DESIGNING AND ANALYSIS THE PERFORMANCE OF MEDIUM VOLTAGE CABLE USING FINITE ELEMENT METHOD (FEM)

Abdullah Ameer bin Izer

Bachelor of Electrical Engineering (Industrial Power)

June 2014

" I hereby declare that I have read through this report entitle " *Designing and analysis the performance of medium voltage cable using finite element method* " and found that it has comply the partial fulfullment for awarding the degree of *Bachelor of Electrical Engineering (Industrial Power)*"

Signature	:	....
Supervisor's Name	:	NOR HIDAYAH RAHIM
Date	:	17/6/2014

DESIGNING AND ANALYSIS THE PERFORMANCE OF MEDIUM VOLTAGE CABLE USING FINITE ELEMENT METHOD

ABDULLAH AMEER BIN IZER

A report submitted in partial fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2014

I declare that this report entitle " *Designing and analysis the performance of medium voltage cable using finite element method* " is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

Signature : ....

Student's Name : Abdullah Ameer bin Izer

Date : 18 JUNE 2014

To my beloved parents and family

Izer Ismail
Zulaina Mohd Zawawee
Usamah
Balqis Syed
Muhammad Zaahid
Aniisah Syafiyyah
Nur Sakinah
Abdullah Fahmi
Abdullah Munzir
Ahmad Firdaus
Nuha Amani

"Thank you for your patience and support"

ACKNOWLEDGEMENT

In the name of Allah S.W.T, Most Gracious Most Merciful. Praise to Allah for his willingness I had succeeded to finish my Final Year Project report entitled "Designing and Analysis the Performance of the Medium Voltage Cable Using Finite Element Method (FEM)".

First and foremost, I would like to express my deepest gratitude to my project supervisor, Puan Nor Hidayah bte Rahim, for her advice, motivation, guidance, critics, stimulating suggestions and encouragement throughout this project. She always gives positive feedback to my project and willing to spend her time upon needed.

Besides that, I also want to denote my thankful to all my PSM panels, Ms Nur Hazahsha bte Shamsudin, Mr R. Hery Satriyo Soeprapto, Mr Azhar bin Ahmad as well as Dr Aminuddin bin Aman for their advices, guidances, tips and positive criticism during my project presentation. Without their bless, this project would not have been as good as recorded in this thesis.

Finally, my sincere appreciation also extends to my parents, family, relative and colleagues for their patience, prayers and understanding over the entire period of my studies. Thank you very much.

ABSTRACT

Nowadays, electricity is very vital to all mankind after water. Most of our daily work includes the using of electricity. Usually, the underground medium voltage (MV) power voltage will be used in distributing the electricity to the consumer by Tenaga Nasional Berhad (TNB). A single core MV power cable consists of three major components. They are conductor, insulation, and a protective jacket. Presently, TNB has it's own standard in selecting the suitable and the exact size of the underground cable. Cables are usually selected based on their ampacity or current carrying capacity. However, there are some parameters that influence the cable ampacity such as soil thermal resistivity, depth of cable laying, ambient temperature, methods of cable installation and cable size and dimensions. Thus, this project proposes to design and analyse the single core MV power cables using the ANSYS Maxwell software. Then, the cables will be analysed in term of ampacity using Finite Element Method (FEM). The analysed result then will be tabulated and presented in graphs. After that, the comparison between the standards from the Institute of Electrical and Electronics Engineers (IEEE) and International Electrotechnical Commission (IEC) and the result from this project will be conducted to ensure the compatibility and validity of the analysed result.

ABSTRAK

Pada masa kini, bekalan elektrik amat penting dalam kehidupan manusia selepas bekalan air. Kehidupan harian manusia kini banyak menggunakan bekalan elektrik pada setiap hari. Kebiasannya, kabel voltan sederhana bawah tanah digunakan dalam menghantar kuasa elektrik kepada pengguna oleh Tenaga Nasional Berhad (TNB). Sebuah kabel voltan sederhana teras tunggal terdiri daripada tiga bahagian utama seperti konductor, penebat dan jaket pelindung. Kini, TNB mempunyai standard tersendiri untuk memilih saiz kabel voltan sederhana bawah tanah yang sesuai. Kabel ini biasanya dipilih berdasarkan keupayaannya membawa arus elektrik. Walaubagaimanapun, terdapat beberapa parameter yang mempangaruhi keupayaannya membawa arus elektrik bagi sebuah kabel voltan sederhana bawah tanah. Parameter itu adalah rintangan haba tanah, kedalaman meletakkan kabel, suhu ambien, kaedah pemasangan kabel, saiz kabel dan dimensi kabel. Oleh itu, projek ini dijalankan bagi mereka bentuk dan melakukan simulasi terhadap kabel voltan sederhana teras tunggal meggunakan perisian ANSYS Maxwell. Kemudian, kabel tersebut akan dianalisis menggunakan kaedah FEM berdasarkan keupayaannya membawa arus elektrik. Keputusan analisis kemudiannya akan dijadualkan dan dipapar dalam bentuk graf. Selepas itu, perbandingan keputusan akan dijalankan diantara piawai yang dikeluarkan oleh IEEE dan IEC dengan keputusan analisis yang dibuat dalam projek ini. Hal ini dilakukan untuk memastikan kesahihan keputusan yang dianalisa di dalam projek ini.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	**i**
	ABSTRACT	**ii**
	TABLE OF CONTENTS	**iv**
	LIST OF FIGURES	**vii**
	LIST OF TABLES	**ix**
	LIST OF ABBREVIATIONS	**x**
	LIST OF SYMBOLS	**xi**
	LIST OF APPENDICES	**xii**
1	**INTRODUCTION**	**1**
	1.0 Overview	1
	1.1 Research Background	1
	1.2 Problem Statement / Project Motivation	2
	1.3 Project Objective	2
	1.4 Scopes of research	2
	1.5 Expected Project Outcome	3
	1.6 Report Outline	3

CHAPTER	TITLE	PAGE
2	**LITERATURE REVIEW**	**5**
	2.0 Overview	5
	2.1 Theory and Basic Principles	5
	2.1.1 Single core medium voltage power cable construction	5
	2.1.2 Cable Ampacity Principles	7
	2.1.3 Heat transfer mechanism in cable	8
	2.2 Related previous work	9
	2.2.1 Effects of backfilling on cable ampacity analysed by FEM	9
	2.2.2 New approach to ampacity evaluation of cables in ducts using FEM	10
	2.3 Summary of reviews	10
3	**METHODOLOGY**	**12**
	3.0 Overview	12
	3.1 Flow of the Study	12
	3.3 Literature Review	14
	3.4 Design the cable using the ANSYS Maxwell software	14
	3.4.1 Steps in designing cable	14
	3.5 Analysis of cable ampacity using Finite Element Method software	22
	3.6 Project Milestone	23

CHAPTER	TITLE	PAGE
4	**EXPECTED RESULT**	**25**
	4.0 Overview	25
	4.1 Design and Simulate the single core MV power cable	25
	4.2 Cable ampacity analysis using FEM	26
	4.2.1 Soil Thermal Resistivity	27
	4.2.2 Depth of Cable Laying	30
	4.2.3 Ambient Temperature	32
	4.2.4 Method of Cable Installation	33
	4.2.5 Cable Size and Dimension	34
5	**CONCLUSION**	**37**
	5.0 Overview	37
	5.1 Conclusions	37
	5.2 Recommendations	38
REFERENCES		**39**
APPENDICES		**41**

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Basic single core MV cable construction	6
2.2	Heat transfer mechanism in cable	9
3.1	Methodology Flowchart	13
3.2	Maxwell 15.0 (64-bit) desktop background	14
3.3	Adding a design to the ANSYS Maxwell software	15
3.4	Geometry mode sets toolbar	15
3.5	Maxwell Desktop 2D Modeller	16
3.6	Solution type set toolbar	17
3.7	Model unit sets toolbar	17
3.8	Default material set toolbar	18
3.9	Step to set cable boundary	18
3.10	Eddy Current on conductor part of the cable	19
3.11	Current density in the cable	20
3.12	Project validation check	20
3.13	Step to exemplify result	21
3.14	Graph of depth of cable laying (m) versus cable ampacity (A)	22
3.15	Project Gannt Chart	24

FIGURE	TITLE	PAGE
4.1	A sample design of a single core 11kV power cable using the ANSYS Maxwell	26
4.2	Cable ampacity (A) at various soil thermal resistivity (°C.m/W)	28
4.3	Cable as a heat source	29
4.4	High thermal resistivity soil (left) and low thermal resistivity soil (right)	29
4.5	Mechanism of heat transfer in soil	30
4.6	Cable ampacity (A) at different depth of laying (m)	31
4.7	Cable ampacity (A) at different ambient temperature (°C)	32
4.8	Cable ampacity (A) for different types of cables using direct buried method (m)	33
4.9	Cable ampacity (A) for different types of cable sizing and dimension	35

LIST OF TABLES

TABLE	TITLE	PAGE
4.1	Soil thermal resistivity values in Malaysia	27
4.2	Cable ampacity based on the cable size	35

LIST OF ABBREVIATIONS

MV	-	Medium Voltage
XLPE	-	Cross-linked Polyethylene
PE	-	Polyethylene
PILC	-	Paper Insulated Lead Covered Cable
FEM	-	Finite Element Method
IEEE	-	Institute of Electrical and Electronics Engineers
IEC	-	International Electrotechnical Commission
HV	-	High Voltage
T_4	-	External Thermal Resistance
LV	-	Low Voltage
PSM	-	Projek Sarjana Muda
TNB	-	Tenaga Nasional Berhad

LIST OF SYMBOLS

k	-	Kilo
V	-	Voltage
°C	-	Degree Celcius
I	-	Ampacity or Current Carrying Capacity
$\Delta\theta$	-	Temperature Different
Wd	-	Dielectric Loss in the Insulation
T_1	-	Thermal Resistivity of Dielectric
T_2	-	Thermal Resistivity of Inner Sheath
T_3	-	Thermal Resistivity of Outer Sheath (jacket)
T_4	-	Tduct + Tair + Texternal
R	-	Resistance Per Unit Length
n	-	Number of Cores
λ_1	-	Sheath Loss Factor
λ_2	-	Armour Loss Factor

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	IEEE Std 525-1992, 1993: Guide for the Design and Installation of Cable Systems in Substations	41
B	IEC 60287-1: Electrical Cables	46
C	IEC 60287-2: Thermal Resistance	49

CHAPTER 1

INTRODUCTION

1.0 Overview

This chapter will elaborate about the research background, problem statement, project objective, scopes of research, expected project outcome and project outline.

1.1 Research Background

A single core MV power cable consists of three major components. They are conductor, insulation, and a protective jacket. It is used for transmission of electrical power. Insulation is a vital part in MV cable. Cable insulation materials such as cross-linked polyethylene (XLPE), polyethylene (PE) and paper insulated lead covered cable (PILC) have a maximum allowable operating temperature which limited the cable ampacity or current carrying capacity. There are five major parameters that influence the cable ampacity discussed in this project. They are soil thermal resistivity, depth of cable laying, ambient temperature, methods of cable installation and cable size and dimensions [1]. The MV power cables may be exposed, buried in the ground, installed as permanent wiring within buildings, run overhead or lay underwater. Modern MV power cables come in a variety of types, materials, and sizes, each particularly relevant to its function [2] . In Malaysia, MV power cable range between 11kV to 33kV [3].

The aim of this project is to design and simulate single core MV power cable. To design and simulate the cable, ANSYS Maxwell software is used. After that, an analysis will be conducted. Cable ampacity analysis will be performed using FEM. The analysis result then will be compared to the IEEE and IEC standards to ensure the analysis is compatible and valid. Guiding from the result analysis, the most suitable type of cable size, which work optimally can be determined.

1.2 Problem Statement / Project Motivation

Nowadays, TNB as the electrical distributor in Malaysia has its own general standard in selecting the exact size of the underground cable. Usually, the selection of the cables is based on their current carrying capacity or ampacity. However, the cable selection basically are influenced by a certain parameters. Therefore, it is motivated to investigate the parameter that influences the cable ampacity in order to find the suitable cable size to be consumed. In addition, the rationale of this project is to provide a guideline to the future student upon the selection of the underground power cables. Other than that, in [4], the author only focusing on the external thermal resistance (T_4) which is only part of the cable ampacity. So, in this project, it is motivated to study the whole part of the cable ampacity.

1.3 Project Objective

The following are the objectives of this research:

i. To design single core MV cable using the ANSYS Maxwell software.
ii. To simulate single core MV cable using the ANSYS Maxwell software.
iii. To analyse the performance of the single core MV cable in term of ampacity using FEM.

1.4 Scopes of project

This research work will be focused on two main scopes. First, the research of this project is restricted to underground MV power cable with voltage range between 11kV to 33kV [3]. Other than that, in this project, it's only focusing on five parameters that influence the cable ampacity which are soil thermal resistivity, depth of cable laying, ambient temperature, methods of cable installation and cable size and dimensions [5]. For designing purpose, IEEE Std 525-1992: Guide for the Design and Installation of Cable System in Substation will be referred. Besides that, in analysis part, two standards will be used as a guidance which is IEC 602871-1: Electrical Cables and IEC 60287-2: Thermal Resistance.

1.5 Expected Project Outcome

This final year project required the student to design, simulate and analyse the performance of single core MV power cable. This process, including the usage of ANSYS Maxwell software to design and simulate the single core MV power cable and FEM to analyse the cable ampacity. The analysed cable ampacity then will be compared to the standards that have been set by the IEC and IEEE. The result will be present in the form of graphs for further discussion. Hopefully this research can be a reference or guidance for the student to design and simulate the cable as well as to analyse the ampacity of the single core medium voltage power cable for further research in the future.

1.6 Report Outline

This report basically is divided into five chapters;

Chapter 1- Introduction

This chapter provides readers a first glimpse at the basic aspects of the research undertaken, such as research background, project motivation, objectives, scopes, and the expected outcome of this report.

Chapter 2- Literature Review

This chapter reviews the basic theory and principles of single core medium voltage power cable, review of previous related work and a summary of reviews of previous works.

Chapter 3- Methodology

This chapter presents the flow of the study and methodology being used in this study. ANSYS Maxwell software and will be used as the tool for designing and simulating the single core medium voltage power cable while Finite Element Method is used to analyse the cable ampacity.

Chapter 4- Result and Discussion

This chapter shows project achievement by highlighting the results achieved from the analysed parameters which is soil thermal resistivity, depth of cable laying, ambient temperature, methods of cable installation and cable size and dimensions. The result then will be compared to the standards from IEC and IEEE for validation and compatibility.

Chapter 5- Conclusions

This chapter consists of conclusions based on the overall works and results. This is followed by recommendations and suggestions for future study work.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

This chapter briefly focused on the theory and basic principles of the single core MV power cable, related previous work and the summary of the related previous work. Books, articles related to the project and past journals are source of review of this research.

2.1 Theory and Basic Principles

This topic emphasize about the single core MV power cable construction, cable ampacity principles and heat transfer mechanism in cable.

2.1.1 Single core medium voltage power cable construction

Single core MV power cables have voltage grade greater than 11 kV. It usually goes up to 33 kV and high voltage (HV) is considering all voltage levels above 33 kV [3]. Single core MV power cables consist of several components such as conductor, conductor screen, insulator, insulator screen, metallic sheath and jacket.

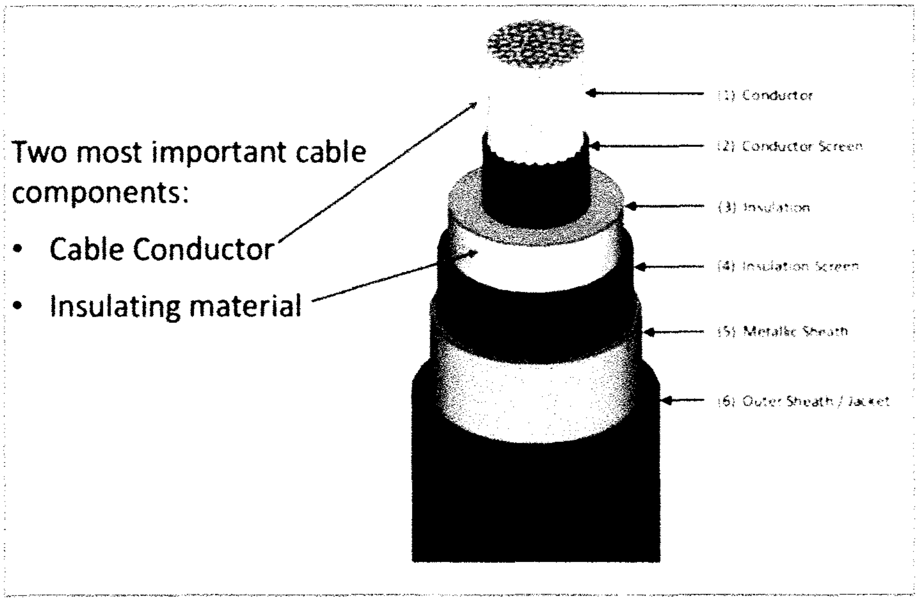

Figure 2.1: Basic single core MV cable construction [6]

MV power cables use stranded copper or aluminium conductors to carry the design rated current. The cable may include uninsulated conductors used for the circuit neutral or for ground connection. The overall assembly may be round or flat. Nonconducting filler strands may be added to the assembly to maintain its shape. Special purpose MV power cables for overhead or vertical use may have additional elements such as steel or Kevlar structural supports.

Conductor screen is an extruded semi-conductive compound used to fill in the interstices on a stranded conductor. It has also helped to smooth out any irregularities over the stranded conductor's contours as well as to reduce the probability of protrusions into the insulating layer in order to avoid localized stress that may exceed the breakdown strength of the insulation. The metallic protrusion of the irregularities conductor's surface shall cause localised stress that shall lead to partial discharge and electrical tree.

An electrical insulator is a material whose internal electric charges do not flow freely, and therefore does not conduct an electric current under the influence of an electric field. A perfect cable insulator does not exist, but usually for underground MV cables, XLPE or PILC were used to handle the designed stress level on the cable which include the rated voltage and transient voltage. These materials also provide insulation between conductors and earth, to prevent short circuit from conductor to earth beside provide safety for the users against electrical hazards. The thickness of the insulator depends on the voltage ratings of the cable. The more the voltage ratings, the more the thickness the insulator will be.

As mentioned before, the insulation screen is also part of the single core MV power cable. This extruded semi-conductive compound provides a uniform earth potential layer to enable symmetrically spaced electrostatic flux lines and concentric equipotential lines in the insulation. Meanwhile, the metallic screen provides a return path for fault current, keep out moisture and ground for the whole length of cable. The outer part of the cable called jacket prevents corrosion of neutrals, provide mechanical protection and provides a moisture barrier for the cable [7, 8].

2.1.2 Cable Ampacity Principles

All power cables including MV power cable have their own maximum amount of electrical current they can carry before sustaining immediate or progressive deterioration. It is described as ampacity or current carrying capacity, is the root mean square electric current which a cable can continuously carry while remaining within its temperature rating. According to [5], cable, whether only energised or carrying load current, is a source of heat. This heat energy causes a temperature rise in the cable, which must be kept within limits that have been established. For example, XLPE insulated cable can withstand about 90°C while PILC can cater about 70°C. Hence, ampacity is limited by the allowable maximum operating temperature of the cable insulation.

There are several sources of heat in a cable, such as losses caused by current flow in the conductor, dielectric loss in the insulation, circulating current in the shielding, the sheath and armour and the adjacent cables. The heat must flow outward through the various cable materials that have varying resistance to the flow of that heat. It is this careful balancing of temperature rise to acceptable levels and the ability to dissipate the heat that determines the cable ampacity. Ampacity is relative. The values depend on parameters that affecting the ampacity.