Medium Voltage Technical Loss Reduction Strategy for Distribution Networks

Case Study: UMEME LTD Medium Voltage Distribution Network.

May 2016

Irumba Oscar
Department of Computer and Electrical Engineering,
Makerere University,
College of Engineering, Design, Art and Technology,
Kampala, Uganda

Tushabe Catherine
Department of Computer and Electrical Engineering,
Makerere University,
College of Engineering, Design, Art and Technology,
Kampala, Uganda

***Abstract*— Technical losses are attributed to the physical properties of the components of the power system equipment. This paper presents a study aimed at determining an appropriate strategy to reduce the medium voltage (MV) technical losses in distribution networks. A case study of six UMEME MV feeders was considered. Technical losses per feeder were determined by rigorous calculations and simulations implemented using Dig SILENT Power Factory software. Causes of the current high MV technical losses, current methods used to reduce these losses, and a conclusive technical loss reduction strategy for the MV network have been expounded.**

Keywords* — *Technical losses, After Diversity Maximum Demand, technical loss reduction strategy.

I. INTRODUCTION

The Distribution network in Uganda, run by UMEME roughly consists of over 60 33/11 kV substations, over 30,000km of 11kV and 33kV lines serving over 12,000 distribution transformers supplying up to 10,000km of LV network with a customer base of over 600,000 customers with a peak demand of 570MW and an annual energy consumption of 3000GWhrs.

Electricity loss has a direct impact on the utility's bottom line and hence, it is a key component in measuring the efficiency and financial sustainability of the power sector. Power generated at power stations passes through large and complex networks made of overhead lines, cables, transformers and other equipment that are not a hundred percent efficient. This inefficiency in such equipment is the origin of power system losses.

Power losses can be technical or non-technical where by Technical losses are naturally occurring losses in power system caused by the physical properties of the components of the system whereas non – technical losses are those attributed to power theft [5] [6].

II. METHODOLOGY

A. *Scope*

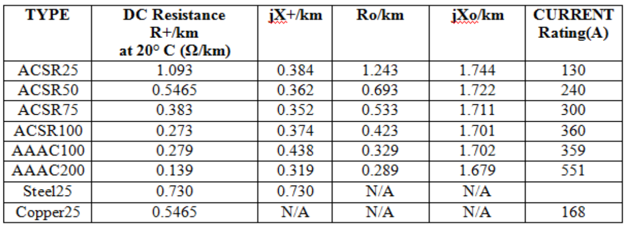
Random and convenience sampling methods were used to select which feeders to concentrate this loss reduction study on from a summary of high loss MV feeders as per the July - October period of 2015 on the UMEME MV network. In order to have a fair coverage of the MV distribution network, the feeders were chosen on the basis of the feeder length as shown in table 1.

Feeder	Category	Length(km)
Nakulabye – Namungoona 11kV	Short	3
Kiriri – Mityana 33kV	Medium	35
Nakifuma – Mukono 33kV	Medium	45
Namasagali – Kamuli 11kV	Medium	45
Upper Ring Masaka 11kV	Long	250
Busunju – Hoima 33kV	Long	180

Table 1: Sampled MV feeders

B. *Data Requirement*

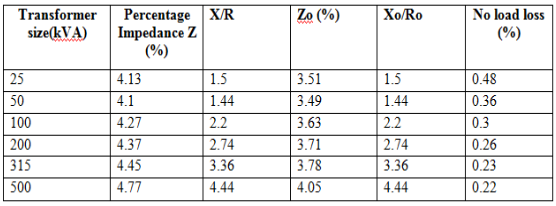
A large amount of data was required as input in Dig SILENT Power Factory software in order to calculate losses of the chosen sample of MV feeders. These had to be modeled 'as built' to precisely determine the technical loss levels. MV Feeder/Line Raw Technical Data Inputs were extracted from equipment manufacturer's catalogues and the UMEME's Geographical Information System (GIS). UMEME uses British Standard overhead conductors whose parameters are as shown in table 2.



TYPE	DC Resistance R+/km at 20° C (Ω/km)	jX+/km	Ro/km	jXo/km	CURRENT Rating(A)
ACSR25	1.093	0.384	1.243	1.744	130
ACSR50	0.5465	0.362	0.693	1.722	240
ACSR75	0.383	0.352	0.533	1.711	300
ACSR100	0.273	0.374	0.423	1.701	360
AAAC100	0.279	0.438	0.329	1.702	359
AAAC200	0.139	0.319	0.289	1.679	551
Steel25	0.730	0.730	N/A	N/A	
Copper25	0.5465	N/A	N/A	N/A	168

Table 2: Conductor specifications/parameters.

MV/LV Transformer Raw Technical Data Inputs in table 3 were obtained from UMEME's GIS and the planning department.



Transformer size(kVA)	Percentage Impedance Z (%)	X/R	Zo (%)	Xo/Ro	No load loss (%)
25	4.13	1.5	3.51	1.5	0.48
50	4.1	1.44	3.49	1.44	0.36
100	4.27	2.2	3.63	2.2	0.3
200	4.37	2.74	3.71	2.74	0.26
315	4.45	3.36	3.78	3.36	0.23
500	4.77	4.44	4.05	4.44	0.22

Table 3: MV/LV transformer sizes, No load loss (%) and Percentage Impedance Z (%)

C. *Distribution transformer load estimate.*

Due to lack of meters on UMEME distribution transformers, the After Diversity Maximum Demand (ADMD) method was used to estimate all transformer loads. [18] I.e. The ADMD of N number of consumers is determined by:

$$\text{ADMD} = \frac{\mathit{Maximum\ Demand\ of\ N\ consumers}}{N}\ (\text{kVA})$$

The Load at a given transformer is determined by obtaining the product of the ADMD and the total number of domestic supply points (DSPs) or consumer metering points on the distribution transformer.

$$\text{Transformer load} = \text{ADMD x DSPs (kVA)}$$

D. *Procedure for MV Line Technical loss calculation.*

The power losses of each feeder conductors were obtained on the basis of the loading on the feeders, resistance, size of each feeder conductor, route length of each feeder and maximum current drawn from each feeder conductor as follows;

- First, the current per phase of a modelled feeder was determined as;
  Current per phase = section loading (%) * rated current of conductor
- Determine the conductor resistance of that phase as;
  Resistance (R) of a given length (L) of a conductor type = L * r
- Calculate the phase conductor power losses as;
  Line losses $P_L = 3\ (I^2R)$
- Determine the total power losses of the feeder as a summation of all the power losses in the conductor sections. i.e.
  Total power line losses $P_T = \sum P_L$ for all subsequent conductor sections of the feeder.

Where: I is the single phase current,
R is the resistance of a conductor,
r is the resistivity of a particular type of conductor,
L is the length of the conductor.

Note: In cases where feeders are highly branched, it's practical to put the feeder load and branching factors into consideration to obtain accurate technical loss calculations.

The branching factor is an empirical factor that accounts for the variability in feeder topology, current density and load diversity i.e. it reflects the characteristic branching of MV feeders [1].

E. *MV/LV transformer technical losses calculation.*

A look up table method was used to determine MV/LV distribution transformer technical losses i.e. no load and load losses. This approach is based on a tabulation of 'typical' Technical losses by transformer utilization. The tabulation was developed for UMEME's distribution transformers and was used to determine the losses of the transformers of feeders in the case study.

Procedure for MV/LV Distribution Tx Technical loss calculation.

- First, the MV/LV Distribution transformer utilization on its kVA capacity is determined from the MV feeder load flows using DIgSILENT.
- From table 4 , look up the total technical loss figure that matches the MV/LV Distribution transformer utilization on its kVA capacity
- Using the No load loss (%) from Table 3 corresponding to a given transformer's kVA capacity, determine the no load and load losses of the MV/LV distribution transformer.

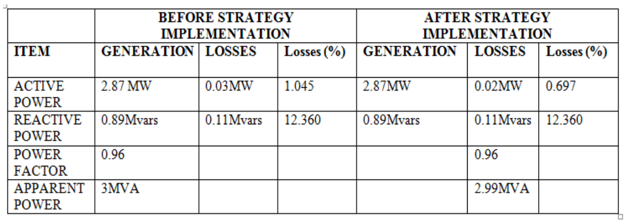
III. CASE STUDY RESULTS AND OBSERVATIONS

a) Nakulabye – Namungoona 11kV Feeder

Component	Power Loss(W)	Power Loss (%)
MV Conductors	20,590. 81294	0.717
MV/LV Txs	9,428	0.329
Total	30,018.81294	1.046

Table 4: Summary of NAM – NAK 11kV Line and Transformer losses before strategy implementation.

From Table 4, it was observed that the MV conductors were the greatest contributor to the technical losses of Nakulabye – Namungoona 11kV feeder (0.717 %) compared to the losses of the MV/LV distribution Txs measured at 0.329 %. The loss reduction strategy that was implemented was re-conductoring using low resistance conductors. The whole length of the feeder i.e. 3km (+10%) was re- conductored using AAAC 200 conductor. The feeder input parameters were not altered. Table 5 shows a summary of losses before and after implementing the strategy.



	BEFORE STRATEGY IMPLEMENTATION			AFTER STRATEGY IMPLEMENTATION		
ITEM	GENERATION	LOSSES	Losses (%)	GENERATION	LOSSES	Losses (%)
ACTIVE POWER	2.87 MW	0.03MW	1.045	2.87MW	0.02MW	0.697
REACTIVE POWER	0.89Mvars	0.11Mvars	12.360	0.89Mvars	0.11Mvars	12.360
POWER FACTOR	0.96				0.96	
APPARENT POWER	3MVA				2.99MVA	

Table 5: Summary of active and reactive power losses

b) Namasagali - Kamuli 11kV Feeder

Component	Power Loss(W)	Power Loss (%)
MV Conductors	5,401	1.742
MV/LV Txs	4,599	1.484
Total	10,000	3.226

Table 6: KAM-NAM 11kV Line and Tx losses before strategy implementation.

Technical loss reductions for the above feeder were achieved through feeder re-conductoring because the utilization factor of the MV/LV distribution transformers was averagely low. A length of about 37km (+10%), was re - conductored using AAAC 200 conductor to achieve loss reductions in table 7.

Component	Power Loss(W)	Power Loss (%)
MV Conductors	3152.797	1.017
MV/LV Txs	4599	1.484
Total	7751.797	2.501

Table 7: KAM-NAM 11kV Line and Tx losses after re-conductoring.

c) Upper ring Masaka 11kV Feeder

Component	Power loss(W)	Power Loss (%)
MV Conductors	542,276	8.50
MV/LV Txs	67,724	1.062
Total	610,000	9.562

Table 8: MSC – URM 11kV Line and Tx losses before strategy implementation.

For efficient and reliable operation of power systems, voltages and reactive power in the system are maintained within acceptable limits. The allowable voltage drop for UMEME MV feeders is ±10%. Voltage profiles of chosen long feeders were developed to show the voltage drop along the feeders. The voltage drop calculated at some terminals down stream of the Upper Ring Masaka 11kV feeder were up to 35%. This could be due to the long conductor length spanning over a distance of about 250km with about 208 transformers.

It should be noted that transformers always absorb power regardless of their loading and low levels of reactive power cause voltage reductions in electric networks. Figure 1 shows the Masaka – Upper Ring 11kV feeder voltage profile and Figure 2 is a bar graph showing line voltage in magnitude (kV) and maximum voltage voltage drop (line to line) at the remote end terminals obtained from the load flow simulations.

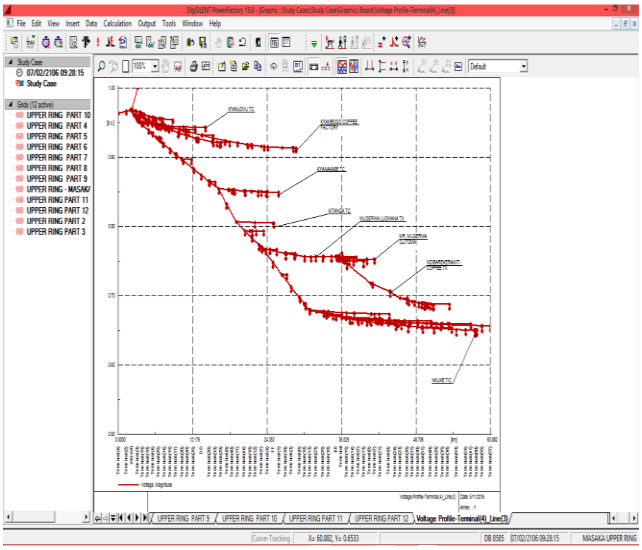


Figure 1: Masaka – Upper Ring 11kV feeder voltage profile.

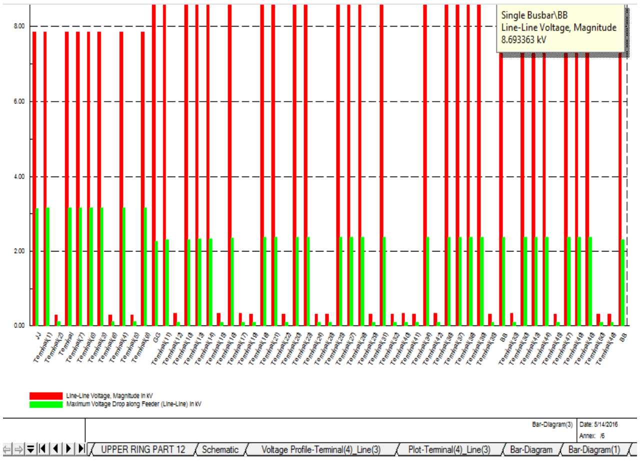


Figure 2: line voltage in magnitude (kV) and maximum voltage drop (line to line)

The technical loss reduction strategy that was implemented was reactive power compensation using pole mounted shunt capacitors of about 2Mvars in total. In addition, conductor sections of steel 25 and ACSR 25 amounting to about 30km out of the 250km were re-conductored using AAAC 200 conductor. The capacitors were put, one at Kyamayimbwa and the other at Kanoni along the feeder.

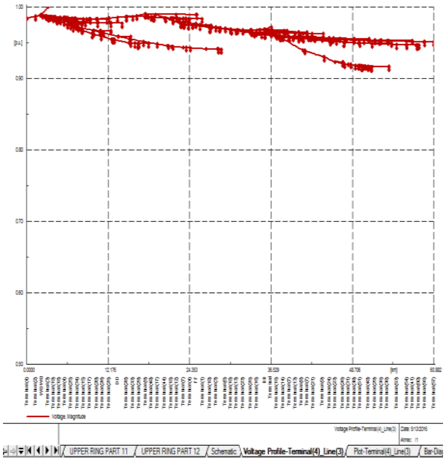


Figure 3: Improved Upper Ring Masaka 11kV Feeder voltage profile.

Figure 4: Line to line voltage (kV) and maximum voltage drop at downstream end of the feeder.

Due to the reactive power compensation by the total 2Mvars capacitors and re-conductoring effort, apparent and reactive power needed from the Masaka Central substation reduced as shown in Table 9.

	Apparent Power	Reactive Power
From Substation	6.05 MVA	0.45 MVArs
From Capacitor	0.86 MVA	2 MVArs
Total	6.91MVA	2.45 MVArs

Table 9: Apparent and reactive power supplied by Masaka central substation and the new capacitor banks.

	before strategy implementation		after strategy implementation	
Item	Losses	Losses (%)	Losses	Losses (%)
active power	0.61 MW	9.562	0.26 MW	3.763
reactive power	0.74 MVArs	28.03	0.48 MVArs	19.592

Table 10: Active and reactive power losses of the Upper Ring Masaka 11kVFeeder

Note: Reactive Power Compensation as a method of voltage control can also be achieved using the following devices,

- Over excited synchronous generators
- Over excited compensators
- Static shunt capacitors
- Static series capacitors
- Static VAr compensators
- Static Compensators(STATCOM)

Shunt capacitors as used in reactive power compensation in the Upper Ring Masaka 11kV feeder were chosen because they are very economical i.e. low cost and their flexibility of installation and operation in that they can be applied at various points on the power system.

The benefits accruing from the addition of capacitor banks onto long distribution feeders include;

- Shunt capacitors in distribution networks are essential for power flow control,
- Leads to system stability improvement.
- Leads to power factor improvement/correction,
- Voltage profile management and
- Losses minimization.

d) Busunju - Hoima 33kV Feeder

Component	Power Loss(W)	Power Loss (%)
MV Conductors	362,487	9.718
MV/LV Tx	27,513	0.738
Total	390,000	10.456

Table 11: Summary of HMA-BUS 33kV Line and Transformer losses before strategy implementation.

This is a 180km(±10%) feeder. Load flow simulation results showed a voltage drop of about 14% at some terminals at the down stream end of the feeder due to high reactive power losses calculated at 14%.

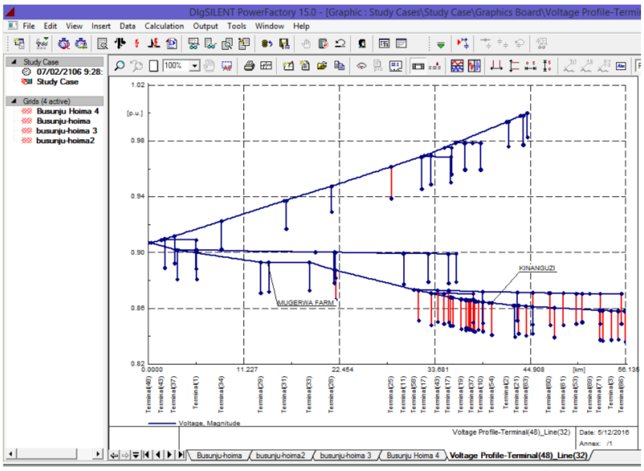


Figure 5: Busunju – Hoima 33kV Feeder initial voltage profile.

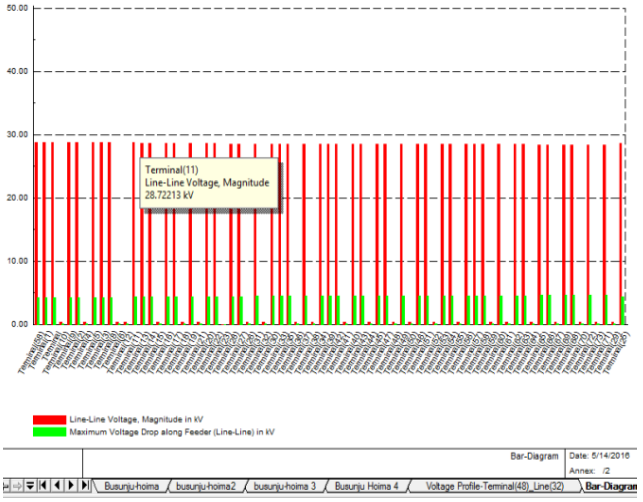


Figure 6: Line to line voltage (kV) and maximum voltage drop along the feeder.

The implemented strategy was reactive power compensation using capacitors of 3Mvars. These were assumed to be 2 pole mounted capacitor banks of 1.5 MVArs each that were placed at terminals of Mugerwa farm and Kananguzi as indicated in Figure 5.

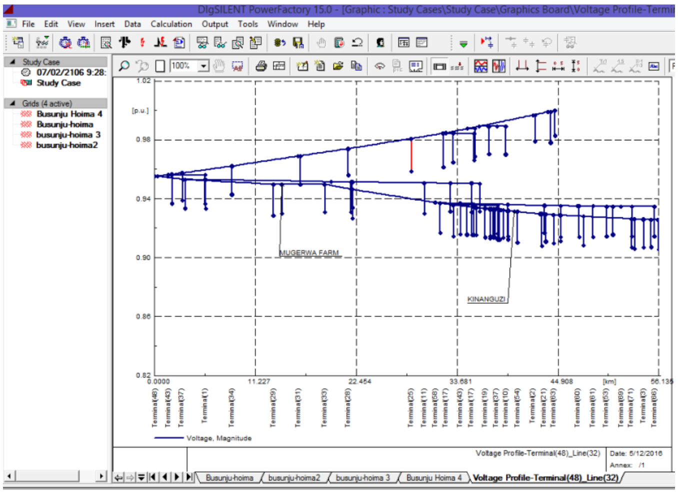


Figure 7: HMA-BUS 33kV Feeder profile after reactive power compensation.

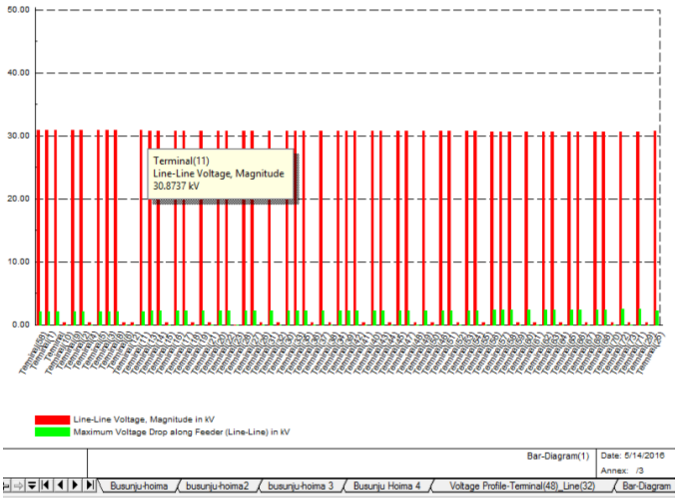


Figure 8: Line to line voltage (kV) and maximum voltage drop along the feeder.

Before Strategy Implementation		
Generation	Losses	Losses (%)
3.5MW	0.39MW	11.14
4.57MVArs	0.64Mvars	14.0
0.63(PF)		

Table 12: Active, reactive power losses and PF of the HMA-BUS 33kV feeder.

After Strategy Implementation		
Generation	Losses	Losses (%)
3.5MW	0.16	4.57
4 MVArs	0.32	8
0.91(PF)		

Table 13: Active, reactive power losses and PF of the HMA-BUS 33kV feeder after addition of capacitors.

IV. MEDIUM VOLTAGE TECHNICAL LOSS REDUCTION STRATEGY

A strategy for reducing Technical losses was developed by simulating changes in the conductors, loads, and voltage for the modeled high loss MV feeders. Modeling was implemented using low resistance conductor types to achieve loss reductions, coupled with reactive power compensation on other loss models. The simulations determined that the opportunity for the Medium voltage technical loss reduction in the distribution network will be achieved as follows:-

i. *Installation of energy meters:*

These should be installed at substation auxiliary transformers to measure the internal consumption and invoice the company to avoid considering substation consumption as losses. Furthermore, energy meters should be installed at all distribution transformers to facilitate acquisition of reliable and accurate data pertaining distribution transformer loading so that power losses can be accurately determined. Survey and identify the defective meters to replace them, and replace meter seals with new tamper-proof ones.

ii. *Medium voltage 33kV and 11kV feeder networks:*

According to the length of the feeders, re-conductoring of sections or the entire length of the short or medium MV high loss feeders with less resistive conductors, and re-conductoring coupled with reactive power compensation on the long high loss MV feeders will reduce losses, increase the MV distribution network capacity, and improve voltage regulation.

V. RECOMMENDATION

For a low cost of implementation and maintenance, the capacitors to be used should be pole mounted capacitors which are installed where reactive power compensation is needed along the MV feeders as compared to having a single bulk capacitor bank at one location.

VI. CONCLUSION

Operating feeders with high technical losses leads to increased financial losses yet a deliberate effort taken by distribution companies like UMEME to cut down on the levels can lead to improved revenue accrual. The cost of the suggested loss reduction measures can be recovered within a short operating period to clear all capital and maintenance costs involved.

VII. REFERECNCES

[1] Emmerton Associates, Umeme Distribution Technical Loss reduction report, Umeme Uganda limited, 2013.

[2] Parsons Brinckerhoff Africa (PTY) Ltd (PB), Study on distribution system losses and collection rates by Umeme ltd Report, Electricity Regulatory Authority (ERA), 24 October 2011.

[3] Norconsult, Output Based Aid (OBA) scheme to reduce distribution losses in Umeme's grid, Electricity Regulatory Authority (ERA), August, 2006

[4] Raúl Jiménez, Tomás Serebrisky, Jorge Mercado, Sizing Electricity Losses in Transmission and Distribution Systems in Latin America and the Caribbean, Inter-American Development Bank 1300 New York Avenue, N.W. Washington, D.C. 20577, Pg10, 2014

[5] Y. Al-Mahroqi, I.A. Metwally, A. Al-Hinai, and A. Al-Badi, Reduction of Power Losses in Distribution Systems, World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:6, No:3, 2012

[6] J.P Navani, N.K Sharma, Sonal Sapra, "Technical and Non-Technical Losses in Power System and Its Economic Consequence in Indian Economy'' IJECSE, Volume1, Pg. 1 – pg. 3.

[7] [Online]. Available: http://electrical-engineering-portal.com/total-losses-in-power-distribution-and-transmission-lines-1 [Accessed 25th December 2015]

[8] [Online]. Available: https://electricalnotes.wordpress.com/2011/03/23/what-is-corona-effect [Accessed 8th January 2016]

[9] [Online]. Available: http://www.electrical4u.com/corona-effect-in-power-system [Accessed 8th January 2016]

[10] [Online]. Available: http://www.electrical4u.com/hysteresis-eddy-current-iron-or-core-losses-and-copper-loss-in-transformer/ [Accessed 2nd Feb 2016]

[11] Isaac Ramalla1, Nithin Namburi, ''Analytical Review of Loss Reduction Techniques in Indian Power Distribution Sector – techno managerial approach", IJRET: International Journal of Research in Engineering and Technology, Volume: 03 Special Issue: 12, Jun-2014**,** Pg. 3.

[12] [Online]. Available: https://en.wikipedia.org/wiki/Joule_heating [Accessed 8th January 2016]

[13] [Online]. Available: https://en.wikipedia.org/wiki/Contact_resistance [Accessed 2nd Feb 2016]

[14] Camille HAMON, Modelling of Technical Losses in the Senegalese Transmission and Distribution Grids and Determination of Non-technical Losses, MS Thesis, Electrical Power System division, School of Electrical Engineering Royal Institute of Technology (KTH) Stockholm, Sweden, December, 2012.

[15] Tamizharasi.P, Anuradha.R, Ayshwarya.A.R, Analysis of Distribution Transformer Losses in Feeder Circuit, International Journal of Innovative Research in Advanced Engineering (IJIRAE)**,** Volume 1, Issue 1, March 2014, pg. 2 – pg. 5.

[16] B.M. Weedy, B.J. Cory, N.Jenkins, J.B. Ekanayake, G. Strbac," Fundamentals of the Economics of Operation and Planning of Electricity Systems" In Electric Power Systems, Fifth Edition, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2012, pp.458.

[17] [Online]. Available www.yourpowergridplan.com [Accessed 2nd April 2016]

[18] Ibrahim S.H.a*, Baharun A.a, Nawi M.N.Mb., Chai C.J.a, Efficient Planning of Electrical Distribution System for Consumers in Sarawak, Malaysia, Department of Civil Engineering, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia December 2014.

VIII. BIOGRAPHIES

IRUMBA OSCAR received his bachelors of Science degree in Electrical engineering from Makerere University, Kampala – Uganda in 2016. Oscar has special interest in acquiring knowledge in the fields of power systems analysis, protection, planning, renewable energy and energy conservation and storage. He is currently a student member of the Uganda Institute of Professional Engineers (UIPE), and a former student member and General Secretary of Makerere Engineering Society (2014 - 2015).

TUSHABE CATHERINE her bachelors of Science degree in Electrical Engineering from Makerere University, Kampala – Uganda in 2016. Catherine has special interest in acquiring knowledge in the fields of power systems analysis, power quality, renewable energy and electronics design.