Polyethylene
PD	-	Partial discharge
PVC	-	Polyvinyl Chloride
SR		Silicon rubber
TDR	-	Time Domain Reflectometry
FFTs	-	fast Fourier transforms
RF	-	Radio frequency
GFCI	-	Ground Fault Current Interrupter
TD	-	Time delay

LIST OF SYMBOLS

H/m	-	Hendry per meter
Ω/m	-	Ohm per meter
μs	-	Micro per second
S/m	-	Simon per meter
F/m	-	Farad per Meter
Zo	-	Characteristics impedance
ns	-	Nano second
us	-	Micro second
Vi	-	Voltage incident
Vr	-	Voltage reflection
$\alpha(\omega)$		Attenuation
β(ω)		Phase velocity
ε		Permittivity
μ		Permeability
c		Velocity
ℓ		Length

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CHAPTER 1

INTRODUCTION

1.1 Overview

Polymeric cables are commonly used in power system application as cable insulation, such as XLPE, PE, PVC, SR and other. In economical perspective, it is reported that there is significantly reduction demand of paper-type cable and increasing of polymeric ones. The introduction of polyethylene (PE) extruded cables into the power distribution sector in the early 1950s required a rapid development of partial discharge (PD) detection technique and testing standards to assess the reliability of these cables.

One of the polyethylene insulation materials is a crosslink polyethylene (XLPE) which is widely used as insulation material in power cable. XLPE cable provides the low dielectric losses. However, after the put into the service, the cable will be affected caused by the surrounding factor. In order to ensure the quality of power supplies the aging status installed the cable. One of the primary causes of aging breakdown will be traced in year 1972 due to moisture ingression into the insulation is water treeing[1]. Water trees from and convert to electrical trees and le

ad to water trees. Water tree leads to decreased insulation resistance an increased in leakage current[2].

A fundamental interest of power utilities is to increase the total reliability at a minimum cost by improved maintenance routines. Diagnostic testing of installed XLPE power cables is of high interest because of the large number of old cables in service with high probability of failure caused by water tree degradation[3].

Tenaga Nasional Berhad (TNB); a power utility company in Malaysia reported that during 1 September 2010 – 31 August 2011, statistically there is a failure of underground cable (medium voltage, 6.6 kV) due to water tree/water ingress is about 16.5% which occurred in Selangor territory[2].

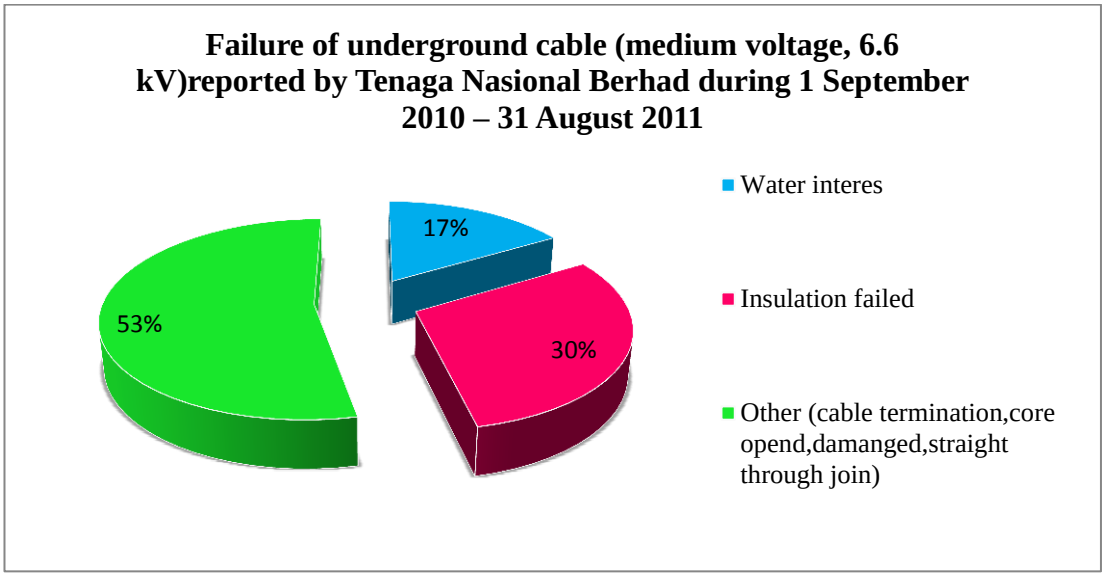

Figure 1.1 Diagram of underground cable failure reported by *Tenaga Nasional Berhad* during 1 September 2010 – 31 August 2011

Therefore, this paper attempts to model the water tree degradation in underground polymeric cable and analyse the data using time domain reflectometry (TDR) as the proposed method for the detection mechanism.

1.2 Problem Statement

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. Besides technological efforts, it has been a challenge up to now to overcome such failures by improved insulating compound, mainly on the basis of the chemically crosslinked low density polyethylene (XLPE).

Consequently, a need for investigating of water tree has arisen, and thus reduces the need of cable testing to compare and preselect materials. The detection and mechanism of water tree in polymeric cable is not clearly understood yet

1.3 Objective of Project

The objective of this project is to model water tree degradation in underground polymeric cable. The degradation and location of water tree in underground polymeric cable using TDR concept is also analysed.

1.4 Scope of Project

In order to achieve the objective of the project, there are several scopes that have been outlined which are:

i. The five type of 6.6kV XLPE cable will be investigated

ii. The test cable varied in two different length that is 25m and 100m length
iii. The test cable divided two part that is ideal/unaged cable XLPE and degraded XLPE
iv. Time Domain Reflectometry (TDR) method is applied to analyze the signal and detect the water tree mechanism
v. This project only involves simulation using MATLAB software to be model polymeric cable and the experimental set-up developed using PSpice circuit simulation

1.5 Development Software

This project uses two types of software which are:

i. MATLAB R2010a
   For simulation to get the wave propagation characteristic of the ideal cable and degraded cable.
ii. PSpice
   For experimental set up to detect water tree degradation and location using applies time domain reflectometry (TDR) method.

1.5 Outline of Thesis

This thesis consists of five chapters. The first chapter introduces the background of the project, the problem statement, the objective, and the development

software of this project. The second chapter will be discussed about the literature reviews that are related to the study.

Chapter 3 will explore the methodology to realize this project. Then, chapter 4 will discuss the result and discussion of overall project. Last but not least, the conclusion and recommendation will be summarized in Chapter 5.

REFERENCE

1. Kuan, T.M., et al. *Wave propagation characteristics of polymeric underground cables*. in *2011 5th International Power Engineering and Optimization Conference, PEOCO 2011 - Program and Abstracts*. 2011.
2. Y. Z. Arief, M.S., Z. Adzis, M. Z. H. Makmud *Degradation of Polymeric Power Cable due to WaterTreeing under AC and DC Stress.* 2012 IEEE International Conference on Power and Energy (PECon)Kota Kinabalu Sabah, Malaysia, 2-5 December 2012.
3. M. Ahmed, M.A.A.-O., M. A. Garwan, K. Y. Shoufi, Z. M. Hamouz, *How Good are Electrical Diagnostic Tests to Predict Water Trees In HV Cables – An Evaluation Using Optical Microscopy.* Journal of Electrical Engineering, 2005. **vol. 56**: p. pp-31- 35.
4. Eriksson, G.M.a.R., *High frequency characteristics of a shielded medium voltage XLPE cable.* Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 2001
5. Ariffin, A.M., et al. *Application of time domain reflectometry technique in detecting water tree degradation within polymeric-insulated cable*. in *Condition Monitoring and Diagnosis (CMD), 2012 International Conference on*. 2012.
6. Tze Mei, K., A.M. Ariffin, and S. Sulaiman. *Signal analysis to detect water tree location in polymeric underground cables*. in *Research and Development (SCOReD), 2011 IEEE Student Conference on*. 2011.
7. Hashmi, G.M., R. Papazyan, and M. Lehtonen. *Determining wave propagation characteristics of MV XLPE power cable using time domain reflectometry technique*. in *Electrical and Electronics Engineering, 2009. ELECO 2009. International Conference on*. 2009.
8. A. Giovanni Gonzalez, I.P., Richard M White, Paul K. Wright, *Novel Onlin RF technique for Detection of Water Trees in Underground Powered Distribution Cables.* 2011 Electrical Insulation Conference, Annapolis,Maryland, 5 to 8 June 2011.
9. Berhad, U.C.M., *XLPE Insulated Power Cables*, in *Leader* 1976.

10. Dubickas, V., *On-Line Time Domain Reectometry Diagnostics Of Medium Voltage XLPE Power Cables*, in *Licentiate Thesis Stockholm*. Sweden 2006, Royal Institute of Technology.
11. Indiamart. *Nicco Corporation Limited*. 1996-2014.
12. Division, T.D., *Underground Cable System Design Manual June 2012 Asset Management Department.* 2012.
13. Note, L., *Transmission Line*. 2014.
14. Md Thayoob, Y.H., A.M. Ariffin, and S. Sulaiman. *Analysis of high frequency wave propagation characteristics in medium voltage XLPE cable model*. in *Computer Applications and Industrial Electronics (ICCAIE), 2010 International Conference on*. 2010.
15. E. F. Steenis, F.H.K., *Water treeing in polyethylene cables.* IEEE Transactions on Electrical Insulation, October 1990. Vol. 25, No. 5, pp. 989-1028.
16. Papazyan, R., *Techniques for localization of insulation degradation along medium voltage power cables*. June 2005, Royal Institute of Technology (KTH), Stockholm, Sweden.
17. Kai Zhou, W.Z.a.X.T., *Toward Understanding the Relationship between Insulation Recovery and Micro Structure in Water Tree Degraded XLPE Cables.* IEEE Transactions on Dielectrics and Electrical Insulation, December 2013. Vol. 20, No. 6.
18. Atkinson, J.M. *TDR Tutorial - Introduction to Time Domain Reflectometry*. Copyright ©2002, Granite Island Group.
19. Dyer, S.A., *Survey of instrumentation and measurement*, N.Y.W. Interscience., Editor. 2001.
20. R. Villefrance, J.T.H., M. Henriksen, *Estimation of Medium Voltage Cable Parameters for PD-Detection.* Conference Record of the 1998 IEEE Int. Symp. On Electrical Insulation, Arlington, Virginia, USA, June 7-10, 1998.
21. Rahim, N.H., et al. *Simulation of TDR circuit for the analysis of wave propagation in XLPE cable model*. in *Power and Energy (PECon), 2012 IEEE International Conference on*. 2012.
22. W.T.Shugg, *Handbook of Electrical and Electronic Insulating Materials.* 1986.

23. Tze Mei Kuan, A.M.A., *Development of treeing detection method for cable with three insulation regions using TDR tecnique.* The 7th International Power Engineering And Optimization Conference (Peoco2013),Langkawi,Malaysia, 3-4 June 2013

24. Pozar, D., *Microwave Engineering*. Second ed. 1998: John Wiley and Sons Inc.