STUDY ON THE PERFORMANCE OF UNDERGROUND XLPE CABLES IN SERVICE BASED ON TAN DELTA AND CAPACITANCE PARAMETERS

ASMARASHID BIN PONNIRAN

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

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

MARCH 2005

To my Beloved

Wife

Siti Noraidah binti Mohamed

Parents

Ponniran bin Semat and Ruhinah binti Surif

Brothers

Asmarizal

Mohd. Saiful

Mohd. Ridzuan

Hairul Amin

For Their

Love, Encouragement, Sacrifice, and Best Wishes

ACKNOWLEDGEMENT

Praise be to Allah S.W.T., the Most Merciful and the Most Compassionate. Peace be upon him, Muhammad, the messenger of God.

I would like to express my gratitude to my supervisor, Prof. Madya Hj. Tarmidi bin Tamsir for his valuable guidance and support throughout the two semesters until this project completes successfully. I am grateful to Ir. Abdul Rashid bin Haron (Former State Chief Engineer – TNBD Johor), Hj. Abdul Nasir bin Abdul Jabbar (Present State Chief Engineer – TNBD Johor) and Abdos Salam b. Md. Isa (Senior Engineer – TNBD Johor) for their co-operation and opinions.

I would also like to thanks to all lecturers and technicians from IVAT – FKE at the Universiti Teknologi Malaysia, Skudai for their comments and co-operations.

I would also like to thanks to Kolej Universiti Teknologi Tun Hussein Onn (KUiTTHO) for their generous financial support.

My thanks are also extended to my fellow colleagues for sharing their ideas and discussions. Finally, I would like to thank my wife, parents and brothers. They continue to supply the unconditional love and support, which allow me to achieve what I have and will.

ABSTRACT

By the rapid of urban growth, it is impossible to accommodate the number and size of feeder required for distribution using the overhead line system approach. As an alternative the underground cables becomes more increasingly necessary to replace some of the overhead line for power transmission and distribution. Because of that reason, underground XLPE cables are the most popular for the underground systems. Performance of underground cables in service is being critical because of ageing mechanisms influences. There are many suitable techniques can be used to evaluate performance of aged and unaged underground cables. One of the techniques is based on tan delta and capacitance parameters of underground cables. This study only focuses on underground XLPE cables, which are voltage rated at11kV and 22kV for 1-core and 3-cores types. By using Tettex Instruments – Schering Bridge Model 2816, tan delta and capacitance data of XLPE underground cables are obtained. Tan delta and capacitance measurements were performed at ambient temperature (26.6^{o}C) and at power frequency (50 Hz). From these analyses, show that tan delta values will be increased proportional with aging time of cables in service. Aging mechanisms are contributes these deteriorations of cables in service and consequently values of tan delta are increased with aging time of cable. Meanwhile, form capacitance analysis, the values of capacitance will be increased when contaminants, protrusions and voids are affected cables insulation and when moisture enters inside underground cable systems.

ABSTRAK

Pembangunan yang pesat terutamanya di kawasan bandar menyebabkan penghantaran bekalan elektrik menggunakan sistem talian atas adalah mustahil dan kurang sesuai. Sebagai gantinya, sistem bawah tanah sangat diperlukan bagi menggantikan sistem talian atas untuk penghantaran dan pengedaran bekalan elektrik. Atas sebab tersebut, kabel XLPE bawah tanah telah meluas digunakan didalam sistem bawah tanah. Prestasi kabel bawah tanah dalam perkhidmatan menjadi kritikal disebabkan pengaruh mekanisma-mekanisma penuaan. Terdapat beberapa teknik yang sesuai dan boleh digunakan bagi menilai prestasi kabel bawah tanah. Salah satu daripadanya adalah berdasarkan parameter tan delta dan kemuatan kabel tersebut. Kajian ini hanya memfokuskan kabel XLPE bawah tanah bagi kadar voltan 11 kV dan 22 kV serta jenis 1 teras dan 3 teras. Dengan menggunkan peralatan Tettex Instruments – Schering Bridge Model 2816, data tan delta dan kemuatan kabel XLPE bawah tanah telah diperolehi. Daripada analisis ini, menunjukkan bahawa nilai tan delta akan meningkat berkadaran dengan tempoh masa kabel dalam perkhidmatan. Mekanisma-mekanisma penuaan telah menyumbang dengan tinggi ke arah penurunan prestasi kabel dalam perkhidmatan dan sebagai akibatnya nilai tan delta meningkat mengikut tempoh kabel dalam perkhidmatan. Manakala daripada analysis kemuatan, nilai kemuatan kabel akan meningkat apabila *contaminants, protrusions* dan *voids* menjejaskan penebatan kabel dan apabila kelembahan memasuki sistem kabel bawah tanah.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

LIST OF SYMBOLS AND ABBREVIATIONS

XLPE	-	Cross-linked Polyethylene
LDPE	-	Density Polyethylene
TRXLPE	-	Tree-retardant Cross-linked Polyethylene
EPR	-	Ethylene Propylene Rubber
WTR	-	Water Tree Retardant
IEC	-	International Electrotechnical Commission
TNB	-	Tenaga Nasional Berhad
TNBD	-	Tenaga Nasional Berhad – Distribution
VLF	-	Very Low Frequency
U_o	-	Rated power frequency voltage between conductor and earth or metallic screen for which the cable is designed
AC	-	Alternating Current
DC	-	Direct Current
rms	-	root-mean-square
R	-	Resistor
C	-	Capacitor
Z	-	Impedance
Y	-	Admittance
$\tan \delta$	-	Dissipation factor of cable insulator
δ	-	Loss angle
θ	-	Phase angle
PD	-	Partial discharge

DR	-	Dielectric response
ε	-	Real permittivity
$\varepsilon^{"}$	-	Imaginary permittivity
ε_o	-	Permittivity in vacuum
ε_r	-	Relative permittivity or Dielectric constant
SIC	-	Maximum permittivity
σ	-	Conductivity
CPV	-	Contaminants, Protrusions or Voids

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.0 Introduction

By the rapid of urban growth, it is impossible to accommodate the number and size of feeder required for distribution using the overhead line system approach. As an alternative the underground cables becomes more increasingly necessary to replace some of the overhead line for power transmission and distribution. Many cities in the world are practicing to apply this trend.

Power cable technology had its beginnings in the 1880s when the need for power distribution cables became important [1]. Some of the earliest power cables consisted merely of duct with the copper conductors insulated from ground by glass or porcelain insulators. Some of the more common early solid and liquid insulating materials employed in various underground cable installations were natural rubber, gutta-percha, oil and wax, rosin and asphalt, jute, hemp and cotton. First oil-impregnated-paper power cable was introduced in 1890 and that cables was installed in

London in 1891 for 10kV operation. After that, many researches had been done to find alternative insulations which are provided more good characteristics of dielectric.

In the late 1960s power distribution cables insulated with cross-linked polyethylene (XLPE) began making their appearance in Canada and United State in 1965 [1]. Cables insulated with XLPE presently dominate the distribution cable field in North America, Japan and Northern Europe. After that, Cross linked Polyethylene (XLPE) has been used over the world as electrical insulating material in underground distribution and transmission class cables because of their excellent dielectric strength, low dielectric permittivity and loss factor, good dimensional stability, solvent resistance and good thermo-mechanical behavior.

1.1 Background Study

Underground power distribution system is become more important in Malaysia environment especially in urban area. Because of that, more electricity power is needed to supply those facilities in compact urban area. Therefore, that underground electrical supply system is most important to apply. Underground XLPE insulators cables are widely used for underground cables system especially in urban or compact area with many of facilities are provided. Even though underground XLPE cables provided excellent dielectric strength, low dielectric permittivity and loss factor, good dimensional stability, solvent resistance and good thermo-mechanical behavior, unfortunately, there are some weakness is faced by XLPE cables which is bring down their performance in service. Several aging mechanisms can affects performance of cables system in service. For instances, because of internal discharge, improper cable joints, terminations and moisture absorption will make the cables fail in service. In order to evaluate the performance of underground XLPE cables, there are several factors or parameters should be considered. In this study, tan δ and capacitance parameters of XLPE cables are being considered on the cable are taken from service. From this study, some finding or conclusion should be obtained to know the performance of XLPE cables in service.

1.2 Objectives

The objectives of this study are listed below:

1. To study and understand the concepts of underground XLPE distribution cables system.
2. To Identify the aging mechanisms of underground cables system.
3. To perform measurements of tan δ and capacitance of underground XLPE distribution cables from service.
4. To analyze performance of underground XLPE distribution cables in service based on tan delta and capacitance parameters.

1.3 Scopes

The scopes and limitation of this study are as follows:

1. This study only focus on underground XLPE distribution cables that voltage rated at 11kV and 22kV for 1-core and 3-core types.
2. All samples of XLPE cable are taken from service.
3. Data of tan δ and capacitance of XLPE cables are measured by using Tettex Instruments – Schering Bridge Model 2816.
4. All analysis will be based on data are obtained from measurements of XLPE cables samples.
5. The areas of research are only around Johor Bahru and Kulai, Johor.

1.4 Expected Results

The expecting result for this study is the performance of underground XLPE cables can be evaluated by looking their tan δ and capacitance parameters for aged XLPE cables where are taken from service. From those analysis of tan δ and capacitance data, several factors may be affected the performance of underground XLPE cables in service can be predicted. The tan δ and capacitance parameters data of underground XLPE cables are measured by using Tettex Instruments – Schering Bridge Model 2816.

REFERENCES

1) R. Bartnikas and K.D. Srivastava (2000). “Power and Communication Cables: Theory and Apllications” New York: Institute of Electrical and Electronics Engineers, Inc. B.

2) A S Pabla (1997). “Electric Power Distribution.” 4th edition. New Delhi: Tata McGraw-Hill Publishing Company Limited.

3) Lothar Heinhold (1990) “Power Cables and Their Application – Part 1” 3rd Edition. Germany: Siemens Aktiengesellschaft, Berlin and Munich.

4) E. Kuffel, W. S. Zaengl and J. Kuffel (2000) “High Voltage Engineering – Fundamental.” 2nd edition. England: Newnes.

5) M. S. Naidu and V. Kamaraju (1995) “High Voltage Engineering.” 2nd edition. New Delhi: Tata McGraw-Hill Publishing Company Limited.

6) Anthony J. Pansini (1983) “Electrical Distribution Engineering” USA: McGRAW-HILL Book Company.

7) P. V. Hunter and J. Temple Hazell (1956) “Development of Power Cables” London: George Newnes Limited.

8) B. M. Weedy (1988) “Thermal Design of underground System” Great Britain: John Wiley & Sons Ltd. B.

9) John Densley, 1995, *IEEE International Conference on Conduction and Breakdown in Solid Dielectrics*, 1-15. J.

10) Densley J., Bartnikas R., and Berstein B., 1994, *IEEE Trans. Power Delivery*, 9, 559-571.

11) Day, A G., 1975, *Conf. on Dielectric Materials, Measurements and Applications*, IEE Publ. 129, 200-204.

12) Ieda M., 1987, *IEEE Trans. Electrical Insulations*, Vol. 22, 261-267.

13) Barlow A., Hill L. A., and Maringer M.F., 1983, *IEEE Trans. Power Application and System*, PAS 102, 1921-26.

14) Fukuda T., 1988, *IEEE Electrical Insulation Magazine*, 4, 9-16.

15) IEC Standard, Publication 840, 1988.

16) Rizzetto S., Stone G.C. and Boggs S.A., 1987, *Annual Rept. CEIDP*, 89-94.

17) Orton H.E., Fletcher R.G., Cartlidge D.M., Bradley J.F., Colwell M.J. and Wong J.Y.,*1987 JICABLE*, Paper A1.3, 14-22.

18) Ball E.H., Holdup H.W., Skipper D.J. and Vecellio B., 1984, *CIGRE*, Paper 21-01, 10pp.

19) IEC Standard, Publication 502 – 2nd ed., Extruded Solid Dielectric Power cables for Rated Voltage from 1 kV to 30 kV, 2nd ed., 1978.

20) G. Katsuka, A. Toya, S. Kataki, M. Kanaoka and Y. Sekii (1991). "Influence of Defects on Insulating Properties of XLPE Cable." *Proc. of the 3rd International Conferences on Properties and Applications of Dielectric Materials.* Tokyo, Japan: IEEE. 485-489.

21) Hallvard Faremo and Erling Ildstad (1994) "Rehabilitation of Water Tree Aged XLPE Cable Insulation" *IEEE International Symposium on Electrical Insulation.* Pittsburgh, PA USA: IEEE. 188-192.

22) A. Sivathanu Pillai and U. C. Trivedi (1988). "Aging Effect on Partial Discharge Values and Electrical Performance of XLPE Cable." *IEEE International Symposium on Electrical Insulation.* Boston: IEEE. 211-214.

23) S.V. Nikolajevic (1998). "The Influence of the Water Absorption and Density of XLPE Cable Insulation." *IEEE Trans. On Power Delivery*. 13(2). 297-303.

24) S. Pelissou and H. J. Wintle (1992) "Water Content of XLPE Cable Insulation" *IEEE International Symposium on Electrical Insulation.* Baltimore, MD USA: IEEE. 165-168.

25) IEEE Standard 400 – 2001, IEEE Guided for Field Testing and Evaluation of the Insulation of Shielded Power cable Systems, December 2001.

26) Frank H. Rocchio, H.R. Stewart, and Donald A. Voltz (2001). "Comparing US and International Power and Control Cable Standards." IEEE Industry Applications Magazine, January/February 2001.

27) H. N. Nagamani and Channakeshava (1998) "Investigations on the Failure Modes of XLPE Cables and Joints" *IEEE Trans. On Power Delivery*. 13(3). 706-711.

28) T. Nagata and N. Shimizu (1998) “Deterioration In Aged XLPE Cables” *IEEE Trans. On Power Delivery*. 579-585.

29) H N Nagamani and S N Moorching (1998) “A Study on the Influence of Partial Discharge on the Performance of Solid Dielectrics” *IEEE International Conferences on Conduction and Breakdown in Solid Dielectric.* Sweden: IEEE. 127-130.

30) Bolarin Oyegoke, Petri Hyvonen, Martti Aro and Ning Gao (2003) “Application of Dielectric Response Measurement on Power Cable Systems” *Oyegoke et al.: Application of Dielectric Response Measurement on Power Cable Systems.* IEEE. 862-870.