INVESTIGATION ON THE PERFORMANCE OF XLPE CABLE INSULATION USING TANGENT DELTA METHOD

ROSITA BINTI MISUARI

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

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

FEBRUARY 2022

DEDICATION

I dedicate this work to Allah S.W.T my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. Special dedication to my beloved parents, Hj Misuari bin Ariff and Hjh Frika Abaka, my brothers and sisters Amina, Aishah, Kamil, Adenan and Anita who always support me all the way and encourage me to finish this work successfully. Lastly, special thanks to my supervisor, lecturers, colleagues, and friends who are always be by my side, helping and supporting me all of the time, thank you so much for everything.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful, Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this dissertation. Special appreciation goes to my supervisor, Ts. Dr. Noor Azlinda Ahmad, for her supervision and constant support, for the precious and relentless guidance for the constructive comments and suggestions throughout the project duration which lead me to the success of this dissertation. I would like to express my appreciation to the Chair, School of Electrical Engineering, Prof. Ir. Dr. Mohd Wazir bin Mustapha for the support and help towards my postgraduate matters.

My acknowledgement also goes to all lecturers and administration staffs of School of Electrical Engineering for the knowledge that had been taught, shared and for assistance. Sincere thanks to all my postgraduate fellow friends for your assistance, moral support along the postgraduate course. Thank you for the friendship and memories.

Last but not least, my deepest gratitude goes to my beloved parents Hj Misuari B. Ariff and Hjh Frika Abaka, to my brothers and sisters for their endless love, prayers and encouragement during my journey in completing my final year project. To those who have provided assistance at various occasions along this journey, directly or indirectly contributed into the completion of this dissertation, your kindness means a lot to me. Thank you very much. May Allah rewards your kindness.

ABSTRACT

Insulation is one of the most crucial components of a cable. Failure of insulating material will lead to breakdown and consequently may cause electrical shock or injury. For that reason, analysis of insulation condition is critical to monitor the performance of high voltage cable insulation so that suitable preventive maintenance and mitigation can be planned accordingly to avoid permanent damage to the cable. In this study, the condition of medium cable (MV) cable insulation is monitored based on tangent delta or dissipation factor value from tangent delta measurement as per IEEE 400.2 Standard. The evaluation will be useful for maintenance personnel to predict the remaining life expectancy and to prioritize cable replacement as well as it is also useful for determining what other tests may be worthwhile to diagnose the cable condition. As expected, the result shows that high value of tangent delta was measured in a degraded cable insulation.

ABSTRAK

Penebat adalah salah satu komponen yang paling penting dalam kabel. Kegagalan bahan penebat akan menyebabkan kerosakan dan akibatnya boleh menyebabkan kejutan atau kecederaan elektrik. Atas sebab itu, analisis keadaan penebat adalah penting untuk memantau prestasi penebat kabel voltan tinggi supaya penyelenggaraan pencegahan dan mitigasi yang sesuai dapat dirancang dengan sewajarnya untuk mengelakkan kerosakan kekal pada kabel. Dalam kajian ini, keadaan penebat kabel pada kabel voltan sederhana dipantau berdasarkan delta tangen atau nilai faktor pelesapan dari ukuran delta tangen mengikut piawai IEEE 400.2. Penilaian ini akan berguna untuk kakitangan penyelenggaraan dalam meramalkan jangka hayat kabel, membantu dalam menganalisa keutamaan penggantian kabel serta ia juga berguna untuk menentukan ujian-ujian lain yang mungkin berbaloi untuk dijalankan untuk mendiagnosis keadaan kabel. Seperti yang dijangka, nilai delta tangen adalah tinggi setelah diukur pada penebat kabel yang merosot .

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TD	-	Tangent Delta
DTD	-	Differential Tan Delta
MV	-	Medium Voltage
IEEE	-	The Institute of Electrical and Electronics Engineers
VLF	-	Very Low Frequency
Hz	-	Hertz
SLG	-	Single Line Diagram
XLPE	-	Crosslinked Polyethylene
PILC	-	Paper Insulated, Lead Covered
PE	-	Polyethylene
Uo	-	Normal phase-to-ground operating voltage.
SDTD	-	Standard Deviation Tan Delta (Stability Tan Delta)
VCB	-	Vacuum Circuit Breaker
GTG3	-	Gas Turbine Generator 3
EEB	-	Electrical Equipment Building
SGM TG3	-	Block 3 Medium Voltage Busbar
BSDG	-	Black Start Diesel Generator
ECP	-	Electro Chlorination Plant
SFC	-	Static Frequency Converter
ATR	-	Auxiliary Transfromer
TR3	-	Transformer Unit 3

LIST OF SYMBOLS

δ	-	Angle
C	-	Capacitance
R	-	Resistance
I	-	Current
V	-	Voltage
I_R	-	Resistive current
I_C	-	Capacitive current
o	-	Degree

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Insulation and electric field profiles for high voltage (HV) and medium voltage (MV) equipment must be carefully designed. Pressure, temperature, humidity, field configurations, nature of applied voltage, flaws in dielectric materials, material & surface characteristics of electrodes, and other factors influence breakdown strength. A good dielectric in solid means low dielectric loss, high mechanical strength, free from gaseous inclusion and moisture, resistant to thermal and chemical deterioration. Insulation failure is invariably unpredictable, and it is frequently violent. Eventually this activity will lead to disruptive failure of the cable feeder. As a result, the degradation of cable insulation is a continues concern.

The reliability and continuity of electrical supply are dependent on the healthiness of the insulating dielectric in power system equipment. The behaviours and conditions that influence the ageing of insulating dielectrics have received a lot of attention. One of the factors related to the insulating dielectric is the loss factor tan delta. Loss factor tan delta commonly known as loss tangent or dissipation factor and usually depends upon frequency, applied electric stress and the temperature. Defects in cable insulation like water trees, electrical trees, moisture and air pockets which may contribute to cable breakdown can be determine through diagnostic test that determine the loss angle delta. An increasing angle indicates an increase in the resistive current through the insulation which mean the insulation is contaminated. Thus, the insulation integrity and quality of electrical equipment should be verified.

As has been discovered, ageing and deterioration of XLPE insulation will certainly occur during the long-term operation of power cables due to electrical, thermal, and mechanical factors. This may cause insulation dielectric strength to deteriorate, increasing the risk of unexpected power cable failure and early life end. Therefore, it is required to conduct a condition assessment of cable insulation to ensure the safety of transmission and distribution power lines.

1.2 Problem Statement

Originally intended to evaluate oil filled transformers, a DC Hipot testing has proven to be a reliable and useful test for Paper Insulated Lead Covered (PILC) cables. When used to XLPE cables, however, several investigations have proven beyond a shadow of a doubt that DC Hipot testing causes premature cable failure due to the creation of space charges [15]. Apart from DC Hipot test that have potential to cause premature failure of cable, there are few other test that can be used to investigate and determine the XLPE cable insulation condition such as VLF testing, Tan Delta or Partial Discharge test. In order to investigate the insulation condition or degradation by means of presence of moisture, electrical trees and water trees, VLF Tan Delta test is able to rate the cables by severity of insulation deterioration based on IEEE 400.2-2013 Standard "Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)" to help to prioritize replacement or to perform other test to further investigate the insulation condition.

1.3 Research Goal

1.3.1 Research Objectives

The objectives of the research are:

(a) To investigate the performance of 6.6 kV XLPE MV cable using tangent delta or dissipation factor measurement.

(b) To analyse the measurement result based on the IEEE 400.2-2013 Standard "Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

1.3.2 Scope of Work

i. The approach method and calculation of the analysis is based on the IEEE 400.2-2013 Standard which is "Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)".

ii. Analysis is only limited to 6.6 kV XLPE cable since there is no offline test or online monitoring system installed at the 6.6 kV cable thus its critical to prioritize it. The 11 kV interconnection unable to be test since it is using bus duct instead of cable, thus tan delta test is not able to be done.

iii. The project is focus on measurement only without any simulation.

REFERENCES

[1] Yuan Y, Lu G, Wang W, Fan W, Liao W, Jia Z, Guan Z. Dielectric loss and partial discharge test analysis of 10 kV XLPE cable. In2013 Annual Report Conference on Electrical Insulation and Dielectric Phenomena 2013 Oct 20 (pp. 124-127). IEEE.

[2] Luo JH, Yang LM, Jiang Y, SHENG LB. Outline of operation and fault and testing for power cable. Electr. Equip. 2004;5:4-8.

[3] Zhixiang Z. The common faults of 35kV XLPE cable and the countermeasure. High Voltage Engineering. 2004;30(S1):136-8.

[4] Chmura L, Jin H, Cichecki P, Smit JJ, Gulski E, De Vries F. Use of dissipation factor for life consumption assessment and future life modeling of oil-filled high-voltage power cables. IEEE Electrical Insulation Magazine. 2012 Jan 16;28(1):27-37.

[5] Mauseth F, Hammervoll KD, Hvidsten S. Dielectric properties of service aged medium voltage XLPE cable joints. In2010 10th IEEE International Conference on Solid Dielectrics 2010 Jul 4 (pp. 1-4). IEEE.

[6] IEEE Guide for "Partial Discharge testing of Shielded Power Cable System in a field Environment". (IEEE. Std 400.3tm -2006)

[7] Plopeanu M, Notingher PV, Stancu C, Grigorescu S. Electrical ageing of polyethylene power cables insulation subjected to an electric field in the presence of water. In2011 7TH INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING (ATEE) 2011 May 12 (pp. 1-4). IEEE.

[8] Amyot N, David E, Fournier D, Jean D, Lalancette D. Dielectric response of cable accessories and its influence on cable diagnostics. InAnnual Report Conference on Electrical Insulation and Dielectric Phenomena 2002 Oct 20 (pp. 434-437). IEEE.

[9] Nikolajevic SV. The behavior of water in XLPE and EPR cables and its influence on the electric characteristics of insulation. IEEE transactions on Power Delivery. 1999 Jan;14(1):39-45.

[10] J. C. Hernandez-Mejia, R. Harley, N. Hampton and R. Hartlein, "Characterization of Ageing for MV Power Cables Using Low Frequency Tan-delta Diagnostic Measurements," IEEE Trans. Dielectr. Electr. Insul., Vol. 16, No. 3, pp. 862-870, 2009

[11] R. N. Hampton, R. Hartlein, J. C. Hernandez and R. Harley, "Practical Issues Regarding The Use Of Dielectric Measurements To Diagnose The Service Health Of MV Cables," JICABLE07, Versailles, France, Paper No. A.7.5, 2007.

[12] J. Densley, "Aging Mechanisms and Diagnostics for Power Cables - An Overview," IEEE Electr. Insul. Mag., Vol. 17, No 1, pp 14-22, 2001.

[13] Wong BV, Tian Y, Neier T. Practical experience using VLF Tan Delta and partial discharge measurement in medium voltage cable. In2016 China International Conference on Electricity Distribution (CICED) 2016 Aug 10 (pp. 1-5). IEEE.

[15] Oetjen H. Principals and field experience with the 0.1 Hz VLF method regarding the test of medium voltage distribution cables. Conf Rec IEEE Int Symp Electr Insul. 2004;(September):376–9.

[16] Conductors I, Society E. IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)(less than 1 Hz). IEEE Std 400.2-2013. 2013. 1–111 p.

[17] Gill P. Electrical power equipment maintenance and testing. 2nd ed. CRC press; 330 -331; 2016

[18] Radu I, Acedo M, Filippini JC, Notingher P, Ftutos F. The effect of water treeing on the electric field distribution of XLPE. Consequences for the dielectric strength. IEEE Transactions on Dielectrics and Electrical Insulation. 2000 Dec;7(6):860-8.

[19] Qingyue Y, Xiufeng L, Peng Z, Peijie Y, Youfu C. Properties of Water Tree Growing in XLPE and composites. In2019 2nd International Conference on Electrical Materials and Power Equipment (ICEMPE) 2019 Apr 7 (pp. 409-412). IEEE.

[20] Chavan MS, Shewale P, Sahasrabuddhe DT. Insulation degradation in the field aged MV XLPE power cable-a key concern for utilities-Improvement opportunities. In2012 IEEE 10th International Conference on the Properties and Applications of Dielectric Materials 2012 Jul 24 (pp. 1-4). IEEE.

[21] Perkel J, Del Valle Y, Hampton RN, Hernández-Mejía JC, Densley J. Interpretation of dielectric loss data on service aged polyethylene based power cable systems using VLF test methods. IEEE Transactions on Dielectrics and Electrical Insulation. 2013 Oct 21;20(5):1699-711.

[22] Du Y, Geng P, Song J, Tian M, Pang D. Influence of temperature and frequency on leakage current of XLPE cable insulation. In2016 IEEE International Conference on High Voltage Engineering and Application (ICHVE) 2016 Sep 19 (pp. 1-4). IEEE.

[23] Heider MZ, Rahman MM, Al-Arainy AA. Study of frequency variant tan delta diagnosis for MV cables insulation status assessment. In2019 5th International Conference on Advances in Electrical Engineering (ICAEE) 2019 Sep 26 (pp. 260-264). IEEE.

[24] Arief YZ, Shafanizam M, Adzis Z, Makmud MZ. Degradation of polymeric power cable due to water treeing under AC and DC stress. In2012 IEEE

International Conference on Power and Energy (PECon) 2012 Dec 2 (pp. 950-955). IEEE.

[25] SY Kuo. Cable Sizing Calculation 2011 Jul 29