Power Flow Investigation of 33kv Distribution Network Using Electrical Transient Analyzer Program: A Case Study of Agip Estate Mile 4, Port Harcourt, Nigeria.

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Abstract- The power flow investigation of Agip Estate Mile 4, 33kv Distribution Network was analysed using Newton-Raphson method was used for the power flow equation while Microsoft Excel was used to justify the current and Electrical Transient analyzer program (ETAP) software was used for the Pre-Upgrade and the Post-Upgrade simulation. The result shows that the power factor, frequency on each Transformers, transformer percentage loading, transformer current, active power, reactive power and apparent power, respectively were determined. The Pre-Upgrade current from Bus to Bus, the nominal voltage of the feeders, respectively was also considered. The post-upgrade of the system was actualized using transformer load tap changer optimization techniques. We concluded that the power system future planners should plan with best operating condition by up-grading the distribution transformers, using transformer load tap changer while feeder bifurcation were found to be effective in improving voltage profile of the weak buses, reduce losses and eliminate over loading from the system.

Indexed Terms- Electrical Transient Analyzer Program (ETAP) Software, Feeder Bifurcation, Transformer Load Tap Changer Optimization Techniques, Pre-Upgrade and Post-Upgrade.

I. INTRODUCTION

Nigerians are faced with acute electricity problems, which are hindering its development notwithstanding the availability of vast natural resources in the country. In the perspective of [1], distribution system is the most noticeable part of a power system and its mostly exposed to critical observation by those who make use of it, the existing distribution system infrastructures are obsolete and weak, this has led to the constant load shedding, overloading and under voltage and erratic power supply experience by consumers at the distribution ends. Substantial amount of power loss and low voltage profile is associated in power system network especially in the primary and secondary distribution system of power supply [2]. Technical losses are a physical consequence of running electrical networks and can be complex, time-varying, stochastic and thus difficult to quantify, they are sensitive to many factors outside distribution network operation (DNO) control with the largest influence being customer behaviour and corresponding power flows, power flows on distribution networks have been relatively predictable in their daily, seasonal and annual variation [3]. The computational problems of power-flow solution can be resolved using load-flow iterative technique – Newton Raphson and Gauss Siedel as contained in [4]. The electricity distribution company in an attempt to mitigate these challenges resulted to an unplanned load shedding, rationing the power supply as an alternative. However, to meet the ever-growing load demand of the distribution system; distribution system upgrade is required and this can be achieved by conducting a power flow study on the existing network to ascertain the various levels of the inadequacy of the power system networks. On this note, the Active Power, Reactive Power, Frequency Power Factor, Complex Power, Transformer Percentage Loading and current rating on each transformer in the network and to improve on any valeted parameters for proper power flow of the distribution transformer, the improvement of bus voltage margin of the distribution feeder was considered. This investigation was aimed at the power flow of 33kv Distribution Network connected to Agip Estate Mile 4, Port Harcourt, Rivers State in Nigeria.

II. ELECTRICITY POWER FLOW ON 33KV NETWORK

Electricity power flow was made available by utility companies from adjacent transmission substations through the use of High Tension (HT) supports strung with Aluminium Conductors, this source-station ranges from 30MVA 132/33kV to 100MVA 132/33kV power Transformer in Nigeria, the span of 33kV line stringing between two High Tension Supports was about 50m for concrete poles, while the Aluminium conductors used for the overhead line to distribute the electric supply are usually of different types depending on the user's choice and area of application [5]. In the perspective of [6], Aluminium Conductor is a physical medium used to transmit or distribute electrical energy from one place to another, it is an important component of overhead and underground electrical transmission and distribution systems, the choice of conductor depends on the cost and efficiency, a typical conductor has the following features: high electrical conductivity, high tensile strength so that it can withstand mechanical stresses, and how specific gravity. In [7], power flow complications include the determination of bus voltages and network current flow within a definite grid resonant with distinct stocking schedule. The methods of power flow are highlighted in the following subsections.

A. Load Flow Analysis on IEEE Bus Systems

The Newton-Raphson or the Gauss Seidel procedures are conventional techniques for solving the load flow difficult. The load flow studies evaluate the voltage magnitudes and phase angles ascertained at each bus in the stable state and can be calculated within a distinct boundary [8]. Once the bus voltage magnitudes and their angles are determined using the load flow, the real and reactive power flow through each network can also be determined. It can be concluded that increasing the reactance loading will result in an increased voltage regulation.

B. Power Flow Analysis of Power System using the Power Perturbation

The Power Flow analysis is an essential tool in power structure investigation. Some researchers are of the opinion that most of the prevailing algorithms were developed to reduce the computational burden by reducing the number of equations, approximating the Jacobian matrix and other variables A new power flow technique known as the perturbation theory of which its objective is that it attempts to enhance the convergence rate by partially linearizing the power flow equation where more attention is on the voltage magnitude and the phase angle in each iterations [9].

C. The General Purpose Fast Decoupled Power Flow

The general purpose fast decoupled power flow, almost all the relevant known numerical methods used for solving the nonlinear equations have been applied in developing power flow mode is. Among various methods, power flow models based on the Newton-Raphson (NR) method have been found to be most reliable. Many decoupled polar versions of the NR method have been attempted for reducing the memory requirement and computation time involved for power flow solution. Among decoupled versions, the fast-decoupled load flow (FDLF) model developed [10].

D. The Fast-Decoupled Load Flow Algorithm

A diakoptic theory based on fast decoupled load flow algorithm which is suitable for distributed computing. If computations for different subsystems of an integrated system are done concurrently using a number of processors load flow can be done in a shorter time. Transmission of data over long distance to the central processing computer can thus be reduced [11].

E. Fast Decoupled Load Flow Method for Distribution Systems with High R/X Ratios Lines

This method is based on a coordinate transformation in Y-matrix for Jacobian matrix in the load flow method. When compared with Newton-Raphson method, a short computation time was realized. In order to overcome the problem, a coordinate transformation in Y-matrix of the Fast-Decoupled method for better convergence in processes [12].

III. MATERIALS AND METHODS

The appraisal of the physical state of Agip Estate 33KV/0.415KV distribution network was evaluated with exact reference to the type and size of conductors, route length and transformers rating. Three years (2016-2018) data load readings on transformers was gotten from the Port Harcourt Electricity Distribution

Company of Nigeria (PHEDN) in Rivers State. Newton-Raphson method was used to determine the load flow on the network and line impedance while Microsoft Excel was used to justify the determined result. Electrical Transient analyzer program (ETAP) was used for the simulations.

A. Description of Agip Estate Mile 4, 33/0.415KV Distribution Network

Agip Estate Mile 4 feeder received electricity power supply from 132KV garden city industrial transmission station in Port-Harcourt Town (Mains Z_2) through UST injection substation. As shown in Fig 1, the UST injection substation that Agip Estate Mile 4 feeder navigate through contained HV bus bars, 5MVA transformer, 1KVA grounding transformers, and one MV bus bars,. Fig 2 shows the electricity distribution to the load centres of Agip Estate, 33/0.415KV network in Rivers State are made of radial network.

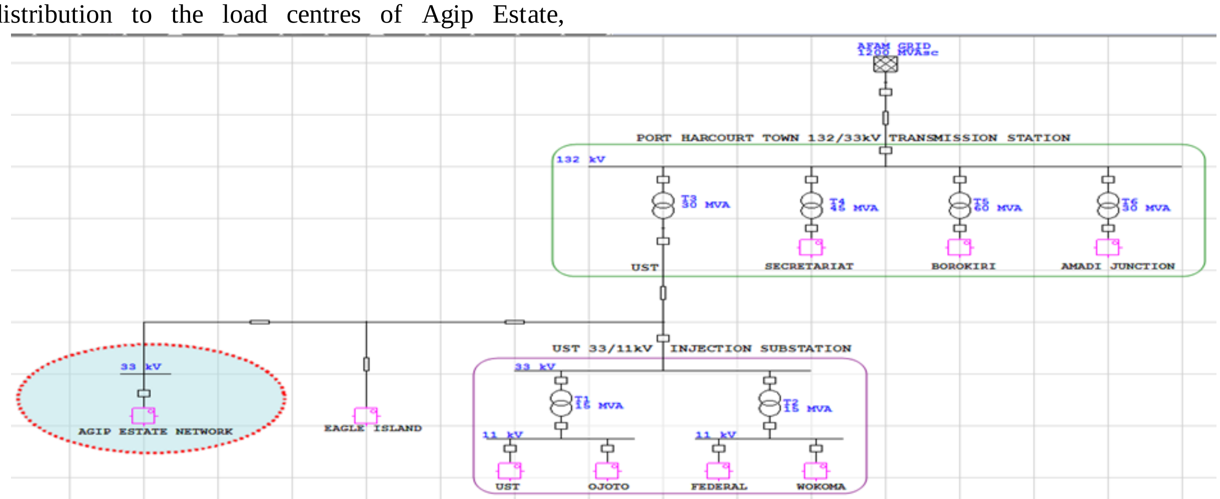

Fig 1: The Existing Network of UST 33kV Network Feeder

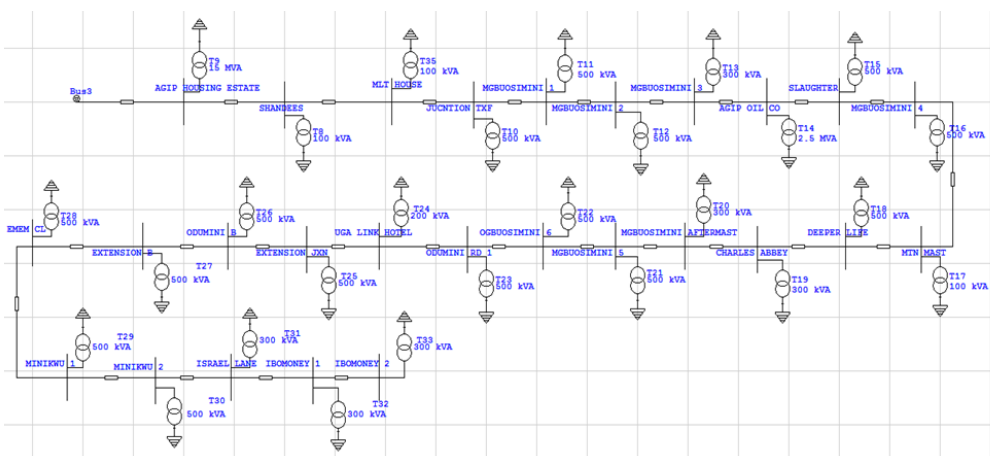

Fig 2: Post-Upgrade Single Line Diagram of Agip Estate Mile 4 33/0.415KV Network

B. Current Data Collected on 33KV Primary and Secondary Transformer in UST 33kV Substation

The data used in this research work were collected from Port Harcourt Electricity Distribution Company (PHED) substations visited. The data collected includes; line impedance, bus voltage ratings, and transformer load readings.

The formulas used in calculating the Load Current in Agip Estate Feeder are based on the Power Triangle, which was used in analyzing the reactive power, apparent power and power factor. Equations (1) to (8) was used in determining the transformer connection in Delta/Star pattern for the system consisting of 30MVA, 33/0.415KV transformer and 200KVA, 33/0.415KV transformer. The low voltage side of the main transformer winding are connected in star. Table 1 shows the result on transformer load current rating in the primary and secondary transformer in UST Substation.

Transformer load in SVA= $\sqrt{3}IV$ (1)

Active power in watts or kW= $\sqrt{3}IV\cos\theta$ (2)

Reactive power in VAR or kVAR= $\sqrt{3}VI\sin\theta$ (3)

Apparent power in VA or kVA= $\sqrt{\text{kW}^2+\text{kVAR}^2}$ (4)

Power factor, $\cos\theta = \frac{Active\ power}{Apparent\ power} = \frac{kW}{kVA}$ (5)

Complex power, $S = P + JQ$ (6)

Current $I = \frac{P(KVA)}{\sqrt{3}IV}$ (7)

Phase voltage $= \frac{\text{line voltage}}{\sqrt{3}}$ (8)

Where:
I = Current;
V = Voltage
$\cos\theta$ = the power factor at primary and secondary of transformers respectively.

Table 1: Load currents of transformer

Base Transformer Rating	Transformer Load Current	Current Connected in Delta/Star
30MVA, 33/0.415KV transformer	Primary Load current I_p	95346.26 A
	Secondary load current I_s	850340.14 A
200KVA, 33/0.415KV transformer	Primary Load current I_p	635.64 A
	Secondary load current I_s	5668.20 A

C. Distribution Line Parameters in Agip Estate Mile 4, Feeders

Table 2 show constant parameters used in the calculations requirements of the distribution line for the Agip Estate Mile 4 Feeder

Table 2: Parameters

Parameters	Symbols	Value
Route Length	L	14.2km
resistivity of aluminum	ρ	2.65 x 10^{-8} Ωm
Number of phases on the line	n	3
Distance between adjacent conductor	D	0.88 m
Area of conductor	A	200 mm^2

The resistance of the Feeder is calculated by (9) while per kilometre inductive reactance (X) of the Feeder is calculated by (10).

$$R = \frac{\rho \times L}{A}\ \Omega/\text{km} \quad (9)$$

$$X = 0.1445 log_{10}\frac{D_{GMD}}{r} + \frac{0.0157}{n}\Omega/\text{km} \quad (10)$$

$$GMD = \sqrt[3]{D_{aa} \times D_{ab} \times D_{ac}} = 1.26D \quad (11)$$

Thus, $D_{GMD} = 1.26\,\text{D} = 1.108$ m

$$r = \sqrt{\frac{A}{\pi}} \quad (12)$$

Where:
R is the resistance of the line
X is the reactance of the line
r = radius of the conductor
D_{GMD} is the geometric mean distance of conductor
D is the distance between adjacent conductor (D=2m)

For per kilometre inductive reactance of the Agip Estate Mile 4 Feeder, (10) is multiplied by L of the Feeder as follows:

$$X = 0.1445\, log_{10} \frac{1.108}{0.0069} + \frac{0.0157}{n}\, \Omega/\text{k}$$

$$X = 0.3239\Omega/\text{km} \times 14.2\text{km} = 4.59938 \cong 4.6\Omega$$

The impedance, susceptance and admittance of the Agip Estate Mile 4 Feeder are determined using (13) – (15) respectively.

$$Z = R + JX \qquad (13)$$

Thus $Z_o = R_o + JX_o = 2650 + j3.304$

$$B = \frac{7.5}{log_{10}\left(\frac{D_{GMD}}{r}\right)} \times 10^{-6} \qquad (14)$$

Equation (14) is multiplied by L to give

$$B = 3.4 \times 10^{-6}\Omega/\text{km} \times 14.2\text{km} = 4.828 \times 10^{-5}\Omega \cong 4.83 \times 10^{-5}\Omega$$

$$Y = G + JB \qquad (15)$$

Where
Z is the impedance of the line
G is the conductance of the line = $1/R$
B is the susceptance of the line
Y is the admittance of the line

D. Determination of Overloaded Transformers on Agip Estate Mile Feeders

Apparent power performance index was used to determine the percentage loading of transformers in Agip Estate Mile Feeders. A rating of 60% for design purpose was used based on the principle of transformers distribution loading, while transformers loadings above 60% were considered overloaded, as expressed in (16).

$$\%Loading = \sum_{i=1}^{N_T} \left(\frac{S_{MVA}}{S_{MAX}}\right) \times 100 \qquad (16)$$

Where
S_{MAX} = MVA rating of the transformer
S_{MVA} = operating MVA from power flow calculation
N_T = number of transformers

The transformer data current reading on each transformer in Agip Estate mile 4, distribution feeder was retrieved from the Port Harcourt Electricity Distribution Company of Nigeria (PHEDN) in Rivers State, Nigeria. The data was used to determine each transformer loading and its percentage load.

The load reading data collected was used in calculating the total current that flows through this transformer using (17)

$$\text{Current, } I = \frac{\text{B+R+Y+N}}{3} \qquad (17)$$

For the 30MVA, 33/0.415KV transformer and 200KVA, 33/0.415KV transformer on the network, the transformer-loading, active power, reactive power, apparent power, complex power, power factor and overloaded transformer were calculated by (1) to (6) and (16) respectively.

IV. RESULTS AND DISCUSSION

The power factor (*Cos Ø*) and frequency (H_Z) result, on each Transformer allocated to Agip Estate Mile 4, 33KV Distribution Network were all equal respectively, as shown in Fig 3 and Fig 4. While the result in Fig 5 shows that the transformer percentage loading at locations Mgbuosimini 3, Charles Abbey, Mgbuosimini Aftermast, Mgbuosimini 5, Odumini Rd 1, Israel Lane, Ibomoney 1, and Ibomoney 2 have the highest percentage loading above 60%. The result in Fig 6 shows that the nominal KV, voltage and percentage loading on each bus on the network were relatively high for the Pre-Upgrade Simulation of Agip Estate Mile 4, 33kV Distribution network.

The Post-Upgrade result indicates that optimization technique was used in optimizing the overloaded transformer by using transformer load tap changer, which made all the transformer percentage loading less than 60%, as shown in Fig 7. Bus Voltage result shows that all the transformer Nominal kV, Voltage and percentage loading were all most equal as shown in Fig 8.

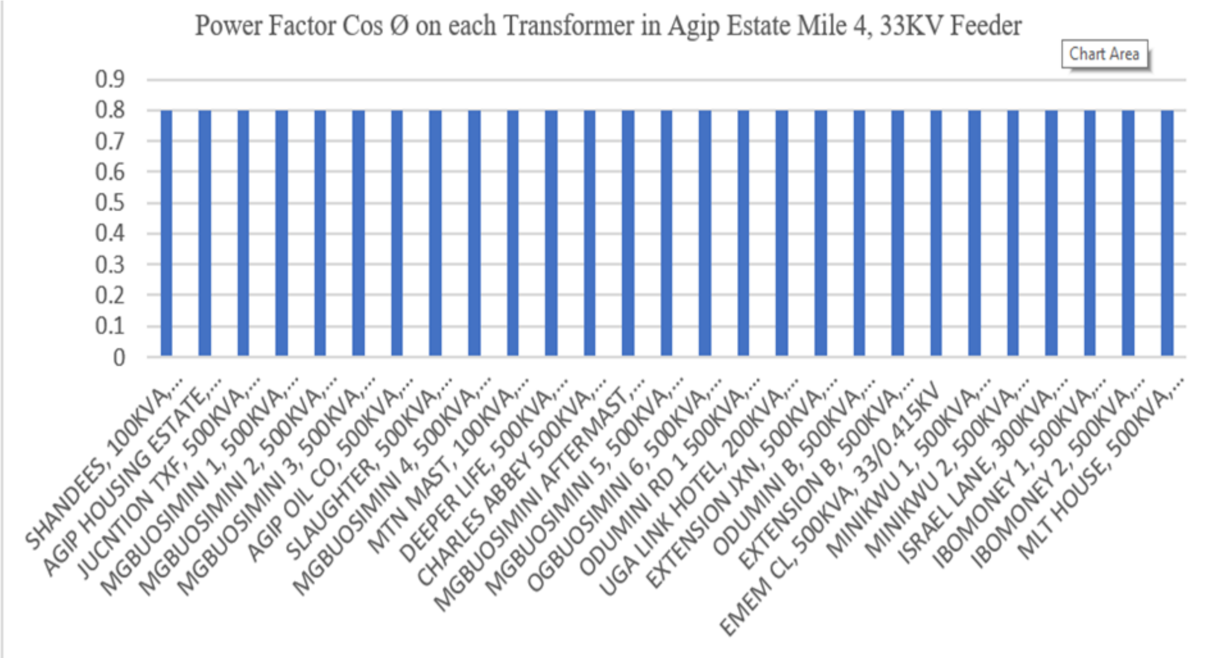

Fig 3: *Cos Ø* on each transformer on Agip Estate Mile 4, 33KV Feeder.

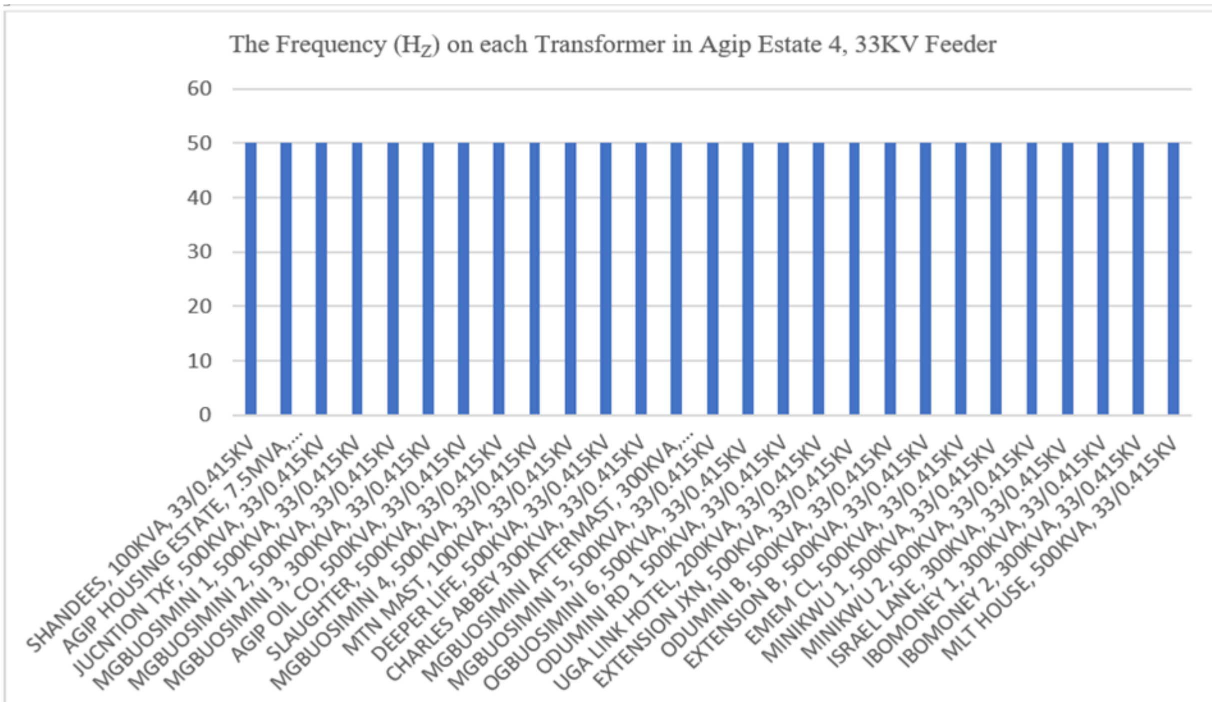

Fig 4: The Frequency (H_Z) on each transformer in Agip Estate 4, 33KV Feeder

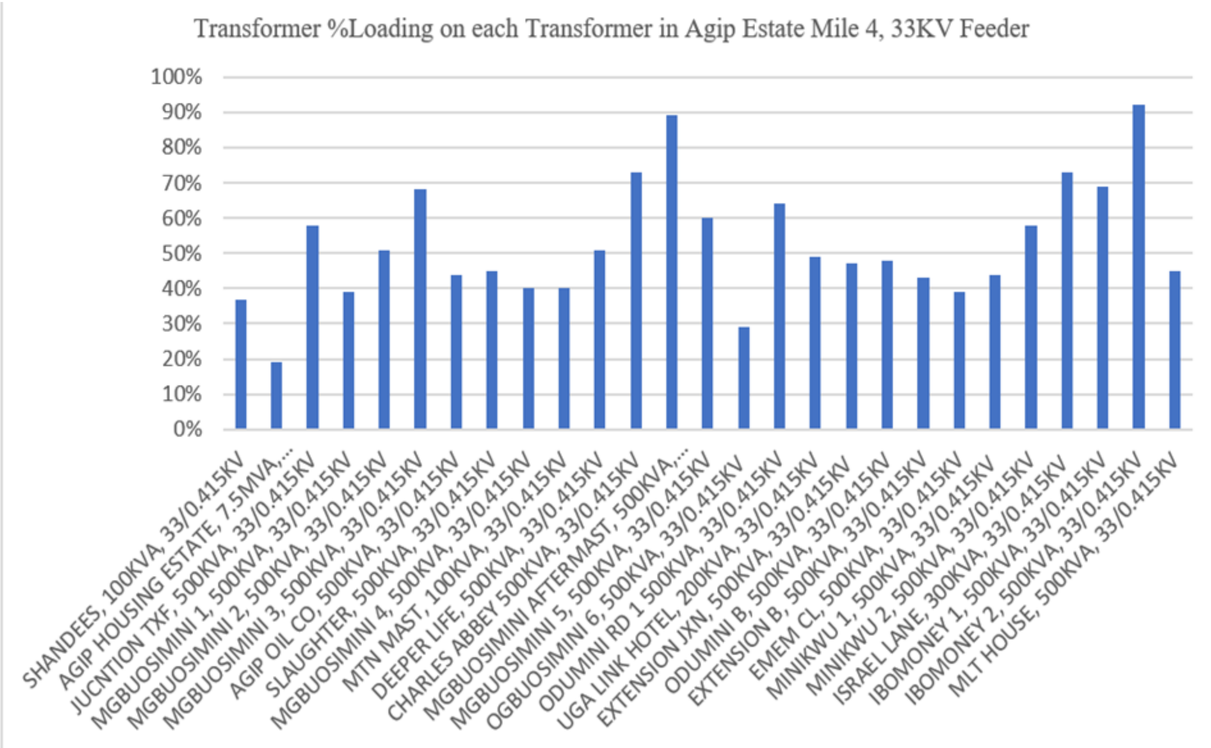

Fig 5: Transformer Percentage Loading on each Transformer in Agip Estate Mile 4, 33KV Feeder

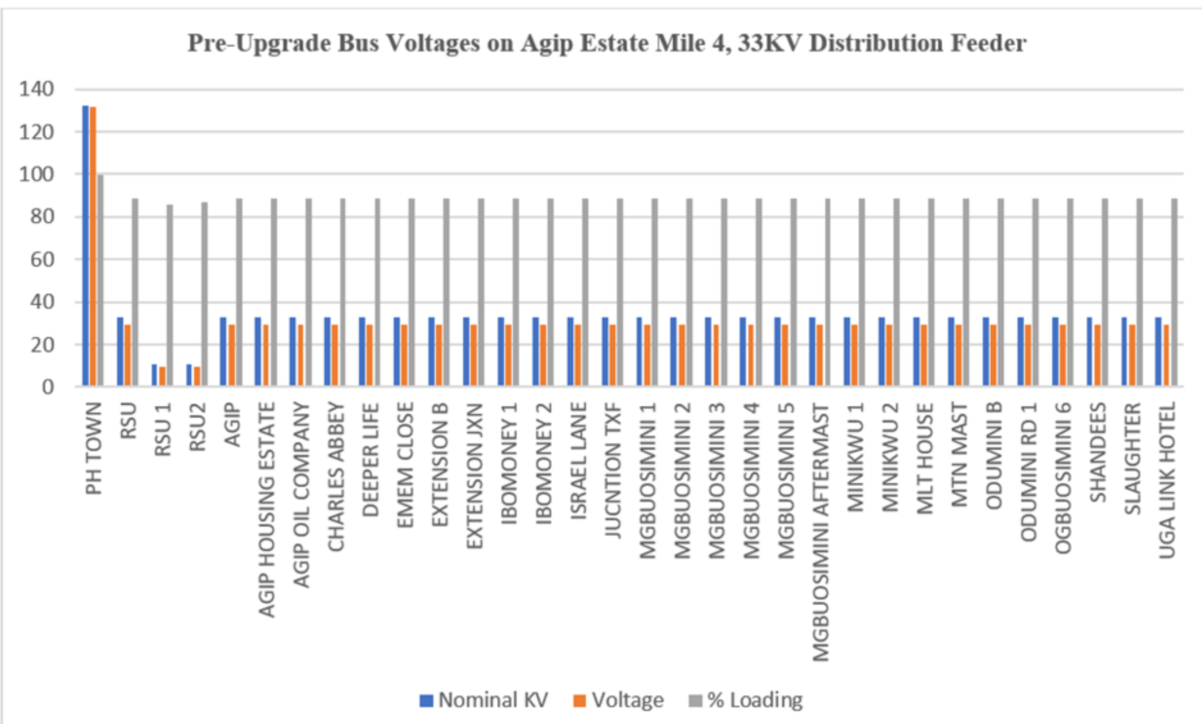

Figure 6: Pre-Upgrade Bus Voltages on Agip Estate Mile 4, 33KV Distribution Feeder

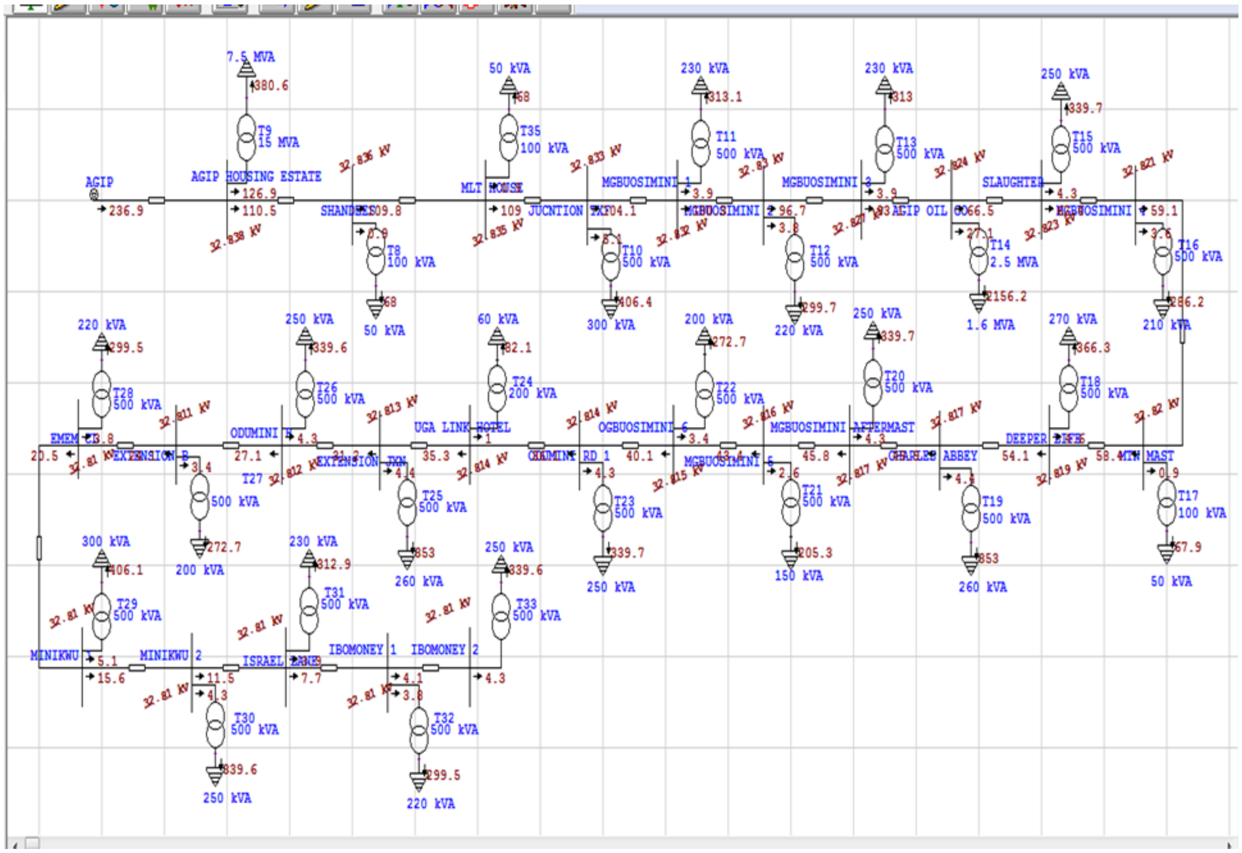

Fig 7: Post-Upgrade Simulation of Agip Estate Mile 4, 33k/0.415V Distribution Network

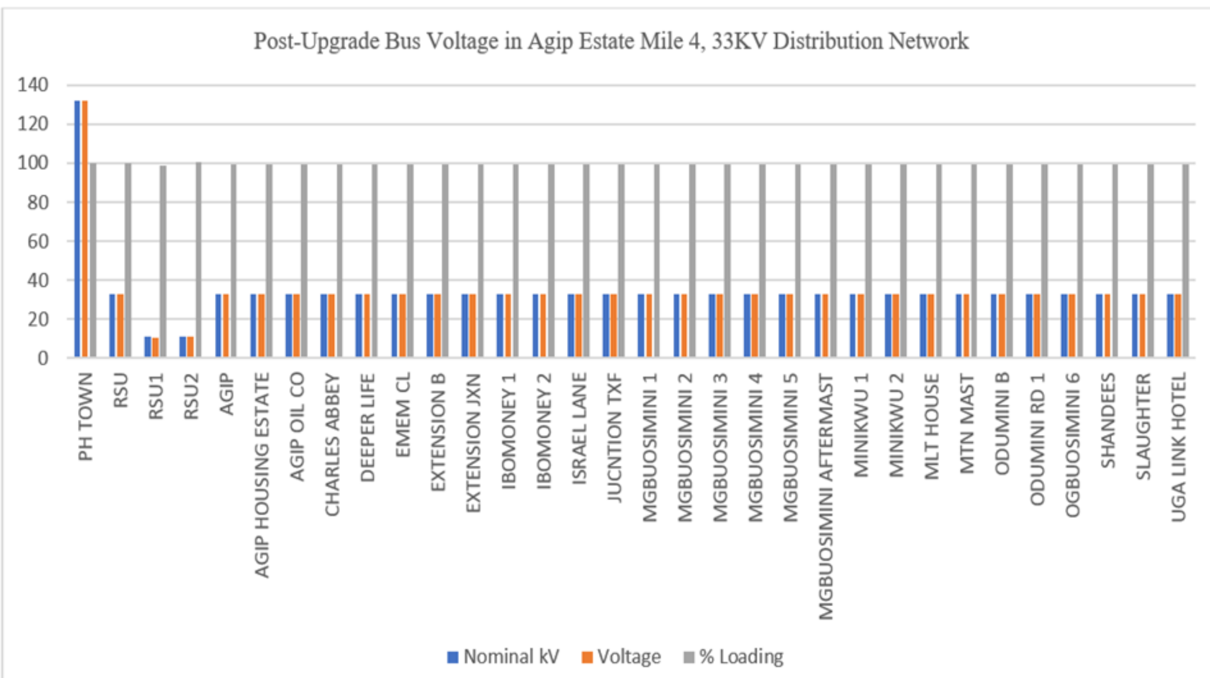

Figure 8: Post-Upgrade Bus Voltage in Agip Estate Mile 4, 33KV Distribution Network.

CONCLUSION

The epileptic electricity power supply in Agip Estate Mile 4, 33kv Distribution Network in Port Harcourt, Rivers State, Nigeria is never-ending following the inadequate power distribution, human error fault, malfunctioning of power equipment and poor distribution infrastructure upgrade. The power flow investigation of the network was analysed using Newton-Raphson method, while Microsoft Excel was used to justify the current and Electrical Transient analyzer program (ETAP) software was used for the Pre-Upgrade and the Post-Upgrade simulation. The results show that sum of the transformer in the area were heavily overloaded. Hence, transformer load tap changer optimization techniques were used for the post-upgrade of the system.

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