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# Load Flow Studies of 132/33KV Transmission Line in Port Harcourt Zone Using Newton Raphson's Method

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***Abstract*- This paper critically examines the Load Flow condition of the Port Harcourt Mains and Town 132/33kV transmission networks. In carrying out the Load flow study, the Newton Raphson power flow method in Electrical Transient Analyzer Program (ETAP) was used to evaluate the performance of both networks. Findings from the simulation exercise showed a lot of grey areas that required urgent attention within both networks. The combined transmission efficiency recorded low and the total system apparent losses stood at 52.5912MVA. All transformers were critically loaded as some exceeded 100% loading. The percentage operational bus voltages were below threshold as bus voltage magnitudes fell outside the +/- 5% nominal rated values. The systems also had undesired power factor levels. These threatening findings led to the quest to improve the networks. Three system improvement algorithms were used in this research viz: capacitor placement, transformer upgrade and transformer load tap modifications. These algorithms were superimposed in a stepwise mznner to obtain the most desired result. The final simulation result saw the performance of both networks within acceptable limits as the systems were greatly improved. The total system apparent losses reduced to 26.129MVA (50% improvement). All percentage loading of transformers were seen below the 60% benchmark. Bus voltage levels with significantly within the +/-5% limit and finally the power factor values were good.**

***Keywords*- ETAP software, Improvement algorithms, Load Flow Studies, Newton Rapshon, Transmission networks.**

## I. INTRODUCTION

The primary aim of any power system is to deliver clean, reliable and efficient power to its end users at the most favorable economic and technical optimizable standpoint [1].

Continuous expansion in the economic and demographic nature of areas have seen surge in load demands exceeding the available supplies of electric power, in this regard, utility companies have resulted to load shedding as the most desirable means of handling this issue. More so, the transmission networks have faced intricacies in the management and control of issues concerning the flow of reactive power. Transmission lines and transformers are being operated outside their operational limits [2].

These ill practices and many more have resulted to low voltage profiles within network buses, increased apparent power losses which has generally reduced the efficiency and performance of the network. In a bid to deliver clean and reliable energy, these problems needs to be carefully curbed. In curbing them, a load or power flow study has to be conducted on the network under consideration [3], in this case the Port Harcourt Town and Mains transmission networks.

This study will highlight the grey areas and parameters of the networks that needs attention as well as best algorithms that would be meted in improving the overall system. The aim and objectives of this research are born out of the need to have a generally improved Port Harcourt Mains and Town transmission networks when compared to their existing states. A generally improved system capable of delivering clean and reliable power to connected areas bearing in mind the complimentary projections in incremental load profiles. We shall employ Capacitor placement technique, Transformer upgrade and Load Tap modifications as improvement algorithms in a stepwise approach [4].

The application of these improvement techniques will be aimed at generally improving the entire system, but particularly targeted to appreciably reducing the total system apparent losses. Ensuring that all transformers within the networks are operated within the acceptable load limits (less than 60%). That the operational bus voltage profiles and magnitudes are within the acceptable threshold, which is +/-5% of the rated buses [5].

More so the power factor level across both networks are within acceptable healthy limits (as near to unity as possible).

## II. LITERATURE SURVEY

This research paper focuses on investigating the working framework the networks and proffering the best possible solutions to the daunting issues as seen in past literatures. A large proportion of past literatures have pointed to a rather singular fact that the inductive nature of most loads creates a lagging power factor which stimulates the flow of more current in the system as such there is increased I2R losses [4].

This loss reduces the power transmission efficiency which results in unhealthy voltage profile levels. [5] In his research pointed out that unhealthy voltage level is the major cause of power system problems. Reactive power cannot be transmitted over long distances especially under heavy load conditions, this scenario causes voltage levels to drop and this low voltage levels generate excess heat in devices and associated high system losses. [4]

Explained that the most loads within a power system are inductive by nature, the inductive nature of most loads makes room for lagging power factor which ultimately consume excess reactive power, when this happens there is increase in the flow of current, as current increases I2R losses comes into play which now results in unhealthy voltage profiles. [2]

In their publication explained that the problem of poor voltage control problems, poor transmission network control and highly overloaded transmission feeders are the leading causes of today's system failures which are eminently characterized as spurious voltage variations and frequent power outages.

Literatures have also captured the various solutions researchers have proffered in solving the various problems. [6]

In his work explained how placing the prescribed capacitor banks in shunt with two marginally affected load feeders improved the voltage levels, power factor levels and reduced the apparent power losses within the system. [7]

In their work explained how using capacitor placement and transformer tap setting improved the voltage profile on the two 11/0.415kV transformers improved by 1.96% and 8.2% on capacitor placements and 4,8% and 6.85% with load tap settings. More so, the 11kV feeders saw 4.84% and 1.98% in voltage level improvements. [8]

In their research considered Feeder bifurcation algorithm is also an improvement method to improving the performance of a distribution network. The overload conditions on the transformers were seen to have reduced appreciably to acceptable operational limits.

## III. MATERIALS AND METHOD

**1. Materials:**
The materials used in this research work include:

- A Single Line Diagram (SLD) of both networks.
- A working computer system compatible with the Electric Transient Analyzer Program (ETAP) soft ware.
- Existing ratings and Specifications of station parameters, machineries and devices.
- Load profile and data of both stations.

**2. Method:**
The Newton-Raphson technique of load flow analysis on ETAP 16.0 was implored in this analysis. A base case simulation of the designed stations on ETAP showed the prevailing status of both stations as well as it's parameters such as bus voltages, branch power factor (P.F) levels, transformer utilization and loading levels, power losses, power and current flows, etc. The outcome of the simulation however, showed that both networks are currently on the verge of an eminent breakdown, hence the need to improve the networks thereby making it most suitable for efficient and reliable power transmission.

Modeling, as well as analyzing results of the network performance in the ETAP simulation environment required two major parameters. The transmission network parameters and control parameters. The transmission network parameters were peculiar to each network while the control parameters served a guide in analyzing the performance and operational status of each network.

Sequel to the outcome of the simulation, three major improvement algorithms, viz: capacitor placement, transformer upgrade and load tap setting were then used in a stepwise manner on the networks to improve their over performance.

**2.1 Bus Admittance:** To understand the system behavior, the current flowing through the transmission line as well as the voltage magnitude within buses needs to be known per time. Although, this sequence of analysis is embedded in the ETAP software, It is most imperative that some light be shed here.

$$|\mathbf{I}_{bus}| = |\mathbf{Y}_{bus}|\ |\mathbf{V}| \qquad (1)$$

Where V and I are the n-element nodal voltage and current matrix respectively and Ybusis given as:

$$\begin{array}{l|l} & \mathbf{Y}_{11} \quad \mathbf{Y}_{12} \ldots\ldots \mathbf{Y}_{1n} \\ & \mathbf{Y}_{21} \quad \mathbf{Y}_{22} \ldots\ldots \mathbf{Y}_{2n} \\ \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots & \\ & \mathbf{Y}_{n1} \quad \mathbf{Y}_{n2} \ldots\ldots \mathbf{Y}_{nm} \end{array} \qquad (2)$$

It was thus formulated that the current entering bus i is given as

$$n$$

$$I_i = \sum_{k=1} Y_{ik} V_k;\ i = 1, 2, \ldots\ldots\ldots n \qquad (3)$$

**2.2 Newton-Raphson Technique:** [13] inferred that the Newton-Raphson method of solving load flow problems is based on the Taylor series expansion for a function of two or more variables. In this series, partial derivatives of order greater than one are neglected.

The system of equations can be developed as follows: At any given bus k, the real power Pk and reactive power Qk flowing into the system of N buses is given by

$$P_k - j\,Q_k = V_k^* \sum_{n=1}^{N} Y_{kn} V_n \qquad (4)$$

**Let**

$$V_k = a_k + jb_k \qquad (5)$$

$$V_n = a_n + jb_n \qquad (6)$$

Were ak and bk are the real and imaginary components of the bus voltage Vk, therefore

$$V_k^* = a_k - j\,b_k \qquad (7)$$

$$\text{and } Y_{kn} = G_{kn} - j\,B_{kn} \qquad (8)$$

The new equation now yields,

$$P_k - j\,Q_k = (a_k - j\,b_k) \sum_{n=1}^{N} (G_{kn} - j\,B_{kn})\,(a_n + jbn) \qquad (9)$$

On comparing both sides of (4)
Pk = real part of the RHS of (9) and Qk = negative of the imaginary part of the RHS of (9)

At the voltage controlled buses ( say bus P) the square of the voltage magnitude is given as:

$$|\,V_p\,|^2 = a_p^2 + b_p^2 \qquad (10)$$

The changes in ap and bp will be calculated for each iteration. However, the sum of the squares of ap and bp must converge to the square of the value specified at the voltage-controlled bus.

In the each iterative process, the calculated values of Pk and Qk or | Vk |2 must be compared with the specified values having the error limit or tolerance in mind.

$$\Delta P_k = P_{k,\ \text{Specified}} - P_{k,\ \text{Calculated}} \qquad (11)$$

$$\Delta Q_k = Q_{k,\ \text{Specified}} - Q_{k,\ \text{Calculated}} \qquad (12)$$

$$\Delta|V_k|^2 = |V_{k,\ \text{Specified}}|^2 - |V_{k,\ \text{Calculated}}|^2 \qquad (13)$$

These new values of Pk, Qk and |Vk |2 are now used to calculate for the bus voltages using the (3.10).

We shall for simplicity, consider a three – bus system where bus 1 is taken as the swing bus, bus 2 the load bus with P2 and Q2 specified and bus 3 is a bus with P3 and |V3| specified.

Then the corresponding equations are:

$$\begin{vmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta Q \\ \Delta|V \end{vmatrix} = \begin{vmatrix} \frac{\partial P}{\partial a_2} & \frac{\partial P_2}{\partial a_3} & \frac{\partial P_2}{\partial b_2} & \frac{\partial P_2}{\partial b3} \\ \frac{\partial P_3}{\partial a_2} & \frac{\partial P_3}{\partial a_3} & \frac{\partial P_3}{\partial b_2} & \frac{\partial P_3}{\partial b3} \\ \frac{\partial Q_2}{\partial a_2} & \frac{\partial Q_2}{\partial a_3} & \frac{\partial Q_2}{\partial b_2} & \frac{\partial Q_2}{\partial b3} \\ \frac{\partial\,|V_3|^2}{\partial a_2} & \frac{\partial|V_3|^2}{\partial a_3} & \frac{\partial|V_3|^2}{\partial b_2} & \frac{\partial|V_3|^2}{\partial b_{33}} \end{vmatrix} \begin{vmatrix} \Delta a_2 \\ \Delta a_3 \\ \Delta b_2 \\ \Delta b_3 \end{vmatrix} \qquad (14)$$

(14) can also be written as

$$\begin{array}{c} \Delta P \\ \Delta Q \\ \Delta V_i^2 \end{array} = \left|\begin{array}{c:c} J_1 & J_2 \\ \hdashline J_1 & J_4 \\ \hdashline J_5 & J_6 \end{array}\right| \begin{vmatrix} \Delta a \\ \\ \Delta b \end{vmatrix} \qquad (15)$$

The square matrix of partial derivatives is called the jacobian. The jacobian elements are found by taken the partial derivatives of the expressions for Pk and Qk and substituting the assumed voltages for the first iteration or calculated in the previous iteration... This entire process is repeated until the required precision or tolerance level is reached. This point is were the system converges and a base case simulation on ETAP is said to have been done.

**2.3 Transmission Line Parameters:** These are variables or parameters that must be obtained and entered in the ETAP simulation environment in order to conduct the load flow study. Each phase of the transmission line will be represented by a pi-model equivalent in this study. The conductor found within both networks was Aluminum Conductor Steel Reinforced (ACSR) drake of 186mm2,, 0.25km of total line length coverage and 8m conductor pair spacing.

### 2.3.1 Per Kilometer Resistance of Line, R0:

$$\text{Resistance, } R_0 = \frac{\rho 1000}{A}\left(\frac{\Omega}{Km}\right) \qquad (16)$$

where A= cross sectional area of the conductor, given as 182mm2 = 1.82 x 10-4 m2
ρ = resistivity of aluminum at 20 ℃ = 2.82 x 10-8 Ω.m
R0 is thus evaluated as follows:

$$\mathbf{R_0} = \frac{2.82\times10^{-8}\Omega m \times 1000m}{1.82\times10^{-4}m^2} = 0.1549\Omega/\text{Km}$$

2.3.2 Per Kilometer Reactance of the Line, Xo:
Is obtained by,

$$X_0 = 0.1445\ \text{Log}_{10}\left[\frac{D_{GMD}}{R}\right] + 0.0157\ \Omega/\text{km} \qquad \textbf{(17)}$$

$$\textbf{Where } D_{GMD} = \sqrt[3]{D_{RY}.D_{YB}.D_{RB}} = \mathbf{1.26D} \qquad \textbf{(18)}$$

Where D is the distance between adjacent conductor pairs = 4.8meters

$D_{GMD}$ = 1.26 x 4.8m = 6.048m

$$\mathbf{R}=\sqrt{\frac{A}{\Pi}}\ \mathbf{(m)} \qquad \textbf{(19)}$$

A = 1.82 x $10^{-4}$ $m^2$ and Π = 3.142

$$R=\sqrt{\frac{1.82\times10^{-4}}{3.142}} = 7.6108 \times 10^{-3}\text{m}$$

$$X_0 = 0.1445\ \text{Log}_{10}\left(\frac{6.048}{0.0076108}\right) + 0.0157 = 0.43477\ \Omega\ /\ \text{Km.}$$

**2.3.3 Per Kilometer Capacitive Susceptance Bo:**

$$B_o \text{ is given as } B_o = \frac{7.58}{Log_{10}\left(\frac{D_{GMD}}{R}\right)} \times 10^{-6} \qquad (20)$$

$$= \frac{7.58}{Log_{10}\left(\frac{6.048}{0.0076108}\right)} \times 10^{-6} = 2.6136 \times 10^{-6}\ (\Omega\text{km})^{-1}$$

**2.3.4 Kilometer per Conductance of Line, G:**
The G parameter is obtained by taking the inverse of the line resistance

$$\mathbf{G}=\frac{\mathbf{1}}{\boldsymbol{R}} \qquad \textbf{(21)}$$

$$= \frac{1}{0.1549} = 6.4558\ mho\ km^{-1}$$

**2.3.5 Per Kilometer Impedance, Z:**

$$\mathbf{Z} = \sqrt{\boldsymbol{R_0}^2 + \boldsymbol{X_0}^2} \qquad \textbf{(22)}$$

Now, substituting values obtained from (16) and (17) into (22) yields,

Z = 0.4615 ohms.

**3. Substation Description:**
Port Harcourt Mains and Town 132/33 KV transmission networks feeding a great majority of Rivers State is generically configured as: The Port Harcourt Mains houses 10, 33KV feeders with a cumulative load of 167.5MW and 3 by 60MVA transformers. The Port Harcourt Town harboring 7, 33 KV outgoing feeders having a total load of 179.1MW with 1by 60MVA, 1 by 45MVA, 2 by 30MVA and 1 by 15MVA transformers. Figure 1 shows the simulation of both stations in ETAP.

Table 1. Transmission Network of Port Harcourt Mains and Town Stations.

| Port Harcourt Town Transmission Network | | | Port Harcourt Mains Transmission Network | | |
|---|---|---|---|---|---|
| Location: Nzimiro, Eastern Bypass. | | | Location: Rumubiokani | | |
| Connected Areas ( 33Kv Feeder) | Load (MW) | Connected Transformer (MVA) | Connected Areas ( 33kVFeeder) | Load (MW) | Connected Transformer (MVA) |
| UST | 38.5 | 30 | RSPUB 2 | 17.5 | |
| Secretariat | 37 | | REF 1 | 10.5 | 60 |
| Borokiri | 22.3 | 45 | Abuloma | 12 | |
| UTC | 21.9 | | REF 2 | 18 | |
| Silver Bird | 8 | 60 | Elekahia | 14 | 60 |
| Rumuolumeni | 22 | | UNIPORT | 25 | |
| Nzimiro | 29.4 | 30 | Woji (RSPUB 1) | 12 | |
| | | | FDR 3 | 18 | 60 |
| | | | FDR 2 | 16 | |
| | | | Airport Feeder | 24.5 | |

**4. Control Parameters:**
For the purpose of this research, control parameters refer to those indicators that were used to measure the existing performance of the networks with the already preset standards. They were the deciding factors that brought about the need for the networks to be improved. They

include, bus voltage regulation levels, transformer loading/utilization levels and P.F at the buses.

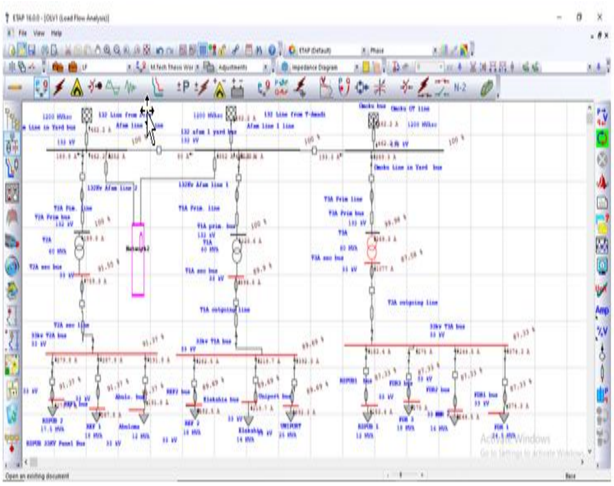

Fig 1. Simulation Result of the Existing Port Harcourt Mains Transmission Network.

Fig 2. Simulation Result of the Existing Port Harcourt Town Transmission Network.

**4.1 Bus Voltage Regulation:** Empirical data of the load profiles shows that the demand on each station has surpassed the install capacity. Simulation result in ETAP however confirms this as the voltage level across the buses were outside the +/5% benchmark. This implies that for any given bus voltages below 95% and above 105% are under and over voltage levels respectively.

The Voltage drop in a bus, Vd is the difference between the sending voltage, VS and the receiving voltage, VR.

i.e $\mathbf{V_d = IZ = V_S - V_R}$

Percentage Voltage regulation

$$= \frac{V_S - V_R}{V_S} 100\% = \frac{V_d}{V_S} \times 100\% \quad (23)$$

Where,
I = current flowing into the bus under consideration
Z = Bus impedance
V = Voltage drop of the bus
$V_S$ = Sending voltage to bus
$V_R$ = Voltage received by the bus

In this study, a total of 47 buses from both networks were modeled in ETAP and the corresponding voltage regulations, stating the conditions of the buses were obtained.

**4.2 Transformer Loading:** The power install capacity of network is a function of the transformer rating and capacity and this determines the power leaving the stations. A transformer is however, been efficiently utilized if it's loading is within 50% - 60%.To measure this, the ratio of the operational apparent power to rated apparent power is used as the index.

Mathematically,

$$\%\ \mathbf{loading\ of\ transformer} = \frac{\mathbf{S_{MVA}}}{\mathbf{S_{Max}}} \times \mathbf{100\%} \qquad \mathbf{(24)}$$

Where,
$S_{MVA}$ = transformer rating is seen on the name plate
$S_{MAX}$ = operational apparent power of the transformer.

## IV. RESULTS AND DISCUSSION

### 1. Results:

The obtained system parameters of the Port Harcourt Mains and Town transmission networks were used to conduct a base case simulation for the existing state of the networks in ETAP and the results are shown in Fig.1 and Fig.2 respectively.

The ETAP simulation produced three distinct color codes across all parameters, inferring to meanings. Red zone implies that it is critical attention is needed, the system is considered to be on the verge of breakdown at this point. Purple zone means this is a marginally operational zone, areas with this code needs moderate attention but not immediate. Such systems could become Red (critical) if not worked on.

Black zone is a perfect working zone; the system is accepted to be optimally functional at this point. Our goal is to make the entire system operate within the Black zone. However, the base case result show that over 95% of both networks were in the red zone, hence there is an urgent need to improve the transmission networks.

**1.1 Network Improvement Techniques:** The result of the base case simulation showed that virtually all facets of the transmission stations needed one form of fixing or the other. The networks were considered inadequate for work.

To transmit reliable and efficient power through these zones the systems needed to be improved.

The following improvement methods were used in a stepwise manner, quite different from previous improvement methods. This study saw the need to have an improvement technique been succeeded by another and the results obtained were fascinating.

**1.1.1 Capacitor Placement:** Placing the required capacitor value on a critically loaded bus will provide the required reactive power needed to improve the bus voltage profile levels, reduce the overall system losses and improve the bus performance. Hence, this was done on all critically loaded (outside the +/-5% preset voltage regulation) buses within the networks under investigation.

The appropriate capacitor value (Var) was evaluated with the formula:

$$\boldsymbol{C(Var) = P_{watt}(tan\theta_1 - tan\theta_2)} \qquad \textbf{(25)}$$

Where;
C (Var) = required capacitor bank value
$P_{watt}$ = Total real power within the affected bus
$\theta_1$ = prevailing power factor angle within the affected bus
$\theta_2$ = desired power factor within the bus

For simplicity, we shall evaluate the capacitor value for 33kV T2A bus,
$P_{watt}$ = 33.7098MW
$\cos\theta_1 = 85\% = 0.85$
$\theta_1 = \cos^{-1}(0.85) = 31.79$
$\cos\theta_2 = 0.98$ (desired power factor)
$\theta_2 = \cos^{-1}(0.98) = 11.48$
substituting all values into (25)
33.7098 (tan 31.79 – tan 11.48) = 14.0469MVAR
Hence, the required capacitor bank size to be placed on the 33kV T2A bus needed to allow the flow of the required reactive power to the load will be 14.0496MVAR (14049.6KVAR).This calculation was done for all the critically loaded values and the newly improved networks were simulated on ETAP.

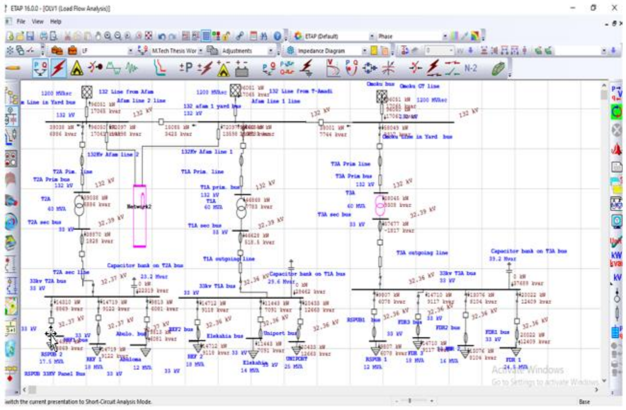

Fig 3. Port Harcourt Mains Transmission Station improved with Capacitor Banks.

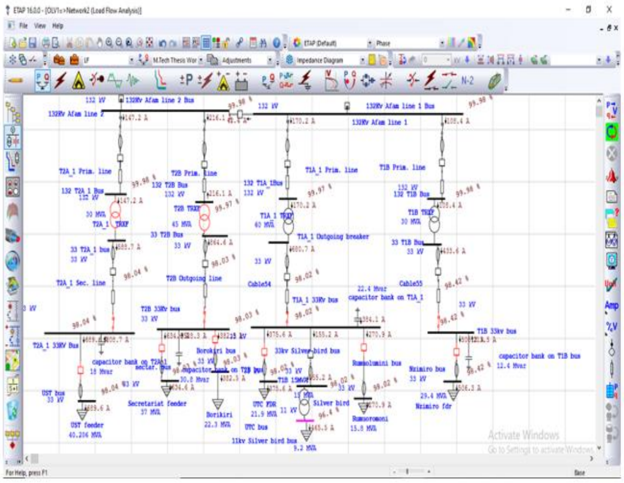

Fig 4. Port Harcourt Town Transmission Station improved with Capacitor Banks.

**1.1.2 Transformer Upgrade:** The introduction of capacitor banks on affected buses proffered an infinitesimal improvement on the percentage loading of transformers. A transformer predictive model was developed with 55% load condition with the existing maximum load of the stations, this model would empirically propose power ratings of the new transformers or replacements.

The 55% load percentage is meant to compensate for the daily incremental load profiles of the networks, just until a major study like this is conducted.The model will be tested on T2A,60MVA transformer located in Port Harcourt Mains network.

From (24)

$$\%\,\boldsymbol{loading\ of\ transformer} = \frac{\boldsymbol{S_{MVA}}}{\boldsymbol{S_{Max}}} \times \boldsymbol{100}\%$$

$S_{MVA}$ = Total apparent loading on the Transformer T2A =

34.388MW + j 24.071MVAR = 41.935MVA

% Loading has been assumed to be 55% = 0.55
From the equation above

$S_{MAX}$ = Maximum rating of the transformer $= \frac{S_{MVA}}{0.55} = \frac{41.935MVA}{0.55} = 76.25MVA$

for this load at a 55% maximum load condition an 80MVA transformer should be used to replace the existing 60MVA transformer.These exact same steps were used for all affected transformer.

Table 2. Predictive Modelling for New Transformer Ratings.

| Transformer Name | Location (Mains / Town) | Present Rating (MVA) | Connected load |  |  | Loading at 55% | Proposed replacement. –New (MVA) |
|---|---|---|---|---|---|---|---|
|  |  |  | MW | MVAR | MVA |  |  |
| T2A | Mains | 60 | 39.038 | 6.885 | 39.641 | 72.07 | 80 |
| T1A | Mains | 60 | 46.868 | 7.783 | 47.510 | 86.38 | 100 |
| T3A | Mains | 60 | 58.045 | 9.307 | 58.786 | 106.88 | 100 |
| T2A_1 | Town | 30 | 32.969 | 6.700 | 33.643 | 61.169 | 60 |
| T2B | Town | 45 | 48.703 | 8.280 | 49.402 | 89.82 | 100 |
| T1A_1 | Town | 60 | 38.224 | 7.184 | 38.893 | 70.715 | 80 |
| T1B | Town | 30 | 24.274 | 4.967 | 24.777 | 45.04 | 60 |

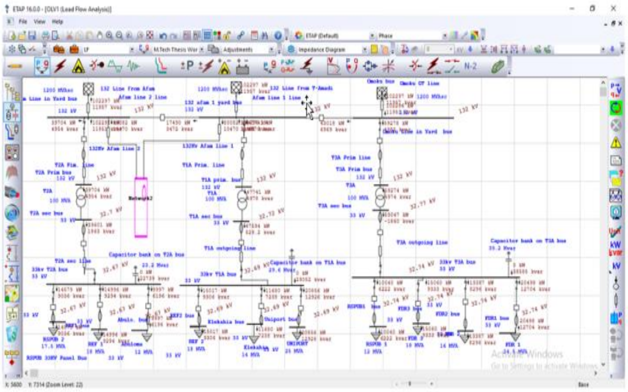

Fig 5. Improved Port Harcourt Transmission Mains network with Capacitor Banks and Upgraded Transformers.

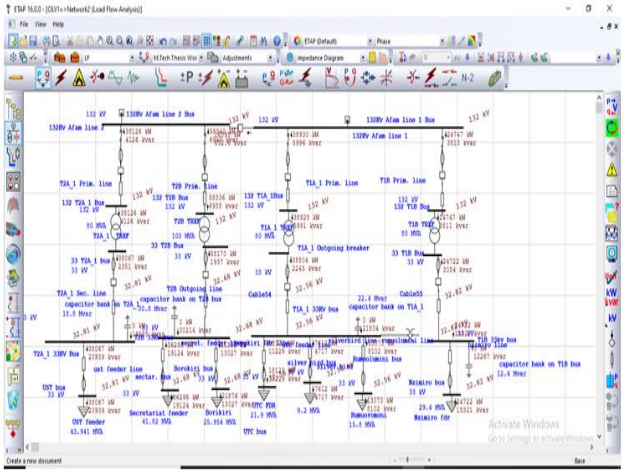

Fig 6. Improved Port Harcourt Transmission Town network with Capacitor Banks and Upgraded Transformers.

**1.1.3 Applying Transformer Load Tap Setting:** This method was lastly used to improve the improved networks. It aims at improving the voltage from the secondary side of the transformer relative to the system loading condition. This practice would greatly improve the voltage profile within the affected buses.

It was seen that the newly improved Port Harcourt Mains station there was voltage disparity between the output of the transformers and the load buses. The Port Harcourt Town network had no disparity and load voltage regulation was nearly 100%. The Load Tap changer will now be applied on the transformers in the Port Harcourt Mains network.The transformer load tap changer is obtained by

$$\textbf{\% Tap setting} = (K-1) \times 100\% \qquad (26)$$

$$K = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Where;

K = per unit turn ratio

$V_1$ = Sending voltage to the feeder

$V_2$ = Receiving voltage into the feeder

The obtained value will be the new tap setting on the primary side of the transformer as this would ultimately improve the secondary output voltage.

For simplicity the load tap setting for transformer, T2A is obtained by:

$V_1$ = 32.7kV

$V_2$ = 32.67Kv

$K = \frac{32.67}{32.7} = 0.9991$

% Tap setting = (K-1) x100%

= (0.9991 -1) x100% = -0.09%

Same analysis was done for T1A and T3A

Table 3. Load Tap Control Setting on Mains Network Transformer.

| Measuring parameter | Transformers in the Mains Network | | | Transformers in the Town Network | | | |
|---|---|---|---|---|---|---|---|
| | 33Kv T2A load bus | 33KV T1A Load bus | 33KV T3A Load bus | 33KV T2A_1 load bus | 33KV T2B load bus | 33KV T1A_1 load bus | 33KV T1B load bus |
| Sending voltage (KV) | 32.70 | 32.72 | 32.77 | 32.81 | 32.68 | 32.56 | 32.82 |
| Receiving voltage (KV) | 32.67 | 32.69 | 32.74 | 32.81 | 32.68 | 32.56 | 32.82 |
| Voltage difference ( KV) | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tap setting (%) | -0.092 | -0.092 | -0.092 | 0.00 | 0.00 | 0.00 | 0.00 |
| % Bus voltage regulation with tap setting | 99.9 | 99.9 | 99.9 | - | - | - | - |

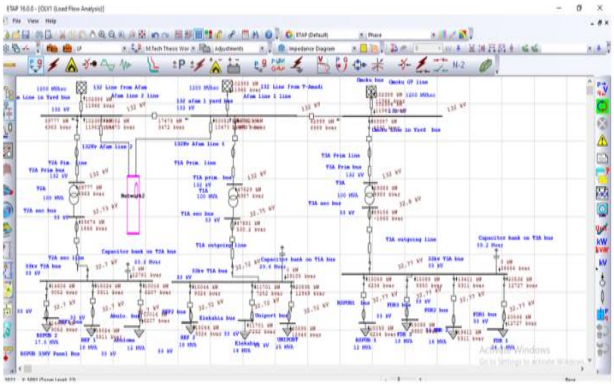

Fig 7. Port Harcourt Mains Transmission Network with Varied Load Tap Transformer Settings.

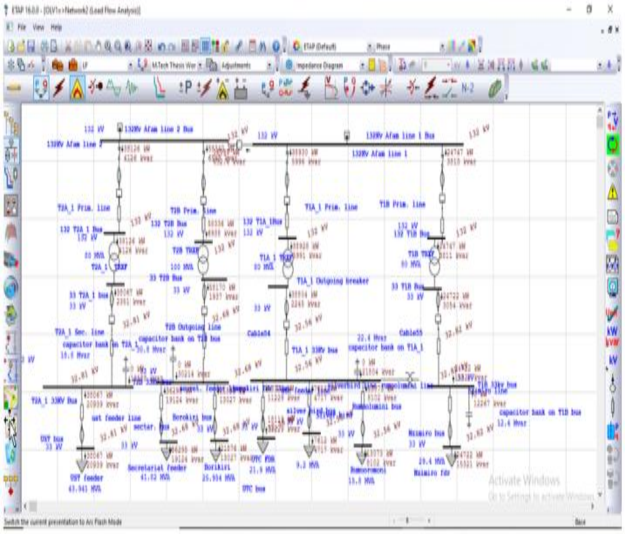

Fig 8. Port Harcourt Town Transmission Network with Varied Load Tap Transformer Settings.

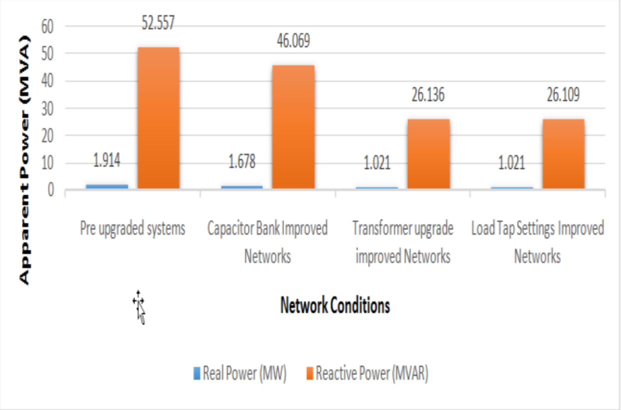

Fig 9. Combined Apparent Power Loss in Port Harcourt Mains and Town Transmission Networks.

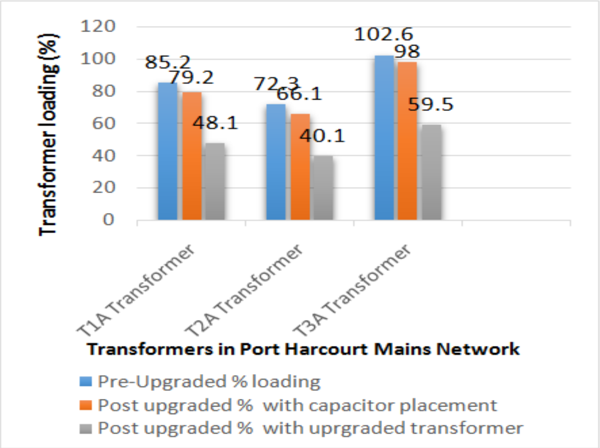

Fig 10. Percentage Load Profiles on Transformers in Port Harcourt Mains Network.

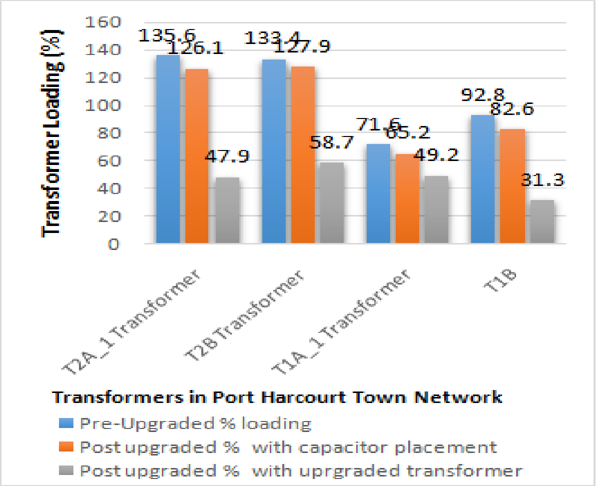

Fig 11. Percentage Load Profiles on Transformers in Port Harcourt Town Network.

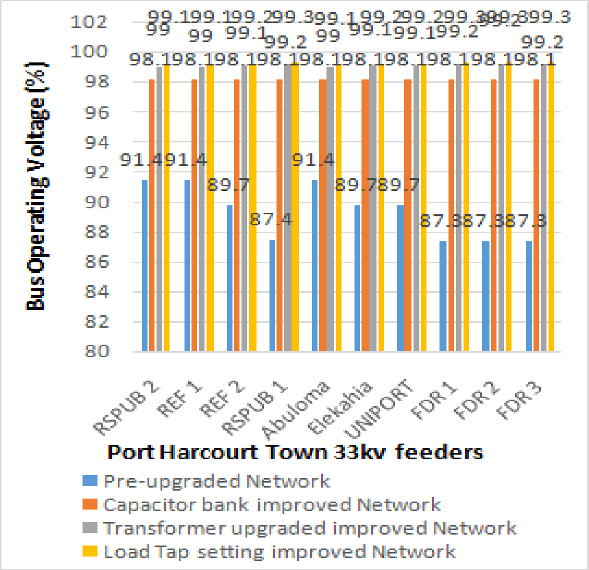

Fig 12. Percentage Load Bus Operating Voltage for Port Harcourt Town.

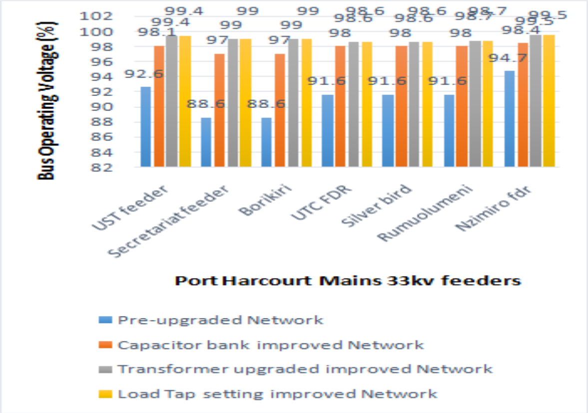

Fig 13. Percentage Load Bus Operating Voltage for Port Harcourt Mains.

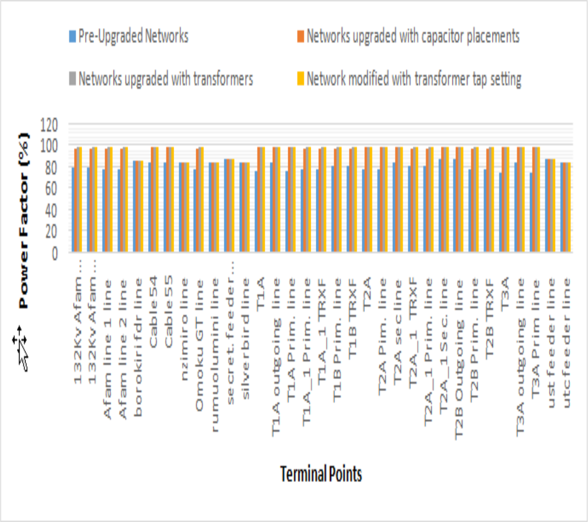

Fig 14. Power Factor Measurements Across Port Harcourt Mains and Town Networks.

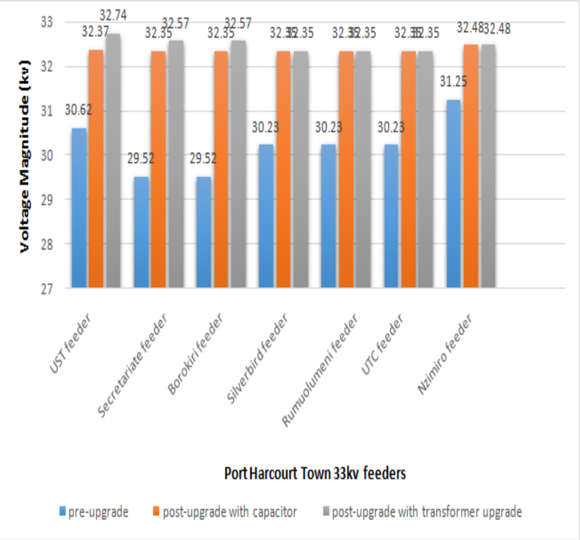

Fig 15. Voltage Magnitude on 33kv Load Feeders in Port Harcourt Mains.

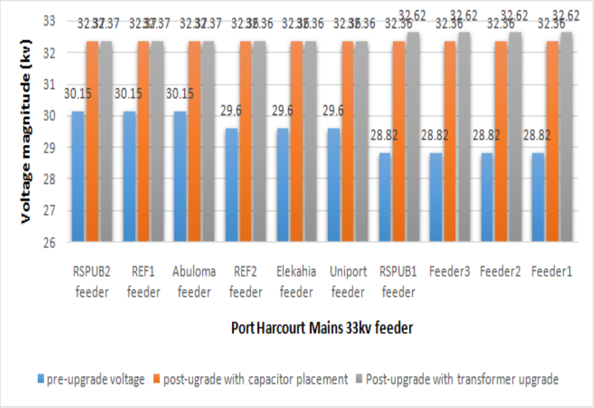

Fig 16. Voltage Magnitude on 33kv load Feeders in Port Harcourt Town.

Table 4. 33kv Bus Voltage levels, Regulation and their connected transformer loading.

| Zone | Measuring Points | | | Measuring Parameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Bus ID | Power source (TRXF) | Connected 33kv feeder | Operational voltage(kv) | | Voltage regulation(%) | | %Transformer loading | |
| | | | | Pre-upgrade | Post-upgrade | Pre-upgrade | Post-upgrade | Pre-upgrade | Post-upgrade |
| Port Harcourt Mains Network | 33kv T2A Bus | 60MVA | RSPUB2<br>REF 1<br>Abuloma | 30.15 | 32.37 | 91.36 | 99.1 | 72.3 | 40.1 |
| | 33kv T1A Bus | 60MVA | REF 2<br>Elekahia<br>Uniport | 29.6 | 32.36 | 89.69 | 99.2 | 85.2 | 48.1 |
| | 33kv T3A Bus | 60 | RSPUB 1<br>FDR3<br>FDR2<br>FDR1 | 28.82 | 32.62 | 87.33 | 99.3 | 102.6 | 59.5 |
| Port Harcourt Town Network. | 33kv T2A_1 Bus | 30 | UST | 30.62 | 32.74 | 92.79 | 99.4 | 135.6 | 47.9 |
| | 33kv T2B Bus | 45 | Secretariate<br>Borokiri | 29.52 | 32.57 | 88.6 | 99.0 | 133.4 | 58.7 |
| | 33kv T1A_1 Bus | 60 | UTC<br>Silverbird<br>Rumuolumeni | 30.23 | 32.35 | 91.61 | 98.6 | 71.6 | 49.2 |
| | 33kv T1B Bus | 30 | Nzimiro | 31.25 | 32.48 | 94.69 | 99.5 | 92.8 | 31.3 |

Table 5. Summary of Reduction in Power losses by System Various Improvement Techniques.

| Power | Pre-Upgraded Networks | Post-Upgraded sequence of improvement techniques | | | Overall % Reduction |
|---|---|---|---|---|---|
| - | - | Capacitor placement | Transformer upgrade | Transformer load tap setting | - |
| Real (MW) | 1.914 | 1.678 | 1.021 | 1.021 | 46.66 |
| Reactive (MVAR) | 52.557 | 46.069 | 26.136 | 26.109 | 50.323 |
| Apparent (MVA) | 52.592 | 46.10 | 26.156 | 26.129 | 50.318 |

## 2. Discussion:

The substation parameters as shown in Table 1 as well as the transmission line parameters were used to design the networks on ETAP simulation environment. A base case simulation using the Newton Raphosn method was conducted. Evidences of the research showed that the Port Harcourt Mains and Transmission networks were both in critical operational states, the red color code in ETAP indicated this at first glance, as seen in Fig.1 and 2 respectively.

On analysis, the problems of both networks were traced to the fact that, all the 47 33kv buses were operating at voltages beyond the +/-5% permissible threshold and transformers in both networks were all been operated outside the operational limit. This anomaly led to a system with poor transmission efficiency and high apparent power losses. The need to improve the system for reliable and efficient power transmission led to utilization of three major improvements techniques in a stepwise manner, viz: capacitor placement, transformer upgrade and load tap setting modification and the results were fascinating. Fig. 9 shows that the initial simulation model of the pre-modified networks showed that their net apparent power loss was at 52.5912MVA, on introducing the the adequate capacitor banks at load buses the entire system losses now reduced to 46.0995MVA which amounted to 12.35% in loss reduction.

When the required transformer capacities the entire system losses reduced to 26.155MVA which was 43.26% of the previous loss and load tap settings were put in place the entire system losses now reduced to26.129MVA, this equates to 0.099% of the previous improvement technique. The improved techniques reduced the overall reactive power loss by 50.32% from 52.5912MVA to 26.129MVA.

Transformer T1A connected to REF2, Elekahia and Uniport feeders which has a total load of 46.589MW (58.2363MVA) and this resulted in a 85.2% loading. When capacitor bank of optimal size was put to the feeder the loading percentage reduced to 79.2%. However, this was still unacceptable as it was still outside the preset transformer loading limit (<60%). An 80MVA transformer was proposed for that feeder, taking consideration of future loading expansion and thus reduced the loading to 48.1%.

This result was a healthy one for the network. Similar practice was done to Transformer T2A feeder were the total load of 59.06MVA from RSPUB2, RF1 and Abuloma feeders was seen and the final loading percentage reduced to 40.1%. Conversely, T3A which was connected to RSPUB1, Fdr3. Fdr2 and Fdr1 feeders with total load of 72.02MVA with initial critical loading of 102.6% was ultimately reduced to 59.5%. With all these improvement algorithms in place the initial percentage loading on all transformers within the Port Harcourt Mains network was greatly improved as all transformers was seen to be operating below 60% loading mark. Similar practice was done for the transformers in Port Harcourt town and the results were obtained and recorded in Table 2.

Tables 4 shows that all the buses were in an under voltage state, the introduction of the various improvement techniques improved the various bus voltage levels as well as regulations to the permissible operational limits. It will be seen that all 7 33kv feeders within the Port Harcourt Town station were in an under voltage state. When various improvement actions were put in place, voltage magnitude levels also improved. UST feeder improved by 6.92%. Critically under voltage Secretariate and Borokiri feeders improved by 10.33% to 32.57KV. Silverbird, Rumuolumeni and UTC feeders improved from 30.23KV to 32.35KV which translates to 7.01% and finally, Nzimiro feeder improved by 3.93%. Similar to the Port Harcourt Town network. The Port Harcourt Mains network all had bus voltage magnitudes in an under voltage state which also experienced improvements in its voltage magnitude levels as the overall system was improved. RSPUB2, FEF1 and Abuloma feeders were all improved by 7.36%. REF2, Elekahia and Uniport feeders improved by 9.32%. Lastly, RSPUB1, Feeder3, Feeder2 and Feeder1 improved from 28.82KV to 32.62KV which corresponds to 13.18%.

The P.F across 33 terminals within the Port Harcourt Mains and Town transmission networks were closely monitored and analyzed in Fig.14, it showed that average power factor across the pre-upgraded networks was at 81.62%. When the systems were upgraded with capacitors the power factor improved to 95.70%, this was a perfect working power factor across both networks. Consequently, with the introduction of upgraded transformers into the network the average power factor improved to 96.56%. This value remained unchanged even with the modification of the load tap setting. 95.56% (0.9556 P.F) was the average final power factor as seen across the final improved network. Though Rumuolumeni, Secretariate, Silverbird and UTC feeder power factors remained unchanged throughout the improvement practices.

## V. CONCLUSION AND RECOMMENDATIONS

Load flow studies forms a fundamental part of any power system operation and planning process. The operational frame of load flow studies entails evaluating the real time operational condition of the system, evaluating the best and ideal system operational parameters required for an efficient power system. The planning process incorporates the various means a load flow study is used to accommodate possible future expansions across any desired network. Operation and planning aspects of load flow studies were employed in the course of this work across the Port Harcourt Mains and Town transmission networks.

The prevailing conditions of both networks were obtained and evaluated. A load flow study in ETAP using the Newton Raphson approach was employed for this study and this showcased the operational conditions of the Port Harcourt zone networks. Simulation findings showed the eminent need for various improvements algorithms. As elaborately discussed in chapter 3 and 4 of this work, the three major system improvement algorithms, viz: capacitor bank introduction, transformer upgrade, transformer load tap setting, were considered in this work yielded an almost perfect improved system. These improvements methods were introduced in a step-wise manner and their corresponding outputs were observed and recorded. The final improvement approach yielded excellent results and this was used to measure the new overall system performance, viz: Apparent power losses, Percentage loading of transformers, Percentage operational Bus voltage profiles, Power Factor (P.F) and Load bus voltage magnitude.

The combined apparent power losses of the Port Harcourt Mains and Towns Transmission networks reduced by 50.32%. The percentage loading conditions on all transformers within both networks were observed to be below 60% loading. The percentage operational bus voltage of all buses within both networks were seen to be in an optimal loading condition. An almost near unity (100%) power factor was seen across the network as the efficiency of power transmission was greatly improved. Lastly, the load bus voltage magnitudes levels as seen across all 17, 33KV outgoing buses were seen to be operating within the normal operational limits.

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