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EVALUATION OF TRANSMISSION DISTRIBUTION LOSS MINIMIZATION FOR POWER SYSTEM PLANNING, USING B-COEFFICIENT-MATRIX TECHNIQUES

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Abstract

Losses in power system are inevitable no matter how it is designed some electrical components will still dissipate an amount of heat-losses due to technical/non-technical scenarios particularly, in Nigerian electricity power supply demand scenario's. That is the power demanded losses is far greater than the electricity supply. This obviously mean that transmission expansion planning is determined by peak energy demand. These activities have led to uncontrollable outages (black-out) in the study zone under investigation. Therefore, this dissertation is aimed to address this incessant power system loss on the view to improve power quality. The research work essentially adopted the application of B-factor technique (using matrix operations), in order to determine the losses in the network under review on the view to model the existing system case under investigation with simulink-block representation based technique in order to determine probable mitigation strategy for purpose of system reliability. The system configuration was modeled at different power factor of 0.8, 0.95 and 0.98 lagging with the aim to penetrate 0.3MVAR reactive power (capacitor bank) into the network. The result shows that at 0.8 power factor the losses reduction was 378.55KW giving voltage level of 380V, similary, for a power factor of 0.95 the losses reduced to 266.25KW with voltage level of 395V. 400V respectively. Evidently, with 0.9 power factor the losses reduced to 379.45KW with voltage level of 395V. having known that electricity power supply is the principal components for day to day activities particularly to derive the socio-economic scenario's. Therefore, availability of electric power supply is a necessity for the sustenance of economic growth, this study has considered a loss-minimization scenario for the penetration for power electronic controllers (capacitor bank) as a mitigation strategy for reliable power supply.

Keyword: Buses, B-Coefficient, Distribution, Transmission, Losses, Voltage profile.

1.0 Introduction

Bulk power evacuation is the transmission of electric energy from one generating source to a substation. This transmission electrical energy is enabled by interconnected network of lines. This phenomenon is different from the local wiring between customers and high voltage substation as in the case of electric power distribution (Rizy *et al.,* 2010).

The combination of the distribution and transmission network is globally called "power grid" In Nigeria, New Zealand, Malaysia, India it is called "National Grid".

The energy systems are faced with the challenge regarding how to reach a clean, reliable and economical energy supply (Ackermann, *et al.,* 2017).

1.1 Problem Statement

Electric power is generated in various generating station and transmitted through transmission - line network and then further distributed to the consumer (at the receiving end). The system consists of generator bus, load bus and slack bus etc. The operation of these buses are categorized as bus voltage, phase angle, active and reactive power. The high demand for electric power in the 21^{st} century which has prompted the call for overhauling of electric power system and deregulation of power sector. Therefore it has become more important to quantify the power transfer capability for purpose of accessing the thermal line capability, line flow limits, bus voltage limit, voltage stability limits in order to avoid overload on the existing network, that is when the transmission line systems is unreliable or incapable of transferring power from one zone to the next area of consumption under consideration and condition, it then becomes a serious problem. This work has identified strongly the overdependence of the 132kv transmission line in the study case without a serious decongestion, these has seriously led to; i. Regular occurrence of outages due to lower cross sectional area of conductor as against the demand load (from receiving end), ii. Extra-ordinary power loss in the network due to overload, iii. Poor power capacity transfer that can be delivered over the lines without violation of the statutory limit condition, iv. Requires higher cost for loss maximization or reduction for purpose of effective power quality and voltage profile, which is favorable for the economy.

1.2 Aim of this Research.

The aim of this work will consider the 132kv transmission loss- minimization for power system expansion and planning using B- factor coefficient technique.

1.3 Objectives of this Research.

To minimize or reduce transmission losses and probably improve the system efficiency for purpose of effective performance, required the consideration of the following:

i. Representation of a single line diagram showing the activities for the system component performance.
ii. Necessary data collection for the study case, for reviewing existing condition,
iii. Determination of existing operating conditions for purpose of avoiding system collapse (that is to prevent the system from operating beyond the declared statutory condition),
iv. To validate the existing system as against improved condition of the network.

1.4 Scope of the Research.

The consistent occurrence of transmission power losses, especially in the developing countries is becoming a major concern to the electricity utilities and consumers. That is, the level of losses in the system affects the amount of power needed to be sold therefore is a factor to be considered when deciding electricity tariff of a utility companies.

Considering the severe impact (losses), on tariff as well as the economy, therefore this work will consider the activities of the study case in Afam power station to Port-Harcourt main (zone- 2).

2.0 Literature Review

Energy is a basic necessity for the economic development of a society. Energy exists in different forms but the most important one is the electrical energy, (Hung, 2010).

In Nigeria, the electric power demand is far beyond the supply. The generated power is conveyed through transmission lines and further stepped down for distribution via distribution substations which spans from one location to another. The expansion of power generation and transmission infrastructure has been greatly affected due to poor investment as can be found in Nigeria, and other developing countries (Acharya, 2006).

Losses in power system are inevitable no matter how it was designed. (De Queiroz & Lyra, 2006). The Depezo loss formula and loss factor, make use of system parameters in computing losses in the losses. The differential power loss, power flow methods and others are explicitly illustrated.

Electric power losses are wasteful energy caused by external factors or internal factors, and energy dissipated in the system (Gupta, *et al.*, 2008). They include losses due to resistance, atmospheric conditions, theft, miscalculations, etc, and losses incurred between sources of supply to load centre (or consumers).

The balance between generation and load plus losses has to be maintained when searching for optimal operating conditions. While the load distribution is assumed to be known and the plant generation is being determined, losses correspond to an unknown variable that has to be evaluated. (Wang 2014).

This evaluation is done by the various methods which would be discussed. Loss minimization and quantification is very vital in all human endeavour. In power system, it can lead to more economic operation of the system. If we known how the losses occur, we can take steps to limit and minimize the losses (Kersting, 2010).

In power system, in expanding transmission network lines, transmission expansion planning (TEP) is generally determined by peak demands. There are many uncertainties involved in transmission expansion planning (TEP) in a deregulated power industry, such as the load predictions of distribution companies, the operating and bidding information of the generation firms, regulation and policy charges (Onohaebi,2017)

3.0 Materials and Method

3.1 Materials Required for Power System

i. The analysis of loss-minimization in transmission of power required;
ii. Reformation of power system component in order to minimize losses.
iii. Data collection from Transmission Company of Nigeria (TCN), Port Harcourt Electricity
iv. Distribution Company (PHEDC), etc. for analysis of system power loss behavior,
v. Single line diagrams from Afam Power Generation to Zone 2 (Port Harcourt mains),
vi. Conductor cross-sectional area (overhead transmission line parameters).

3.2 Method of Analysis

The research work will consider the application of B-factor coefficient techniques to analyze transmission loss minimization in power system, in order to save cost thereby reducing successive losses in the network.

3.3 Formulation of B-Coefficients Technique

The B-coefficient are the loss coefficients, they are taken to be constant and appears as if accuracy is anticipated when real operating states are close to the base case state used to calculate the coefficients. Transmission losses is expressed by the B-losses coefficient, as a function of outputs of all generation.

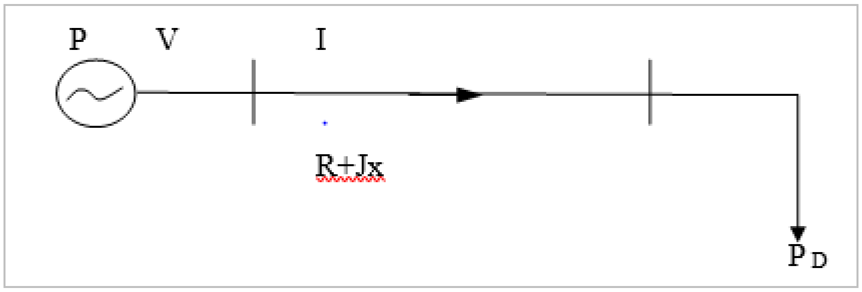

Figure 1: **Single line diagram consisting of a generation and a load**

3.3.1 Determination of B– coefficients

The power generated is given by

$$P = |V||I|\cos\theta \tag{1}$$

where
P = Power generated in KVA
V = Generation voltage in Volts
I = Current in Amperes
Cosθ = Power Factors

The current from equation (1) is given as;

$$|I| = \frac{P}{|V|\cos\theta} \tag{2}$$

Power loss in the system is given as;

$$P_L = |I|^2 R \tag{3}$$

Recall $t = |I| = \frac{P}{|V|\cos\theta}$

$$\therefore P_L = \left(\frac{P}{|V|\cos\theta}\right)^2 R \tag{4}$$

$$P_L = \frac{P^2}{|V|^2 \cos^2\theta^R} \tag{5}$$

The power loss of the system is given by the summation of all the losses from the different buses.

$$P_L = |I_1|^2 R_1 + |I_2|^2 R_2 + |I_3|^2 R_3 \tag{6}$$

$$=\left(\frac{P_1}{|V_1|\cos\theta_1}\right)^2 R_1+\left(\frac{P_2}{|V_2|\cos\theta_2}\right)^2 R_2+\left(\frac{P_1\cos\alpha}{|V_1|\cos\theta_1}+\frac{P_2\cos\beta}{|V_2|\cos\theta_2}\right)^2 R_3 \quad (7)$$

$$=\left(\frac{P_1}{|V_1|\cos\theta_1}\right)\left(\frac{P_2}{|V_1|\cos\theta_2}\right)xR=\left(\frac{P_1}{|V_1|\cos\theta_1}\right)\left(\frac{P_2}{|V_1|\cos\theta_2}\right)xR+$$

Where $\frac{P_1\cos\alpha}{|V_1|\cos\theta_1}+\frac{P_2\cos\beta}{|V_2|\cos\theta_2}$ (8)

From equation (7), we can deduce that;

$$P_L=B_{11}P_1^2+B_{22}P_2^2+B_{12}P_1P_2 \quad (9)$$

The matrix representation of the above loss equation becomes:

$$P_L\ =P_G^2BP_G \quad (10)$$

For a total of K sources

$$P_G=\begin{bmatrix}P_G\\P_{G1}\\\vdots\\P_{GK}\end{bmatrix}\ \ and\ \ B=\begin{bmatrix}B_{11} & B_{12} & ....B_{1K}\\B_{21} & B_{122} & ....B_{2K}\\\vdots & \vdots & \vdots\\B_{K1} & B_{K2} & ....B_{KK}\end{bmatrix} \quad (11)$$

Where;

P_G^T Is the transpose of P_G

The B-coefficient are dependent on the parameters of the system network, configuration, plant power and voltage etc. number of assumption are necessarily made for simplification.

For a two area system, m =n = 2.

$$\therefore\quad B_{mn}=\begin{bmatrix}B_{11} & B_{12} & .\\B_{21} & B_{22} & \end{bmatrix} \quad (13)$$

In power system, B_{12}= B_{21},

Thus

$$P_L\ =\begin{bmatrix}P_{G1} & P_{G2}\end{bmatrix}\begin{bmatrix}B_{11} & B_{12} & .\\B_{21} & B_{22} & \end{bmatrix}\begin{bmatrix}P_{G1}\\P_{G2}\end{bmatrix} \quad (14)$$

3.3.2 Determination of Penalty Factors

The penalty factor bus 1, plant 1 is given as;

$$L_1 = \frac{1}{1 - \frac{\partial P_L}{\partial P_1}} \quad (15)$$

Penalty factor for Bus 2, for plant 2 given as,

$$L_2 = \frac{1}{1 - \frac{\partial P_L}{\partial P_2}} \quad (16)$$

3.3.3 Determination of plant loadings; P1 and P2

$$\lambda = \frac{1}{1 - \frac{\partial P_L}{\partial P_1}} * \frac{dC_1}{dP_1} \quad (17)$$

$$\lambda = \frac{1}{1 - \frac{\partial P_L}{\partial P_2}} * \frac{dC_1}{dP_2} \quad (18)$$

3.3.4 Determination of Transmission Loses

$$P_L = B_{11}P_1^2 + B_{22}P_2^2 + B_{12}P_1P_2 \quad (19)$$

3.3.5 Determination of received power P1

$$P_D = P_1 + P_2 - P_L \quad (20)$$

3.3.6 Determination of efficiency of transmission system

$$\eta = \frac{P_D}{P_1 + P_2} 100 \quad (21)$$

Manual Calculation

Case 1: Determination of B– coefficients

$$\begin{bmatrix} B_{11} & B_{12} & . \\ B_{21} & B_{22} & \end{bmatrix} = \begin{bmatrix} 0.015 & 0.001 \\ -0.001 & 0.02 \end{bmatrix}$$

$B_{11} = 0.015$, $B_{12} = 0.001 = B_{21} = 0.001$ and $B_{22} = 0.02$

Using power loss coefficient technique equation from equation (9)

$$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$$\frac{\partial P_L}{\partial P_1} = B_{11}P_1 + 2B_{12}P_2$$

$$\frac{\partial P_L}{\partial P_1} = 2 \times 0.015P_1 + 2 \times -0.001P_2$$

$$= 0.3P_1 - 0.002P_2$$

$$\frac{\partial P_L}{\partial P_2} = 2B_{12}P_1 + 2B_{22}P_2$$

$$=2(-0.001)P_2 + 2(0.02)P_2$$

$$\frac{\partial P_L}{\partial P_2} = 0.4P_2 - 0.002P_1$$

Case 2: Determination of Penalty Factors

The penalty factor bus 1, plant 1 is given as;

$$L_1 = \frac{1}{1 - \frac{\partial P_L}{\partial P_1}}$$

$$L_1 = \frac{1}{1-(0.03P_1 - 0.002P_2)}$$

Penalty factor for Bus 2, for plant 2 given as,

$$L_2 = \frac{1}{1 - \frac{\partial P_L}{\partial P_2}}$$

$$L_2 = \frac{1}{1-(0.04P_2 - 0.002P_1)}$$

Now $IC_1L_1 = IC_2L_2 = \lambda$

Where λ is the Langrangian multiplier

Case 3: Determination of plant loadings; P_1 and P_2

$$\lambda = \frac{1.0P_1 + 85}{1-(0.03P_1 - 0.002P_2)} = \frac{1.2P_2 + 72}{1-(0.04P_2 - 0.002P_1)}$$

or

$5.5P_1 – 0.3P_2 – 62 = 0$

$7.2P_2 – 0.3P_1 – 78 = 0$

Using determinants matrix to determine P_1 and P_2 respectively as;

$$\begin{bmatrix} P_1 & P_2 \\ 5.5 & -0.3 \\ -0.3 & 7.2 \end{bmatrix} = \begin{bmatrix} 65 \\ 78 \end{bmatrix}$$

then

$$D = \begin{bmatrix} 5.5 & -0.3 \\ -0.3 & 7.2 \end{bmatrix} = 39.51$$

$$D_{P1} = \begin{bmatrix} 65 & -0.3 \\ 78 & 7.2 \end{bmatrix} = 491.4$$

$$Dp_2 = \begin{bmatrix} 5.5 & 65 \\ -0.3 & 78 \end{bmatrix} = 448.5$$

$$P_1 = \frac{Dp_1}{D} = \frac{491.4}{39.51}$$

P_1 = 12.437MW

Similarly

$$P_2 = \frac{Dp_2}{D} = \frac{448.5}{39.51}$$

P_2 = 11.35MW

Case 4: Determination of Transmission Loses

From the values of P_1 and P_2, we can easily determine transmission losses of the system

P_1 = 12.437MW, P_2 = 11.35MW

transmission losses given as

$$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$= 0.015(12.437)^2+2(-0.001)\ (12.437x11.35)+0.02(11.35)^2$

P_L = 4.6MW

Case 5: Determination of received power P_1

$P_D = P_1+P_2 - P_L$

= 12.437 + 11.35 – 4.6

P_D = 19.187MW

(

Case 6: Determination of efficiency of transmission system

$$\eta = \frac{P_D}{P_1 + P_2} 100$$

$$= \frac{19.187}{12.437 + 11.35} 100$$

η =80.66%

Scenario 2: (two-bus system)

Data 2: B – coefficients from system

$$B = \begin{bmatrix} 0.001 & -0.0005 \\ -0.0005 & 0.0024 \end{bmatrix}$$

Assuming the incremental production costs of two units are:

$$\frac{dC_1}{dP_1} = 0.08P_1 + 16N/MWh$$

$$\frac{dC_2}{dP_2} = 0.08P_2 + 12N/MWh$$

The Langrangian multiplier $\lambda = 20$

4.0 Result and Discussion

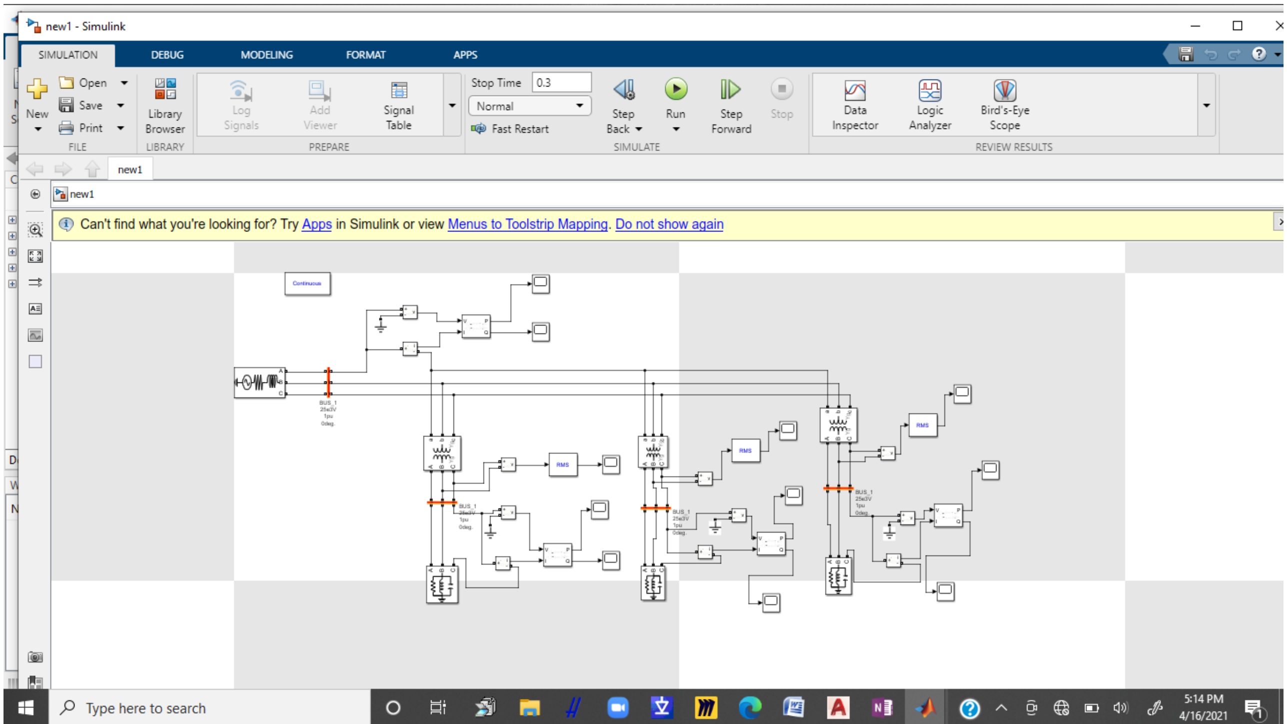

Figure 1: Matlab Simulink Block Representation of Three-Phase Distribution Transformer (Without Simulation)

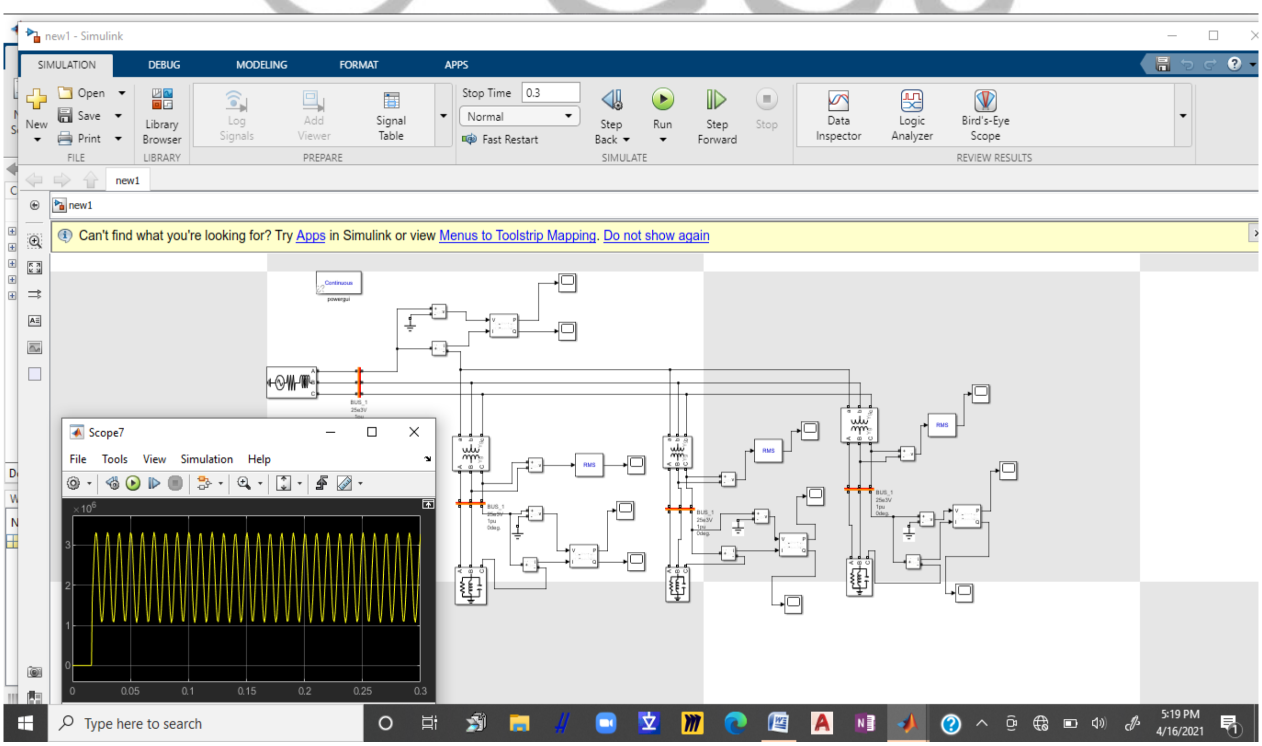

Figure2: Matlab-Simulink Block Representation of Three-Phase Distribution Transformer (with Simulation)

Figure1: shows the Matlab Simulink block representation of three-phase distribution transformer on the study case under investigation (without simulation).

Figure2: shows the simulated Matlab Simulink block representation of three-phase distribution transformer on the study case under investigation. The activities of the distribution transformer overload in the first transformer location (Nwachukwu distribution transformer capacity) was investigated and the result from the transient simulation of the study shows that reactive power losses in the network required a relief transformer (300KVA) with the penetration of 0.3MVA capacitor bank. which impacted positively in mitigating system overload and losses for improved reliable power supply and voltage profile. Similarly, the activities of the second and third distribution transformer was investigated and the result from the transient simulation of the study shows that the third transformer location (Ogbodo/Apu) which necessitate strong mitigation for purpose of improve power quality and voltage profile.

Table 1: Bus Voltage Magnitude and Phase Angle

Bus	**Bus Transformer Terminals**		
	1	2	3
Voltage Mag.	$380V$	$380V$	$380V$
Voltage Phase Angle	0.75	0.75	0.75

Table 2: Bus voltages at transformer tapping at $\mathbf{0.95}pf$lagging

Bus	**Bus Transformer Terminals**		
	1	2	3
Voltage Magnitude	$400V$	$400V$	$400V$
Voltage Phase Angle	0.8	0.81	0.80

Table 3: Bus voltage at transformer tapping at 0.9 power factor lagging

Bus Voltage/ Magnitude	**Bus Transformer Terminals**		
	1	2	3
Voltage Magnitude	$395V$	$395V$	$395V$
Voltage Phase Angle	0.78	0.78	0.78

Consideration of power system with three (3) distribution transformer ($T_1, T_2 and\ T_3$) captured in the study area under investigation at Eneka Community Obio/Akpor Local Government Area of Rivers State) which are represent in Matlab–Simulink representation that measured the activities of power losses, active and reactive power delivered to the substation with capacity ($T_1 = 500KVA, at\ 0.8\ pf$), ($T_2 = 300KVA, at\ 0.95\ pf$) and ($T_3 = 500KVA,\ at\ 0.9\ pf$) respectively. Particularly to the Nwachukwu, Chiomana and Ogbodo/Apu substation under details study. The study case was simulated under different conditions of power factors 0.8, 0.95 and 0.9 respectively with respect to the power delivered to the

respective transformers ($T_1, T_2 and T_3$) on the view to identify the level of losses in order to minimize and enhance power quality and efficient voltage profile distribution to the three (3) study zones. Presentation of a three (3) phase distribution transformer network for the zone under study are identified.
Following from the simulation reports at 0.8 lagging power factor, the system losses was $375.55KW$ with voltage at $380V$ bus-terminalks of the distribution transformer. Similarly at 0.95 lagging power factor, the system losses was $266.25KW$ with voltage level at $400V$ at the terminals of the transformer ($T_1, T_2 and T_3$) respectively. At power factor of 0.9 lagging the losses was $379.45KW$ with a voltage level of $395V$ at the terminals of the distribution transformer ($500KVA, 300KVA$ and $500KVA$).

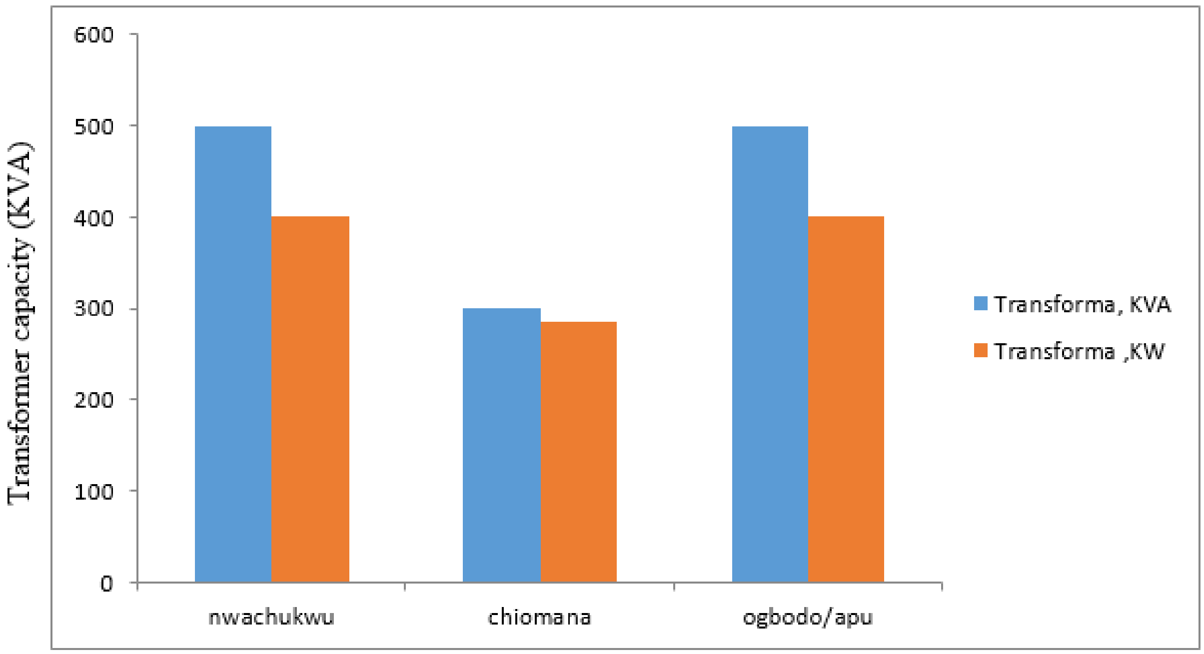

Figure 3: Substation/location of $11/415KV$ distribution transformer

Figure3: shows the distribution of transformer utility with respect to substation locations loads. The consumption pattern in Nwanchukwu and Ogbodo/Apu are almost loaded its full capacity followed by Chiomana feeder. This has makes the network to experience losses due to overload. A relief transformer is needed for improved performance, for a network of 11/0.415KV.

5.0 Conclusion and Recommendation

I. Conclusion

The study examined the existing electric power supply at Rukpokwu 11kv distribution network with consideration of three (3) distribution transformer capacity of 500kVA, 300kVA, and 500KVA, at Nwachukwu, Chiomana and Ogbodo/Apu respectively. Matlab/ Simulink software was used for modeling and simulation of the distribution transformer. Furthermore, transformer load tap charger and feeder bifurcation techniques was used to determine the best operating conditions of the existing system.

II. Recommendation

Based on the findings, the following recommendations are highlighted to improve the reliability of the distribution system.

i. Upgrade and replacement of undersized cable, transformer capacity.
ii. Fixing capacitor banks compensator where necessary in order to improve power quality and voltage profile.
iii. The use of tap charger transformers and regulating transformer switches capacitor bank.
iv. Minimizing losses by reducing either the resistances or impedance of the transmission and distribution network.
v. Appropriate power transformer capacity should be installed in the affected feeders to free uploaded in the network.
vi. Regularly simulated buses and feeder in order to know all the local parameters in the network for improvement power quality.
vii. Feeder should be re-conducted or upgraded to enhance proper maintenance.

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