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Analysis of Technical Power Losses at ILE IFE Distribution Network

Onaopemipo Taiwo

B.Sc., OAU, Ile Ife, Nigeria

Abstract: ***As a result of impedances in Transmission lines, power transformers and distribution lines, as well as metering errors, inaccurate meters, improperly read meters, energy theft and administrative errors, some power losses are incurred at the distribution network. Some of these losses are inevitable and it is desired to bring these losses to the barest minimum to improve the overall efficiency of the network. The Ile Ife Electrical distribution network has been selected as a case study.The Ile-Ife distribution network comprises of three (3), 33/11kV injection substations namely: Ilesha, Ondo and AP. These substations are fed from Ajebandele (132/33kV) which is in turn gets its supply from Osogbo. Each substation supplies various 11/0.415kV from which consumers are fed. For this analysis, the method adopted is the modelling of losses in individual components. This entails obtaining the line diagram for the network, conversion of component values (resistance, capacitance and inductance and impedance) to the respective per-unit equivalents as well as the simulation of the equivalent line diagram using 'Power Systems Analysis Toolbox (PSAT)'. The research aims at improving the efficiency of the network such that its performance in the future can be forecasted.***

Keywords: Distribution Network, PSAT, Efficiency, Power loss, Substation, Line diagram

1. Introduction

Electric power losses in distribution systems refer to the difference between the amount of energy delivered to the distribution system and the amount of energy customers are billed. Energy losses due to Transmission line losses, power transformer losses, distribution line losses as well as low-voltage transformer losses are classified as technical losses. Non-technical losses on the other hand are often attributed to metering errors, inaccurate meters, improperly read meters, unauthorized connections as well as administrative errors.For the case of this research, only technical losses would be analyzed. The components of the network analyzed are the Transformers and distribution lines. The Transformers would be analyzed for Load & No-load losses (using their leakage impedances), while the distribution lines would be analyzed for Resistive, Capacitive and Inductive Reactance. Aluminum conductors of diameters 70mm, 100mm & 150mm are used in this network. The GMD and GMR were used to compute the Inductive and Capacitive reactance. Losses that occur in control devices such as Isolators, Relays and Circuit Breakers are small and negligible. The table below summarizes the components in each Injection substation.

Name of Injection station	Name of Service Area	Number of Transformers
ILESHA	OPA	38
ONDO	ITAMERIN	26
	ITA OSA	21
	FAMIA	19
P 1 & 2	ORONA	13
	PARAKIN	24
	IBADAN ROAD	24
	LAGERE	49

Figure 1: Number of transformers for each Injection Substation

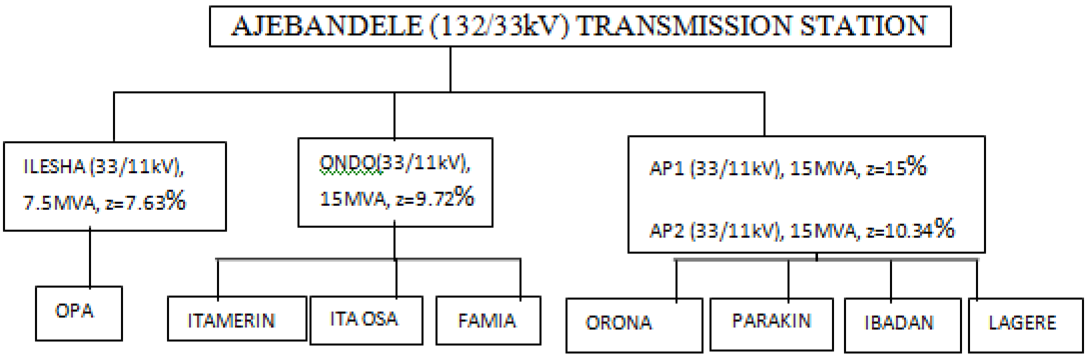
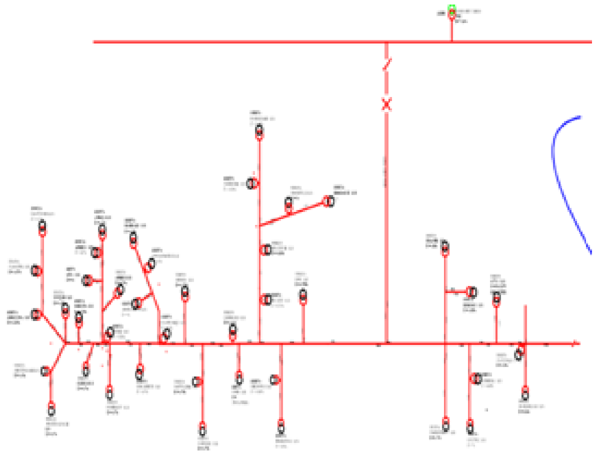


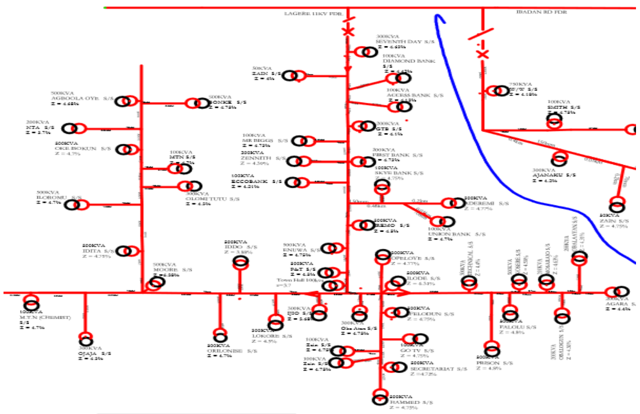
Figure 2: Ile-Ife electric power distribution network chart

2. Methodology

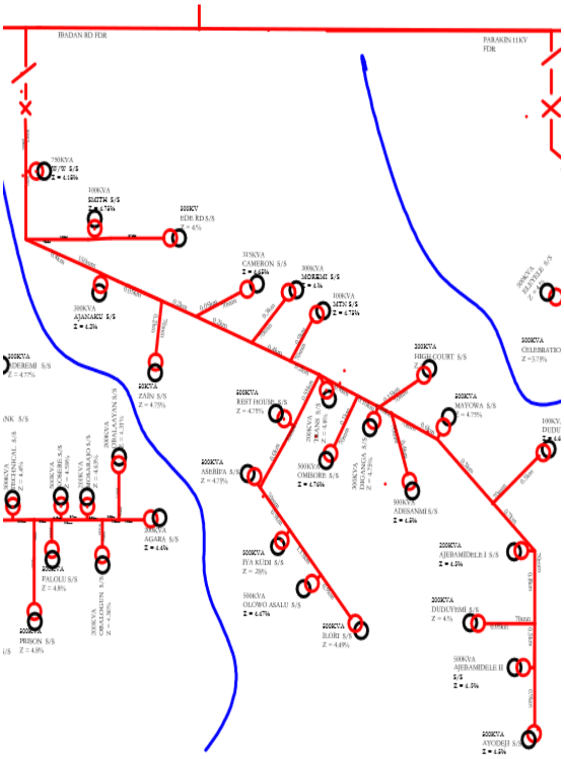
The Line diagram of the network as obtained from IBEDC Lagere is as shown below



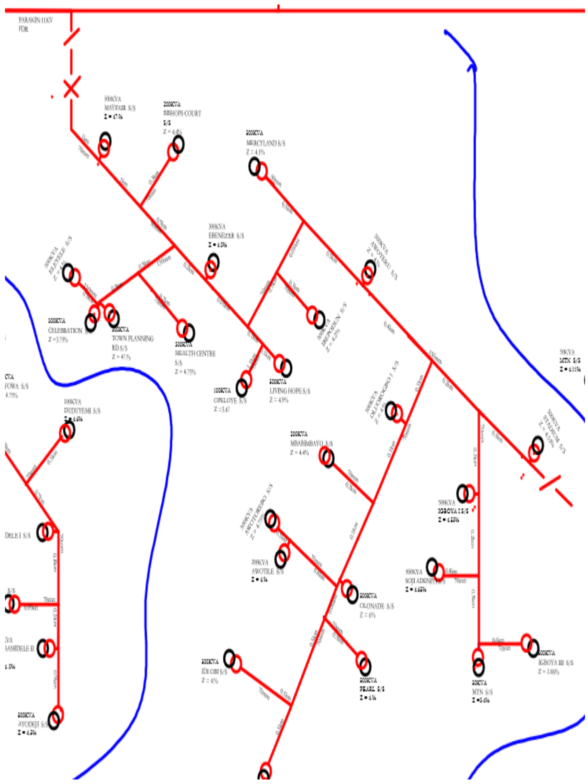
OPA Service Area



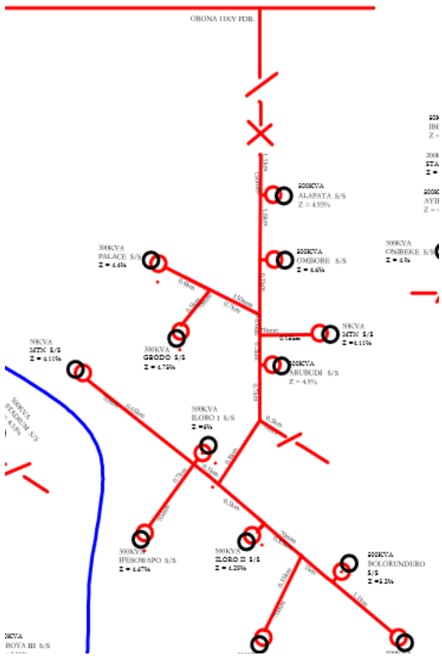
Lagere Service Area



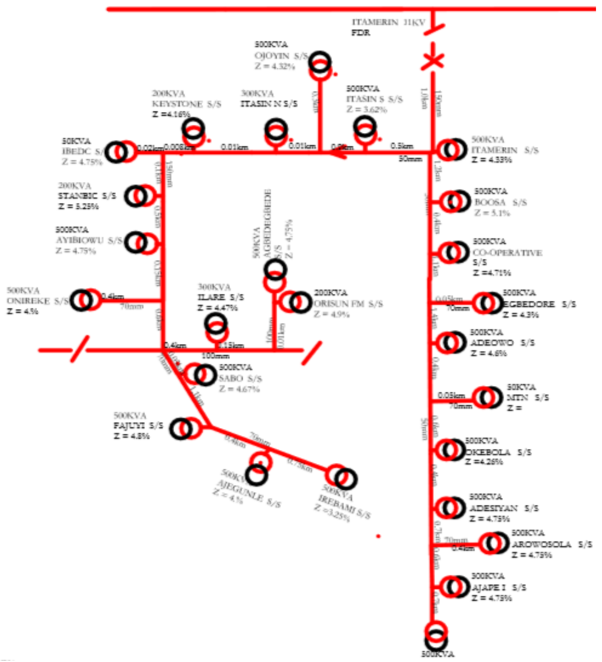
Ibadan Service Area



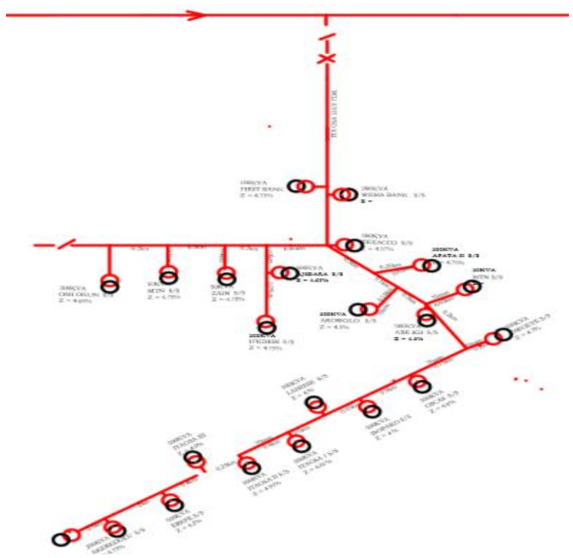
Parakin Service Area



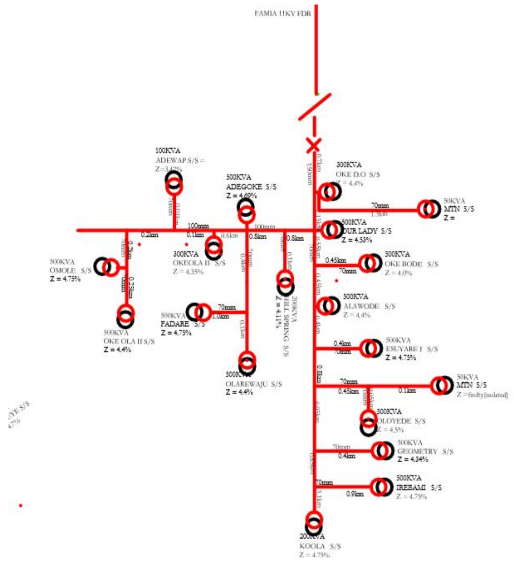
Orona Service Area



Itamerin Service Area



ITA-OSA Service Area



Famia Service Area

2.1 Conversion of Transformer Leakage Impedances to their Per Unit Equivalent

The leakage impedance (in per unit) for each transformer is converted to its new equivalent per-unit value by using base values of 11kV and 10MVA for the network as follows:

$$Z_{new} = \frac{Z_{actual}}{Z_{base_{new}}}$$

$$Z_{pu_{old}} = \frac{Z_{actual}}{Z_{base_{old}}}$$

$$Z_{new} = \frac{Z_{pu_{old}}}{Z_{base_{new}}} Z_{base_{old}}$$

$$Z_{base_{new}} = \frac{V_{base_{new}}^{2}}{S_{base_{new}}}$$

$$Z_{base_{old}} = \frac{V_{base_{old}}^{2}}{S_{base_{old}}}$$

Therefore,

$$Z_{pu_{new}} = \frac{V_{base_{old}}^{2}}{S_{base_{old}}} \times \frac{S_{base_{new}}}{V_{base_{new}}^{2}} \times Z_{base_{old}}$$

With known values of each Transformer's $S_{base\ old}$, $V_{base\ old}$ and $Z_{base\ old}$, the leakage impedance of each transformer can be converted to its new per unit equivalent value.

2.2 Determination of Line Reactance

2.2.1 Determination of Line Resistance

2.2.1.1 Line Description

For easy reference to the line diagram of the network, each junction (point where two or more lines meet) in the network has been labelled and each line, described with respect to the points with which it lies. With the line specifications given (line length and diameter) and with known values of the resistivity (ρ) at different temperatures, the resistance (R) per unit length of each line can be computed at a specific temperature.

2.2.1.2 Line Resistance Determination

In the Ile-Ife electric power distribution network, the AAC (All Aluminum Conductor) is used. The AAC has a resistivity (ρ) of $2.65 \times 10^{-8} \Omega m$ at 20℃ and with known values of the conductor length (l) and conductor diameter (d), the dc resistance per unit length of the conductor can be computed as

$$R_{dc} = \rho \frac{l}{A}$$

$$A = \pi \frac{d^2}{4}$$

From which, the resistance per unit length can be computed as

$$R' = \frac{\rho}{A}$$

2.2.2 Determination of Line Inductance

The inductance of a distribution line is as a result of the magnetic effect of electricity. The conductor sizes in the Ile-Ife distribution network are: 50mm, 70mm, 100mm and

150mm. With the knowledge of the number and sizes (diameter) of strands in each conductor, the GMR (Geometric Mean Radius) for the conductor can be determined. For an AAC with 7 wires (strands) per conductor with each strand having a radius of 'r' (in cm) as shown in Fig 3, the GMR for the conductor can be calculated as follows:

$$GMR = \sqrt[49]{\prod_{K=1}^{7}\prod_{J=1}^{7} D_{KJ}}$$

Where

$$D_{11} = D_{22} = D_{33} = D_{44} = D_{55} = D_{66} = D_{77} = e^{-1/4}r$$
$$D_{12} = D_{23} = D_{34} = D_{45} = D_{56} = D_{67} = 2r$$
$$D_{61} = D_{21} = D_{17} = D_{71} = D_{47} = D_{74} = 2r$$
$$D_{32} = D_{43} = D_{54} = D_{65} = D_{16} = D_{27} = 2r$$
$$D_{72} = D_{37} = D_{73} = D_{76} = D_{57} = D_{75} = 2r$$
$$D_{14} = D_{41} = D_{36} = D_{63} = D_{52} = D_{25} = 4r$$
$$D_{26} = D_{62} = D_{35} = D_{53} = D_{13} = D_{31} = 2\sqrt{3}r$$
$$D_{24} = D_{42} = D_{46} = D_{64} = D_{15} = D_{51} = 2\sqrt{3}r$$
$$GMR = \sqrt[49]{[(e^{-\frac{1}{4}}r)(2r)^{24}(4r)^{6}(2\sqrt{3}r)^{12}]}$$
$$= 2.177r$$

Similarly, with known values of the number and diameter of strands in a conductor, the GMR of conductors with a higher number of strands can be determined.

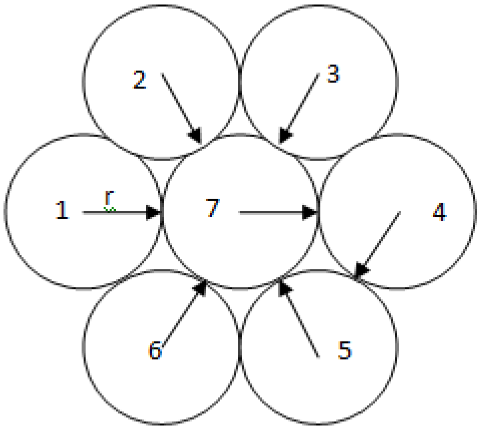


Figure 3: Cross-section of a 7-strand conductor

Similarly, the GMD for a 3-wire distribution network can be determined for the same number of strands per conductor (7), given that the distance between the center of a conductor and the next conductor as 'D'. The arrangement of the conductors in this regard is shown in Fig. 4. The GMD for the arrangement is computed as:

$$GMD = \sqrt[3]{(D)(D)(2D)}$$
$$= 1.26D$$

Having known the GMR and the GMD of the arrangement, the Inductance per unit length of the arrangement can be determined as:

$$L = 2 \times 10^{-7} In\frac{GMD}{GMR} \text{ H/m}$$

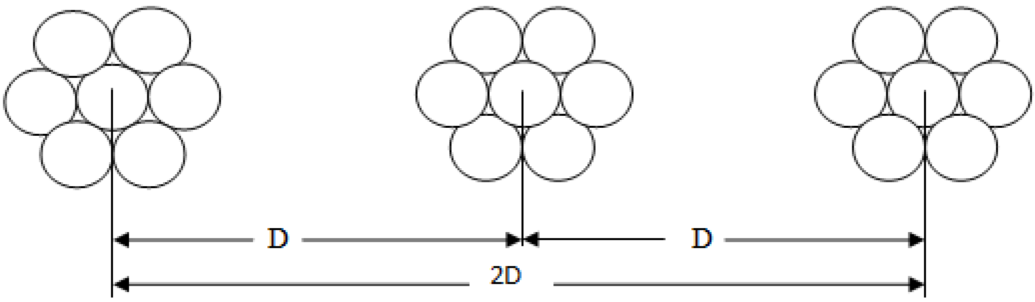


Figure 4: Cross-section of conductors in a 3-wire arrangement

2.2.3 Determination of Line Capacitance

The Capacitance of distribution lines occur as a result of electric fields which are generated when current passes through them. Using the concept of GMD and GMR, the Capacitance per-unit length can be determined as:

$$C = \frac{2\pi\varepsilon_o}{In(\frac{GMD}{GMR})} \text{ F/m}$$

Where ε_o is the permittivity of free space given as 8.854 $\times 10^{-12}$ F/m

2.3 Development of the Equivalent Line Diagram

Having determined the resistance, capacitance and inductance per unit length of conductors, the network can then be represented in terms of the line parameters computed. Since a distribution network consists of Transformers, Transmission lines and loads, the equivalent line diagram of each network consists of: a Slack bus, a PV Generator, Bus bars of different voltage ratings, Transmission lines of different Resistances, Inductances and Capacitances per unit length, Transformers with different leakage impedances as well as constant PQ loads all connected together. After the development of the equivalent diagram comes Simulation. Simulation entails the use of software to determine certain parameters such as voltage, current, resistance in components. Component values can be varied and the parameter variation noted. Conclusions and recommendations can then be made based on results obtained. The software that would be used for the analysis of this project is PSAT (Power System Analysis Toolbox). The PSAT, when used to simulate line diagrams, gives the results which contains information such as:

a) Power Flow Results of each Bus(Voltage in kV, Phase angle in rad, Real power generated in MW, reactive power generated in MVAR as well as Power consumed by each load).
b) Line flows (Real and Reactive power flows as well as Real and Reactive power losses from bus to bus).
c) Total generation (Real and Reactive Power).
d) Total load (Real and Reactive Power).

e) Total losses (Real and Reactive Power, which is the positive difference between the total generation and the total load).

3. Results

Service Area	Total Power received		Total Load		Total Losses	
	Real Power (MW)	Reactive Power (MVAr)	Real Power (MW)	Reactive Power (MVAr)	Real Power (MW)	Reactive Power (MVAr)
FAMIA	5.206	4.433	5.200	3.900	0.006	0.533
IBADAN	0.004	0.069	0.003	0.002	0.001	0.066
ITAOSA	0.014	0.005	0.014	0.011	0.000	-0.006
ITAMERIN	9.540	30.833	8.438	6.329	1.102	24.505
LAGERE	11.815	11.440	11.769	8.826	0.047	2.613
OPA	11.834	9.975	11.800	8.850	0.034	1.125
ORONA	0.042	0.011	0.042	0.032	0.000	-0.020
PARAKIN	7.026	6.404	7.000	5.250	0.026	1.154
Total	**45.481**	**63.170**	**44.266**	**33.200**	**1.215**	**29.971**

Summary of Power flow results

From the results obtained, it can be calculated that the total power lost as a percentage of the total power generated is 2.67% for the real power (P) and 47.44% for reactive power (Q). However, the highest percentage of loss occurs in the Itamerin service area. Only 88.45% of the real power and 20.53% of the reactive power supplied to the feeder is consumed by the load. The feeder also accounts for 90.7% of the real power and 81.76% of the reactive power loss in the system.

4. Recommendations

For the reduction of electric power losses in distribution networks, the following measures should be taken into consideration:

1) It should be ensured that improved core materials be used for the construction of new Transformers dispatched to the network. This is to ensure the reduction of core losses.
2) Methods such as shunt compensation load balancing and reduction of harmonics be used to reduce copper losses and improve Transformer efficiency.
3) Capacitors should be used to reduce line losses. Capacitors supply reactive power which reduces the amount of current in the line and by extension, the I^2R losses are reduced significantly.
4) Also, the use of bundling of conductors should be encouraged. The use of bundling increases the effective cross-sectional area of conductors and as such, the conductor resistance is drastically reduced.

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