Design and Construction of Transmission Lines

Teboho Richard Lekeno (1130992)

***Abstract*— This paper showcases the details of vacation work undertaken at Eskom headquarters, Megawatts Park at Sunninghill over a period of six weeks. The vacation work was carried out under transmission division within the technology group. The vacation work was well structured to include design and construction of transmission lines. Students were able to learn and explore how overhead power lines are designed and constructed taking into consideration conductor selection, insulation, tower selection, lightning protection, stringing etc and how different engineering disciplines collaborate together to create a cost-efficient and reliable solution.**

I. INTRODUCTION

Section II gives a brief background of the genesis of Eskom and how the company is structured. Section III discusses the design and construction of overhead power lines where the building blocks are profiling, conductor and insulator selection, grounding and lightning protection. Section IV discusses the professional ethics, social and economic issues.

II. BACKGROUND

Eskom is a parastatal founded in 1923. It generates approximately 95% of the electricity used within South Africa and it is part of the top seven in terms of power generation capacity. The company has over 48 628 employees. The company has departments that work together to achieve a similar goal of providing electricity to its consumers in quality and reliability. The Generation department is responsible for operations of power plants to produce electricity, then the Transmission division transmits the power all over the country to substations. The Distribution department then steps down the voltage according to clients needs. Figure 1 in the Appendix shows the hierarchy diagram of the company.

III. DESIGN AND CONSTRUCTION OF OVERHEAD POWER LINES

Tower and foundation designing are requirements of transmission line completion, due to the nature of their work not being part of electrical engineering, students vacation work program did not dwell much on those disciplines thus they are not included in this section.

A. Profiling

The design of the transmission line commences with profiling, whereby the path to transport power from point A to B should be obtained and must be cost-efficient. The company may save a lot of money in terms of conductors and structures if the path would be straight-line between two points but sometimes this goal is unattainable since Eskom may not have rights to land required. It was observed that the company failure to acquire the land, result mostly in areas such as farming land, heritage sites, wetlands etc which are protected.

B. Conductor Selection and Optimisation

The conductor of the overhead power line is considered the most essential component since it responsible for carrying electrical power and its cost should prioritize $[1]$. It was discovered that there is an innumerable disposition of accessible conductor and structure pair to select but considering the environment and electricity, a few ranges are acceptable. The following key steps are used at Eskom for conductor selection.

1) Load requirements: A conductor cannot be selected without knowing the current and voltage to be imposed on it. equation 1 and 2 below are used the area (A) for load transfer capability of a conductor and ampacity ratings (I_{AMP}) of the conductor.

$$A \geq \frac{S_{MAX}}{\sqrt{3} \times V_L \times CD} \times 1000 \tag{1}$$

$$I_{AMP} \geq \frac{S_{MAX}}{\sqrt{3} \times V_L} \times 1000 \tag{2}$$

where S_{MAX} is the maximum load to applied to a conductor, CD is conductor current density and V_L is the line voltage.

Equation 1 shows that using a conductor with low current density to transmit high power will result in a thicker conductor of that CD to achieve the goal.

2) Corona limits and EMF: According to $[4, 5]$ it was learned that exposure to the electric and magnetic field are harmful to human and animal well-being. It was observed that Eskom's line designers always limit such fields considered harmful which complies with the authoritative international standards $[2, 3, 4, 5]$.

It was observed that the corona performance of conductors is obtained using features such as conductor diameter, the altitude of the transmission line above sea level, energized voltage, conductor bundle configuration, and tower design.

The following equations assists in selection of a good conductor with less corona losses:

$$E_{MAX} = \frac{q}{2 \times p \times e_a \times N_b \times r} \tag{3}$$

$$E_C = 30 \times m \times d \times (1 + \frac{0.301}{\sqrt{d \times r_e}}) \tag{4}$$

where E_{MAX} is the maximum electric field strength on the surface of the conductor bundle and E_C is the Corona inception filed strength. The Corona inception field strength must be 5% higher than the maximum electric strength to limit Corona formation.

3) Suitable conductors and structures: It was observed that for reliability and quality selection of a conductor, 3-5 different conductors are selected and later a suitable one is selected.

4) Line parameters: Electrical line parameters such as resistance (R), reactance (X) and susceptance (B) for each conductor are determined and used for line modeling. These parameters allow obtaining of line losses and line impedance. The line impedance should be must matched with the existing network characteristic/surge impedance [6].

5) Cost of line losses: Most of the Eskom's line operation cost is due to line losses cost especially when compared to maintenance cost [7]. Most of the line losses occur as a result of its resistance, the loss is calculated by the equations below:

$$L_R = I^2 R \times 8760 \times N_{ph} \times L_f \times 10^{-3} \quad (kWh/km/year) \tag{5}$$

$$C_L = C_m \times L_R = C_m \times I^2 R \times 8760 \times 3 \times L_f \times 10^{-3} \tag{6}$$

where I is the phase current in Amperes, R is the resistance of the conductor at 50Hz, N_{ph} is the of phases and L_f is the loss factor. C_L denotes the life cycle annual cost $(R/km/year)$, C_m is the marginal cost of electricity (R/kWh), ρ is the resistivity of the conductor $(\Omega\text{mm}^2/km)$ and A is the cross-sectional area of the conductor (mm^2).

Equation 3 and 4 aforementioned shows that selecting a large conductor result in high installation cost but later leads to lower life-cycle cost.

6) Maintenance: Different conductors lead to different maintenance cost. The weight and diameter of the conductor determine the type of structure to be used as well as insulation. Conductors weighing more result in the requirement of a strong structure or less span between structures during stringing, to prevent the conductor from snapping due to tension which tends to introduce costly foundation budget.

7) Optimal solution: The electrical engineer assimilates all factors aforementioned using a computer program to obtain an optimal conductor based on the reliability and the above factors.

Figure 2 in the Appendix shows a summary of the conductor selection process.

C. Insulator Selection, Grounding, and Lightning Protection

Most of transmission line faults occur due to a breakdown of insulation. Insulators are important as they prevent direct contact between phases and between any transmission phase and the structure/tower.

1) Major Factors of Insulation Breakdown: Birds have the largest contribution, especially with their streamers. It occurs when a stream of liquid excreted by the bird while at ground potential approaches the hardware thus breaking the insulation gap between the live-line and the tower resulting in a flash-over and damage of the hardware. The nest they build on the insulators may contain conductive material which starts the insulation breakdown.

Most transmission lines have shielding ground conductors from lightning. In most cases, the resistance of the soil is not less enough to allow the lightning current to be drained to the ground. This result in high voltage rise in the structure in the tower which breaks the insulation gap provided by the insulator and enter the live-line stream causing distortion.

Figure 3 in the Appendix shows percentage contributions factors causing line distortions and insulation breakdown.

2) Frequently used to limit insulation breakdown: The company uses surge arrests to protect the transmission line from the high current generated by the lightning. It is connected between a live-line and the tower, it acts as an open switch during normal conditions and when the lightning brings distortion this hardware detects that high frequency then circuit the line with the structure thus taking the high current directly to the ground. The device switches off again when the frequency of operation is normal./newline

IV. PROFESSIONAL ETHICS, SOCIAL AND ECONOMICAL ISSUES

Collaboration is an important aspect of the working environment. It was observed that this is strengthened by weekly meetings held, whereby the staff of transmission lines division gives a presentation of the project they are currently solving and their weekly plan for it. After presentations, an open discussion is held where possible solutions to assist the presenter are suggested. This is a symbol of transparency within this working environment and quality of work to notice unity realizing Eskom's goal of providing efficient-reliable transmission of electricity throughout the country.

The division has an annual team building event where the staff members fully introduce themselves. The similar approach is applied to vacation work students, they perform informal introduction to each particular engineer and in return, the engineer also introduces itself and elaborate on the nature of work he/she does.

Eskom is currently experiencing financial problems whereby retrenching of employees is observed within the company to minimize their cost. It was also noted that the probabilities of students to get employment after graduation are slim unless the company survives depression stage it is currently involved in. The economy of South Africa depends on power generated by Eskom, in order for it to survive it is possible that there will be an exponential increase in the price electricity.

V. Conclusions

It was interesting to notice a portion of work done in the classroom being applied to the working environment such as Eskom. The vacation work did not only provide practical and theoretical learning of electrical engineering but it also gave exposure to the importance of teamwork.

References

[1] D. Dama, et al., "Conductor Optimisation for Overhead Transmission-Lines", in *Proc. IEEE Int.* Conf. *Power Engineering Society Inaugural Conference and Exposition in Africa* , 2005.

[2] A.C. Britten, et al., "Radio interference, corona losses, audible noise power-frequency electric fields as factors in the design of Eskom's 765kV lines in *Proc. IEEE Int.* Conf. *Cigre Regional Conference* , Johannesburg, October 1987.

[3] A.C. Britten, et al "The compaction of conductor-to-tower clerances of Eskom's 765kV transmission lines", in *Proc. IEEE Int.* Conf. *Cigre Symposium, Leningred* , June 1991.

[4] Assessment of health effects from exposure to power-line electric and magnetic fields, NIEHS Working Group Report, US Department of Energy, August 1998.

[5] ICNRP, "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields", in *Proc. IEEE Int.* Conf. *International Commission of of Non-Ionizing Radiation Protection* , Oberschlesshein, 2000. 1991.

[6] J.J Jordaan, "Methods of Selecting Best-Suited Conductor/Structure Combination for Sub-Transmission Lines Based on Specific Network and Environmental Conditions", *Technology Quality Department, Eskom Distribution*, P O Box 36099, Newlands, 0102, South Africa.

[7] Eskom. Transmission Licensee. Multi-Year Price Determination (MYPD 4). September 2018. South Africa, [Online] Available from: http://http://www.nersa.org.za [Accessed 17 February 2019]

Appendix

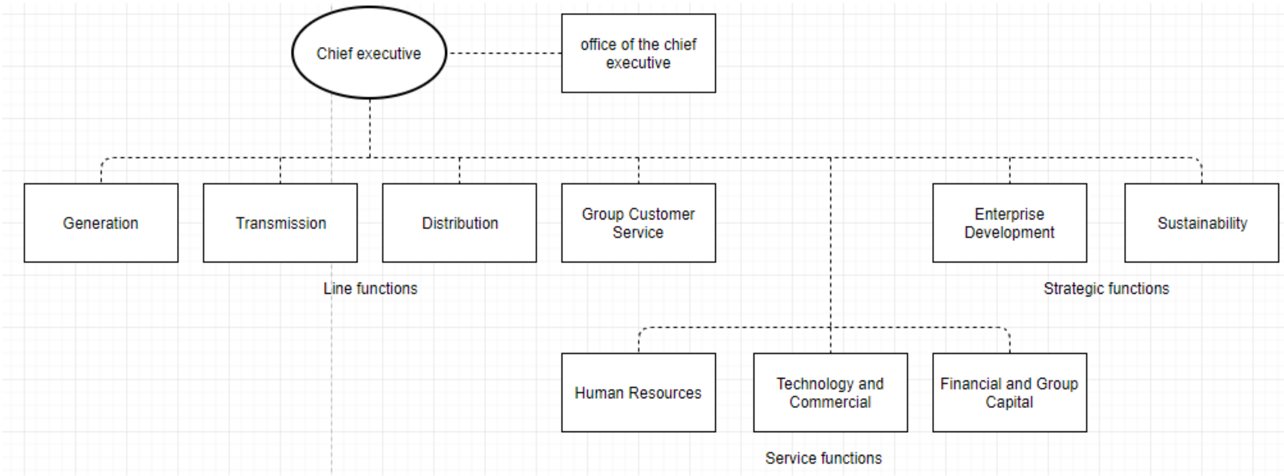

Figure 1: The Eskom's hierarchy of departments.

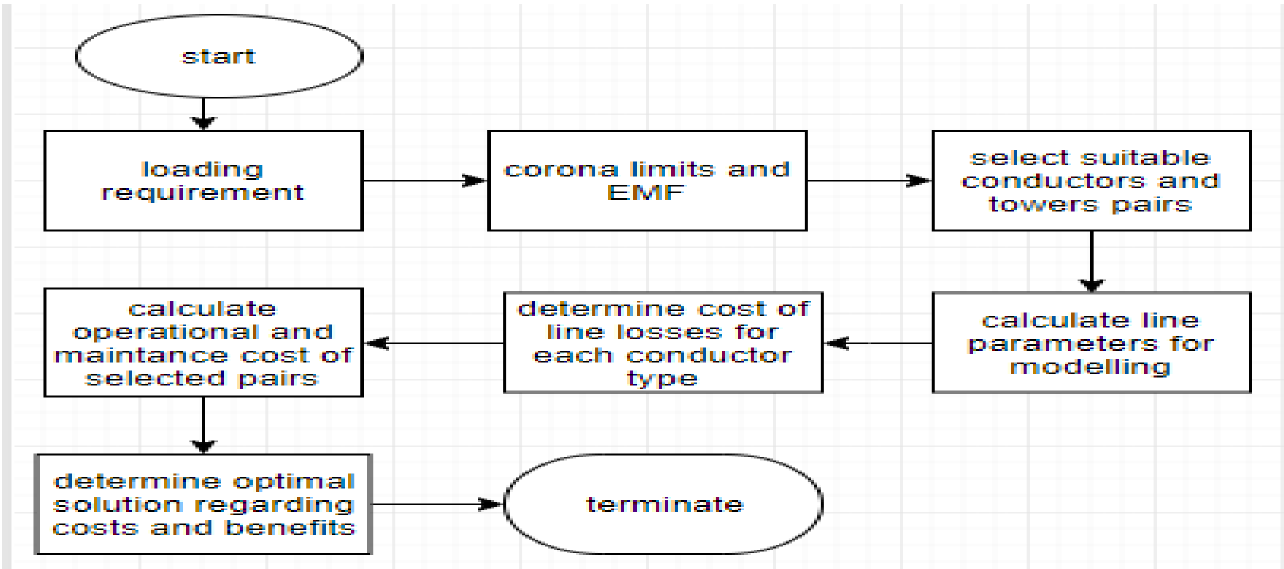

Figure 2: The conductor selection process.

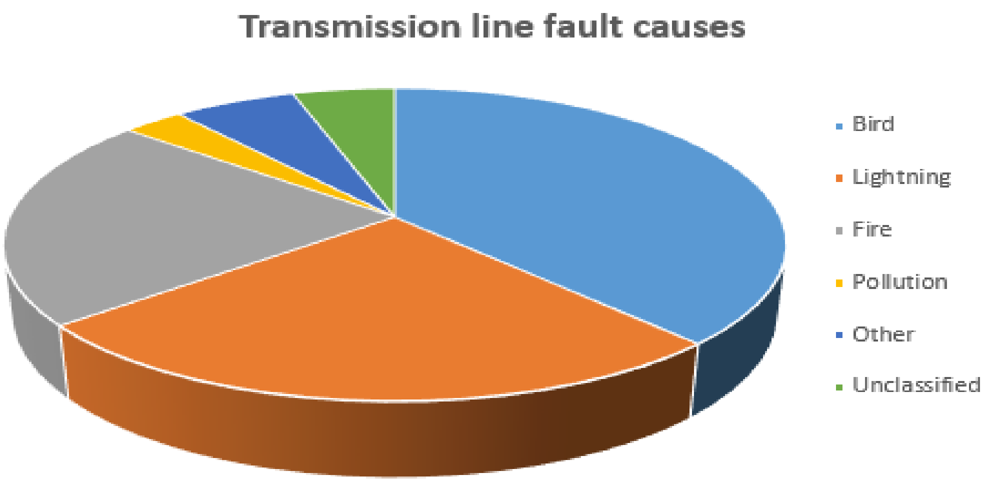

Figure 3: Transmission line fault causes and frequency of their occurrence.