TECHNO – ECONOMIC STUDY OF 33 KV DISTRIBUTION LINES USING AERIAL BUNDLE CABLE AND SPACER CABLE

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This project report is dedicated to my husband, Anthony Kasrul Anak Pulai .I give my deepest expression of love and appreciation for the encouragement and support that you gave and the sacrifices you made during this master program.

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ABSTRAK

Syarikat utiliti kuasa biasanya memilih reka bentuk kabel yang lebih baik berdasarkan aliran kuasa dan keputusan analisis ekonomi. Analisis aliran kuasa adalah proses penting dalam menilai reka bentuk dan biasanya dijalankan semasa peringkat perancangan sebelum prosess pembinaan bermula. Ia menganalisis sistem kuasa dalam operasi mantap normal. Walau bagaimanapun dalam kebanyakan kes, analisis yang dinyatakan di atas hanya mengambil kira pelaburan awal dan kos permulaan operasi sepanjang tempoh jangka hayat dengan penilaian praktikal yang tidak terperinci mengenai prestasi elektrik reka bentuk kabel termasuk aliran kuasa, medan elektrik dan ciri-ciri elektromagnet . Penyelidikan ini bertujuan untuk menilai dan membandingkan prestasi elektrik kable aerial dan kabel spacer menggunakan projek sebenar talian pengagihan 33 kV Murum-Belaga dengan menggunakan perisian DIgSILIENT PowerFactory. Ia boleh membantu mempertimbangkan dan membandingkan kos pelaburan awal dan kos operasi bersama dengan tempoh jangka hayat dan prestasi teknikal. Sebagai tambahan kepada analisis ekonomi, analisis aliran kuasa untuk kedua-dua reka bentuk kabel telah dibentukkan dan dilakukan menggunakan perisian. Kajian projek ini mengambil kira pelaburan permulaan dan kos operasi di sepanjang jangka hayat kabel. Kajian telah menemui bahawa prestasi elektrik simulasi seperti analisis aliran kuasa, beban kabel, kesan Ferranti dan kejatuhan voltan kedua-dua sistem kabel menyumbang dalam proses membuat keputusan dengan melengkapkan kaedah penilaian ekonomi seperti nilai semasa bersih (NPV). Setiap faktor akan memainkan peranan penting dalam prestasi ekonomi , ukuran ketidakpastian dan risiko yang terlibat dalam projek. Penemuan kajian projek boleh membawa kepada penilaian yang lebih baik dalam peringkat perancangan untuk memastikan operasi sistem kuasa yang optimum.

ABSTRACT

Power utility companies typically select their preferable cable design based on the power flow and results of economic analyses. The power flow analysis is a crucial process in evaluating the design and typically being carried out as early as in planning stage prior to the construction stage. It analyses the power systems in normal steady-state operation. Nevertheless, in most cases, the aforementioned analyses only take into consideration the initial investment and operational costs of the lines along with their lifetime period with less detail practical evaluation on the electrical performance of the cable design including the power flow, electric field and electromagnetic characteristics. This project aims to evaluate and compare the electrical performance of aerial bundle cable and spacer cable using actual project of 33 kV distribution lines of Murum–Belaga using DIgSILIENT PowerFactory software. The analysis also considers and compares the initial investment and operational costs of lines along with their lifetime period and technical performance. The actual the line configuration and loading at selected respective site was used in the simulation. In addition to the economic analysis, the power flow analysis for both cable designs was developed and performed using the software. The project takes into consideration the initial investment and operational costs of lines along with their lifetime period. It is found that the simulated electrical performances such as power flow analysis, cable loading, Ferranti effect and voltage drop of both cable systems contribute in the decision making process by complementing the economic assessment method such as the net present value. Each factors would play an important role in an economic performance indicator, uncertainty and risk involved in the project. The project findings may lead to a better reliability assessment in the planning stage to ensure optimal operation of the power system.

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LIST OF ABBREVIATIONS

SAIDI	-	System Average Interruption Duration Index
SAIFI	-	System Average Interruption Frequency Index
UV	-	Ultraviolet
HDPE	-	High Density Polyethylene
XLPE	-	Cross linked Polyethylene
PVC	-	Polyvinychloride
PE	-	Polyethylene
A	-	Cross –sectional of conductor
P	-	Resistivity of conductor
GMD	-	Geometric mean distance between conductors
GMR	-	Geometric mean radius of conductors
R	-	Radius of conductor
C_{inv}	-	Investment cost
C_{equip}	-	Unit price of equipment
C_{inst}	-	Installation cost
N_{equip}	-	Quantity of equipment.
C_{FR}	-	Fault repair cost
N_{fault}	-	Number of fault per km
L	-	Length of distribution line
C_{AFR}	-	Average cost per fault
Ω	-	Ohm
AIR	-	Annual installation rate of present value
EBITDA	-	Earnings before interest, taxes, depreciation and amortization
CTR	-	Corporate tax rate;
DPC	-	Depreciation cost.
HV	-	High voltage
LV	-	Low voltage

p.u - per unit

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CHAPTER 1

INTRODUCTION

Electricity is a symbol of imperative condition for developed country in terms of economy and standard lifestyle for citizens economic and population growth, rise in living standards and shift from rural to urban living account .Its high demand calls for high capital investments for the development of power sector infrastructure comprising predominantly generation facilities and transmission and distribution networks.

The development of modernized energy system for rural areas is constantly a considerable responsibility to energy utilities and state for reaching supply of electricity. In most cases, the extension of electricity is either impossible to supply because of geographic allocation, high financial involved and low demand.

Electric cables have evolved by time to time to suit on current technology connecting link between one piece of electrical apparatus or machinery with range of uses, voltage level and cable specifications. Fundamentally, power cables used in distribution purposes consist of circular or compacted type of conductors, depending to the application (Wareing, 2005).

1.1 Background of Study

Rural villages in Sarawak (shows in Figure 1.1) tend to situate along rivers or coasts as they provide the means for transportation and irrigation. For rural areas situated in interior of Sarawak, they are typically accessed via rivers or logging roads. The roads are generally narrow, winding and traversing through hilly terrains and bridges. With limited land access, it is difficult to construct grid lines to rural area and at later stages to operate and maintain them. In addition, it is unavoidable that some rural line will pass through heavily forested area or oil palm estates. The dense plantation requires frequent trimming in an effort to sustain service reliability, resulting in high budget to utilities (Wareing, 2005).

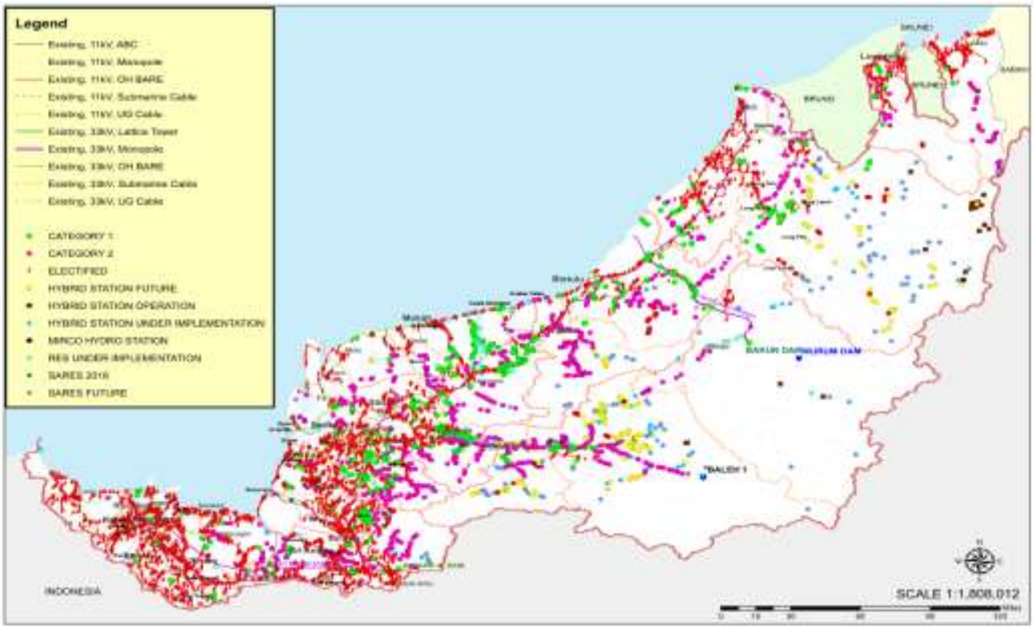

Figure 1.1: Sarawak grid

As a result, expanding coverage of electricity services to rural remote areas via grid connections and maintaining the supply reliability are challenging tasks.

There is no specific line design for rural electrification and the designs typically optimizes based on its effect on environment and cost.

Supply electricity to rural areas have always been associated with poor reliability and difficulty in carrying out operation and maintenance works. Past experiences has taught most utilities the following characteristics about rural lines:

i. Difficult to access
ii. Challenging terrain
iii. Heavy plantation
iv. Radial lines
v. Long lines more than 25km

Individually these factors are contributing to poor SAIDI and SAIFI figures. In additional, due to increasing incidents where rural lines are required to pass through oil palm plantations or heavily forested areas, aerial bundle cable has been increasing deployed with limited length.

1.2 Problem Statement:

Power utility companies typically select their preferable cable design based on the power flow and results of economic analyses Nevertheless, in most cases, the aforementioned analyses only take into consideration the initial investment and operational costs of the lines along with their lifetime period with less detail practical evaluation on the electrical performance of the two cable designs including the power flow, cable loading, Ferranti effect, voltage drop and losses.

1.3 Objectives:

The objectives of the project are as follows:

1. To evaluate and compare the electrical performance of aerial bundle cable and spacer cable using actual project of 33 kV distribution lines Murum – Belaga , Sarawak using DIgSILIENT PowerFactory software .
2. To analyse the initial investment and operational costs of the cable designs along with their lifetime period.
3. To compare the feasibility of spacer cable and aerial bundle cable designs for the Murum – Belaga distribution line

1.4 Scope of Study

By referring to the objectives mentioned above, the limitation and assumption applied in this project is clearly elaborated as the followings:

1. Electrical analysis of overhead line impedances, power carrying capacity, voltage drop and losses, cable loading and Ferranti effect analysed using DIgSILENT PowerFactory software.
2. Economic analysis of investment cost, energy loss cost, fault repair cost and maintenance cost constructed using custom –made of Microsoft Excel template.
3. Both analyses only covers aerial bundle cable and spacer cable design for 33 kV distribution lines of Murum-Belaga, Sarawak

1.5 Project Report Structure

Chapter 1 describes the introduction of spacer cable and aerial bundle cable system. It includes the problem statement, objectives, the scope of this work and the methodology used in completing this project report.

Chapter 2 presents the history, cross section and lines parameters of spacer cable and aerial bundle cable. In addition, it covers economical perspectives and factors involved in costing portion.

Chapter 3 presents research methodology used to analyse technical and economical evaluation for both cables. The economical calculation is described in detail. These calculations are used to perform a commercial assessment and comparison of network expansions through an overall analysis.

In Chapter 4 starts with the validation of overhead line parameters, result output and detail discussion. The technical performance and economical studies were presented and discussed.

Chapter 5 draws the conclusions for the work undertaken are presented and few possible suggestion for future work are highlighted as well.

REFERENCES

Ander Madariaga, J. L. M. I. Z. C. a. O. A.-L., 2013. *Effective Assessment of Electric Power Losses in Three - Core XLPE Cables*, s.l.: IEEE.

Anon., 2013. *IEEE Standard 1973 . Guide for planning and desigining transition facilities between overhead and underground transmission lines,* s.l.: s.n.

Anon.,2017.*WorldDataAtlas.*[Online]Availableat:https://knoema.com/atlas/Malaysia /Inflation-rate[Accessed 2017].

Ariffin, I. F., 2014. *The Challenges in Developing and Implementing the Medium Voltage Aerial Bundled Cable System in TNB Distribution Network,* s.l.: Power Cables & Switchgear Forum – IDC Technologies.

Azim Nowbakht, M. A. M., 2015. *Presenting A New Method To Estimate The Remaining Life of Aerial Bundled Cable Network.* Lyon, s.n., p. 0112.

Baouford, J. D., n.d. *Spacer Cable Reduces Tree Caused Customer Interruptions,* s.l.: s.n.

Boyd, A. a. J., 1965. *Bundle-Conductor-Spacer Design Requirements and Development of "Spacer-Vibration Damper"9*, Toronto: IEEE Transactions of Power Apparatus And Systems .

David Afamefuna*, I.-Y. C. D. H. J.-Y. K. a. J. C., 2014. *Techno-Economic Feasibility Analysis on LVDC Distribution System for Rural Electrification in South Korea*, s.l.: J Electr Eng Technol Vol. 9.

F.M. Gatta∗, A. G. S. L. M. M., 2011. *Steady-state operating conditions of very long EHVAC cable lines: Two case studies,* s.l.: Elsevier.

Gajurel, A., 2015. *Performance Based Contracts for Projects.* s.l.:Springer.

Getachew, S. A. F. a. L., 2011. *Cost and reliability comparisons of underground and overhead power lines,* Madison: Elsevier.

Hardy, D. C. R. B. B. J., 2007. *Transmission and Distribution Electrical Engineering, Third Edition.* s.l.:Elsevier.

Hur, D., 2012. *Economic Considerations Underlaying the Adoption of HVDC and HVAC for the connection of an Offshore Wind Farm in Korea,* s.l.: J.Electr Eng Technol.

I.Sarajcev, M. &. I., n.d. *Calculation of losses in electric power cables as the base for cable temperature analysis,* Croatia: Faculty of Electrical Engineering, University of Split, Croatia & Energy Institute Hrvoje Pozar Zagreb, Croatia.

IEEE, 2003. *Reliability methods,* s.l.: The IEEE Gold Book Standard Network.

J.J.S. Oliveira', W. P. R. F. A. R. F. J. C. E. N. E. D. F. A. C. A. A. R. O. L. C., 1996. *The Aerial Bundled Cables (ABC) and the Characteristics of its Semiconductive Shield,* San Francisco: IEEE Annual Report - Conference on Electrical Insulation and Dielectric Phenomena.

Jae-Han Kim, J.-Y. K. ,. J.-T. C. ,. I.-K. S. ,. B.-M. K. ,. I.-Y. C. ,. J.-H. C. ,., 2014. Comparison between Underground Cable and Overhead Line for a Low-Voltage Direct Current Distribution Network Serving Communication Repeater. *Energies,* pp. 1656-1672.

J, L., 2007. *A Comparison of the Electricity Distribution Investment Strategies.* Austria , 19th International Conference on Electrical Distribution .

Ken Barber, G. A., 2013. Insulation of Electrical Cables Over the Past 50 years. *IEEE Electrical Insulation Magazines.*

Lauer, M., 2010. *Methodology guideline on techno economic assessment (TEA),* s.l.: s.n.

Lehtonen, G. M. H. a. M., 2007. *Covered-Conductor Overhead Distribution Line Modeling and Experimental Verification for Determining its Line Characteristics.* Johannesburg, s.n.

Li Ren, Y. T. J. S. L. L. J. L. a. S. C. C., 2009 . *Techno-Economic Feasibility Study on HTS Power Cables,* s.l.: IEEE.

Mauricio R Soares, F. R. B. N. a. L. D. C., 1996. *Spacer Cable and ABC Distribution Line : A long term analysis,* s.l.: IEEE.

Ming-Bin Li, C.-T. S. ,. C.-L. S., 2008. The impact of covered overhead conductors on distribution reliability and safety. *Electrical Power and Energy Systems.*

Min-Hung Chou, C.-L. S. S. M. I. Y.-C. L. S. M. I. H.-M. C. P. L. F. I. a. P. (. C. L. S. M. I., May / June 2017. *Voltage-Drop Calculations and Power Cable Designs for Harbor Electrical Distribution Systems With HighVoltage Shore Connection,* s.l.: IEEE Transactions on Industry Application.

S.P.Zhu, J. L. K., 1995. *A PC -Based Tool to calculate voltage drops and select cable for final subcircuits,* Singapore: IEEE.

Saha, M. D. a. T. K., n.d. *The Reliability and Power Quality Performance of Overhead Lines –with reference to the Electrical Properties of Wood and Covered Conductors,* Queenland : s.n.

SEB, 2002. *Overhead line Construction Manual,* s.l.: s.n.

SEB, 2016. *Covered Conductor Construction Manual,* s.l.: s.n.

SEB, 2017. *Cost per KM for 33kV Aerial Bundle Cable,* s.l.: s.n.

Srinivasa Kishore Teegala, S. K. S., 2015. Optimal costing of overhead power transmission lines using genetic algorithms. *Electrical Power and Energy Systems,* pp. 298-308.

Tesfay, K., 2014. *Study and Evaluation of the Reliabilty and Design of Power Distribution System: Case Study Addis Ababa Power Distribution,* s.l.: s.n.

Thomas Novak, S. M. I. J. B. J. S. S. M. I. a. J. L. K. S. M. I., 2004. *The Effects of Cable Capacitance on Longwall Power Systems,* s.l.: IEEE Transactions on Industry Applications .

Ujjwal Karki, D. G. Z. P., 2015. *Reactive Compesation of Overhead AC Transmission Lines Using Underground Power Cables,* s.l.: Department of Electricl and Computer Engineering Michagan State University.

Wareing, J., 2005. *Report on Covered Conductor System for Distribution,* s.l.: EA Technology.

Willaim Isley, J. D. F. R., 1996. *Insulated Aerial Conductors-The Australian Experience Over the Last 10 Years.* Kuala Lumpur , s.n.