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Improvement of Power Supply in the Distribution Network of Obio Akpo Local Government Area of Rivers State.

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ABSTRACT
The study examined the improvement of Power supply in the distribution network of Obio/Akpor local government area of Rivers State. Power supply to the Obio/Akpor is via two (2) 132Kv transmission station namely Port Harcourt mains duly linked to Afam power station and duly linked to Omoku power station. The network was modelled in Electrical Transient Simulation software (ETAP19.1) and load flow performed using Newton-Raphson technique. The result obtained from the pre-upgrade network simulation shows the following buses violated the statutory limit condition of 0.95- 1. 05p.u Aba Rd (89.41%), ADP (90.06%), Agip (89.41%) Eligbolo (88.46%), Elimgbo (88.98%), FGC (88.46%), Iguruta (88.98%), Location (89.84%), Market Rd (90.06%), Obi-Wali (88.46%) Ohakwe (85.48%), Okoh Rd (89.41%) Old Aba Rd (85.90%) Rukpokwu (88.46%) Rumuogba (85.90%), Rumuorolu (85.90%). Similarly, over loaded transformers are T1 (96.80%), T6 (96.50%), T8 (104.30%), T9 (123.30%), T11 (98.10%), T14 (143.90%), T1A (113.40%). Also, the total real and reactive power losses are 2787.239 kW and 1660.75 kvar. However, a cost effective optimization techniques was used to improve the network and the operating values after optimization for the buses and transformers are Aba Rd (98.18%), ADP (97.91%), Agip (98.18%), Eligbolo (98.18%), Elimgbo (97.45%), FGC (98.18%), Iguruta (97.45%), Location (97.55%), Market Rd (97.91%), Obi-Wali (98.18%) Ohakwe (97.55%), Okoh Rd (98.18%) Old Aba Rd (96.45%) Rukpokwu (98.18%) Rumuogba (96.45%), Rumuorolu (96.45%). Similarly, over loaded transformers are T1 (41.383%), T6 (41.093%), T8 (44.203%), T9 (51.823%), T11 (41.870%), T14 (60.167%), T1A (57.670%). Also, the total real power loss after optimization is 2233.6 kW and 1785.3 kvar. From the result obtained it is concluded that the proposed optimization techniques impacted significantly in the improvement of the distribution network.
Keywords: *Improvement, Power Supply, Distribution, Feeder, Network, Electric Power Supply.*

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I. INTRODUCTION

The main goal of an electric power system is to increase the uninterrupted, optimum supply of electrical power to the vast number of users that it serves (Uhunmwangho, 2018). An increasing load demand is an ongoing challenge for the distribution system. Conducting a power flow analysis on the distribution system may be done in order to fulfill the requirement for an efficient distribution system improvement (Apoorva, 2018).

The distribution system, which is the most observable component of the power system and is most vulnerable to user criticism, has received significantly less attention as regards upgrading compared to generation and transmission system. The existing distribution system infrastructures are weak and obsolete with high energy losses close to 44% (Sunday, 2015).

As a result, consumers at the distributor ends now often endure load shedding, overload, voltage sags, and irregular power supply.

II. LITERATURE REVIEW

According to Chandra (2014) a capacitor bank is made up of many capacitors that are linked in such a way as to increase the power factor of the system. The arrangement of the capacitor in a typical capacitor bank may be connected in series or parallel units.

Aman (2014) According to the statement, a static capacitor bank in a distribution system improves voltage profile, reduces power loss, and improves power factors. However, they pointed out that the capacitor bank has to be positioned closer to the load centers in order to reap the greatest benefits.

In their research, Mohan and Aravindbabu (2019) suggested an approach for improving voltage stability based on the voltage stability. At various nodes in the distribution systems, reducing losses, voltage profile improvement and the best size and placement of the capacitor bank were examined for the purpose of compensating for reactive power. The result shows the effectiveness of proposed algorithm.

Navpreet (2014) took a concentrate wherein another technique was in the long run proposed. It was really founded on recently arising idea of man-made reasoning standards, for example, the insect state applied in accomplishing ideal capacitor designation in circulation framework arranging. In the proposed method, limits, for example, capacitor exchanging drifters were widely thought of and arrangement got for an arrangement of feeders. They noticed that the framework limit was delivery and decreases in misfortunes are acquired.

Srividya (2013) introduced a new and effective method for determining the ideal position and size of capacitor banks to upgrade a definitive improvement of the voltage profile and decrease of line misfortunes. In their technique, misfortune responsiveness factor was utilized to decide the area of applicant's transport for capacitor positions and Dijkstra calculation was used in discovering the genuine rating of capacitor on that area. The method obviously requires no control variable and treats framework limitations independently. The proposed technique was tried on 33 and 69 spiral appropriation framework was ideal when contrasted and others.

As per Legha (2013) noticed that the power misfortune in appropriation framework relates to around 70% of complete misfortunes in electric influence frameworks. Nonetheless, he called attention to that establishment of shunt capacitor banks on essential feeders of the conveyance frameworks can further develop the power factor, further develop the voltage profile of the feeder, lessens framework misfortune and increment the accessible limit of feeders.

Hamouda (2017) pointed out that transits of reactive components of the current in a power line causes power loss, voltage drop and reduction in line power transmission. In addition, they stated that A distributing system's power loss might go as high as 13%. However, they pointed out that switched capacitor banks are frequently employed to enhance line power transfer, decrease losses, and maintain voltage connection.

Elsheikh (2014) further emphasized the advantages of capacitor installation in distribution systems, including factor correction, bus voltage management, power and energy savings, capacities release for feeders and systems, and energy quality enhancement.

In their view, Siddiqui and Rahman (2012) reaffirmed that installation of shunt capacitors along lines, substations or loads is an effective method of controlling bus voltages. They added that capacitor bank can be connected permanently or as a regulator can be switched on and off depending on the load demand. Also, they noted that capacitors enhance the voltage stability, active power, and system stability in addition to reducing loss.

Chakravorty (2019) also designed a hybrid method responsible for the planning of distribution system. The hybrid technique is conspicuously based on Taguchi and the analytical hierarchy method, paying particular attention to the factors dwelling basically on reliabilitysuch as feeder failure and customer interruption. The proposed technique resulted to an optimum feeder path and substation construction Costs.

Rao (2018) proposed a viable technique which is actually concentrated on Plant growth algorithm for distribution network optimization. The 9, 34, and 85 bus systems were used with the suggested strategy. Results from fuzzy and PSO were examined.He noted thisalgorithm outsmart other known techniques in terms of important yardsticks of performance evaluation used such as speed, losses, voltage profile as well as cost involved.

Network reconfiguration as per Metia (2015) is one of the techniques for misfortune minimization in dispersion frameworks. The procedures are utilized by explicitly opening or shutting tie switches that are in typically open circumstances. It likewise includes sectionalizing of ordinarily shut switches, when this is finished, power will be become diverted.

Li (2012) noticed that network reconfiguration in dissemination frameworks is one of the compelling strategies to accomplish misfortune decrease and further develop conveyance framework robotization. They added that organization can be reconfigured for two reasons; load adjusting and power misfortune decrease in the conveyance framework.

In his view Rugthaicharoencheep (2010) presented that feeder reconfiguration is the most common way of shutting and opening activity of changes in power dissemination framework to change network geography. In his work, the significant and helpfulness of feeder reconfiguration method in lessening feeder misfortune, further develop framework security and dependability was stressed. However, the configuration may vary according to the switching operation by changing the open/close position of the feeder to transferred load current from one feeder to feeder.

Hosseinzadeh (2019) he emphasized in his research that distribution system reconfiguration is a crucial component of operation focused at lowering traditional distribution feed losses and going on to enhance security and reliability to achieve optimal distribution system.

Rao (2010) contends that network reconfiguration for loss minimization, learn the process under typical operating circumstances, and quick service recovery are all necessary for distribution networks planning to be optimum.

Jiansheng (2020) presented new and efficient network reconfiguration techniques in distribution systems. They noted that the proposed technique can be applicable to both balanced and unbalanced condition and very effective in reducing line losses and improving system security.

Chakravorty (2012) extensively explained that optimization operation of distribution system particularly in the area of distribution automation has been a growing interest. He noted that distribution networks may be built radially for efficient control and operation in order to reduce system power losses and relieve the occurrence of overloading. It also goes a long way to enhance the achievement of the optimal operating conditions of the system in general.

In addition, Charles (2015) reaffirmed that about 13% of total power generation is squandered in the distribution network as line losses. By switching the On/Off status of switch and tie lines, they observed that network reconfiguration is an effective strategy for lowering losses and enhancing the dependability of the power supply. Network Reconfiguration is also another technique used to save energy.

Building new parallel express feeders whose loads must be balanced or shared by the feeder Qureshi is known as feeder bifurcation (2019).

Distribution generation is a small-scale power production method, according to DPCA (2012), that produces electricity at a location closer to customers than central station generation.

The reduction in feeder loss is one of the main effects of dispersed generation in a distribution system, according to Philip (2020). The placement of DG Units to minimize loss, they said, is comparable to the placement of capacitor banks to minimize loss. In contrast to capacitor bank, which only gives reactive power, DG contributes both active and reactive power in both scenarios.

EPCOR (2015) further buttressed the benefits of distribution generation in distribution system as follows:

1. DG has a low capital cost because of small size of generating unit.
2. It reduces the need for large infrastructure or upgrade because it can be constructed at the lead centres.
3. It increases power reliability and serves as a back-up or stand by units to consumers.
4. It offers the consumers a choice of meeting their energy demand.
5. It reduces pressure on the distribution and transmission line.

In their work Maheswari and Vijayalakshmi (2012) stated that distribution generation is the most effective method of improving power transfer capability and voltage stability of the distribution system. It helps to meet the increasing demand, enhance efficiency, reliability and operational benefits to the distribution system.

According to Aissaoui (2012) In their study, they made the point that distributed generation, with its quick construction schedule and minimal installation loss, offers an instant response to the rising energy demand. Additionally, they pointed out that the inclusion of DG in the distribution system helps to increase system dependability, safety, and quality of service while also alleviating pressure on transmission and dissemination capacity.

The application of DG allocation algorithms in a networked system with accessible dispersed sources was highlighted by Metia (2015). They observed that whereas networks are often run as passive networks with bidirectional power flow, the addition of DG transforms them into communication links with the same type of power flow. Furthermore, they buttressed that the installation of DG unit in a distribution network has the following advantages such as:

1. Power loss reduction in the network.
2. Decrease congestion in feeder.
3. Increase total energy efficiency.
4. Stability enhancement.
5. Improvement in voltage profile.
6. Improvement in reliability and security.

7. Encouragement for different renewable sources.

However, improper placement and sizing of DG unit may lead negative effect on distribution system. DG units can be classified according to their active and reactive power delivering characteristics.

According to Da Silva (2018) The MWh profit from DG units such solar systems, fuel cells, and micro turbines is increased, but the voltage profile of the system may not be improved. These DG units can only inject power factor.

In a similar spirit, Luis (2011) supported the claim that both asynchronous machine- and voltage source converter-based DG units can inject both active and reactive power. However, changing the power angle may be used to regulate the active and reactive power produced by a PV array using a voltage source inverter (VSI). Last but not least, the DG units used in induction generator-based wind farms may inject power factor but absorb reactive power.

Overview of Power Flow Studies

Power flow or load flow study is a crucial procedure in energy engineering that deals with the systematic investigation of the flow of electric power in a well-connected power grid(Wikipedia, 2016).

Dharamjit (2012) pointed out that a power flow study is seemingly different from the normal circuit analysis. It makes use of conventions and notations such as the concept of single line diagram and its complementary per unit system. Besides, apparent voltage and current components are useful here instead of the usual real components of the current and voltage values.

According to Steven (2019), the main information gotten from a bus operational voltage magnitude and phase angle are studied in terms of power flow.

Das (2016) defended his point of view by pointing out the significance of the knowledge gleaned from the study for the ongoing observation of the conditions in a typical power system. The outcome gained offers the necessary framework for various strategies for system growth in the future to meet rising load demand.

Importance of Power-Flow Studies

1. Power flow analyses are carried out to identify an electricity generation system's steady-state performance. It is utilized to calculate the operational voltage at each bus and the power flow via all circuit branches (Agbetuyi, 2014).
2. It assesses if gear, such as transformer and wires, are overburdened and whether voltages remain within predetermined limits under different emergency scenarios.
3. To determine the requirement for extra generation, inductive or capacitive VAR support, or the installation of capacitor to keep voltage within predetermined limits, power flow studies are frequently utilized (Dorji, 2019).
4. Power flow studies are essential for planned, life and economic, power transfer between utility, control of the current system, and the future extension of that system. (Saadat, 2016).

Power Flow Methods

According to Stevenson (2018), the concept of power flow studyas it involves a system network is an intensive analysis of the working of the network that such that it produces results associated with the steady conditions of the network.

In his view, Ibe (2012) noted that power flow problems involve the bus voltages and line flow of current inside a given network implementing a specific loading schedule are determined. He added that digital solution of the power flow problem requires iterative process by estimating an uncertain bus voltage and continuously computing the added features for each bus voltage until each bus's increase is less than a predetermined lower limit.

Gauss-Seidel Method

According to Sadaat (2016) the repetitive reduction or solution of equations having nonlinear properties is what the Gauss-Seidel iterative technique of conducting load flow studies entails. It was also discovered to be one of the most often employed approaches for resolving power flow issues. In the Gauss-Seidel approach, a set of new factors are first computed using one of the equations, assuming a starting variable. In relation to the computed variable, the solution is instantly updated. The procedure is repeated until the answer converges to a certain number.

Gupta (2016), emphasized the simplicity and benefits of the Gauss-Seidel approach. He emphasized its benefits once more, including its ability to ease the time-constrained nature of such calculations. On the other hand, it also demonstrates a fundamental flaw related to its delayed convergence rate and higher iterations as a result of the increasing number of buses in the network under consideration.

Newton-Raphson Method

According to Wadhwa (2019), the Newton-Raphson method is an incremental approach for converting a collection of non-linear equations to a set of linear equations that was developed from Taylor's linear system and second derivative. In the same vein, Nagrath (2016) stated that the Newton- Raphson method of power flow solution is relatively good and reliable considering the accuracy of solutions it proffers in its analyses.

In addition, Gupta (2016) asserted that the The Newton-Raphson approach takes less time on the computer, needs minimal iterations to attain converge, and is unaffected by slack bus choice and controlling transformers. The disadvantages of the N-R method, however, include complicated solution techniques and additional computations required for each iteration, which results in a lengthy processing time for each iteration.

Fast-Decoupled Method

According to Gupta (2016), the Fast Decoupled Method is a quick and effective way to solve a problem. He observed that the speed and the sparsity characteristic in this approach of admittance matrix is exploited. In addition, it was observed that the large storage capacity constraint and computing requirements observed while executing the very popular Newton-Raphson method may be potentially reduced by introducing certain assumptions. These assumptions may be essentially concentrated on the physical components and properties exhibited by the power network, particularly in high-voltage transmission system. The result of the formulation is described as Fast-decouple Newton- Raphson method.

In his work, Acha (2014) succinctly explained that the number of Jacobian entries required by the Fast-decouple Newton- Raphson hybrid method was adjudged half of those used in Newton-Raphson technique but enjoys the merit of strong convergence characteristics. On the other hand, the Fast Decouple method takes only miniature duration of the time required by Newton- Raphson’s method of iterations.

Properties of Power Flow Solution Method

1. **High computational speed** is significant while managing enormous frameworks, constant applications (on-line), numerous case load streams like in framework security appraisal, and furthermore in intelligent applications.
2. **Low computer storage** is significant for huge frameworks and in the utilization of PCs with little center stockpiling accessibility like smaller than expected PCs for on-line application.
3. **Reliability of solution** is vital that an answer be gotten for poorly molded issues, in blackout reads up and for continuous applications.
4. **Versatility** is the capacity with respect to stack stream to deal with ordinary and extraordinary highlights like the change of tap proportions on transformers, various portrayals of force framework mechanical assembly, and its appropriateness for fuse into additional confounded cycles.
5. **Simplicity** is the simplicity of coding a PC program of the heap stream calculation.

Bus Classification

According to Saadat (2016) a bus is an inter-connection point at which at least one lines, burdens and generators are associated.

In power framework, each transport is related with four amounts, for example, voltage size and stage point, dynamic and responsive power. The initial two out of these parts and the last two are processed through the arrangement of condition contingent on which amount that was indicated (wood, 2016).

Buses are classified into three categories namely load bus, generator or voltage control bus and slack or swing bus:

a. **Load Bus**

In this bus no generator is connected and hence the produced genuine power PG and responsive power PQ is taken as nothing. The genuine and responsive power request is determined at every hub while the voltage and stage point are determined.

b. **Voltage Controlled Bus**

This is additionally called P-V transport, and on this transport the voltage size comparing to age voltage and dynamic power relating to its evaluations are determined. Voltage greatness is kept up with consistent at a predefined esteem by infusion of receptive power. The responsive power created and stage point of the voltage are processed.

c. **Slack Bus**

This bus sets the angular reference for all the other respective buses present in the power system network. In addition, the different magnitudes and phase angles of the various designated voltages, as well as thereal and reactive powers are obtained through solution of equations. Table 2.1 shows the summary of the above discussion in a tabular form as shown below:

Table 1: Summary of Bus Variables

Bus Type	Specified Variables	Unknown Variables
Slack or Swing Bus	$\|V_i\|, \delta_i$	P_i, Q_i
Voltage Controlled Bus	$P_i, \|V_i\|$	Q_i, δ_i
Load or PQ Bus	P_i, Q_i	$\|V_i\|, \delta_i$

III. MATERIALS AND METHOD

Collection of Data

The distribution data shall be collected from the Port Harcourt Electricity Distribution Company (PHEDC) for purpose of analysis and investigation of this base case. The method of analysis in this study case is described according to the respective case of problem formulation.

Materials Requires

i. Load Data
ii. Line Data: ACSR/Gz with cross sectional area of 182mm^2
iii. Electrical Transient Analyzer Program (ETAP 19.1) simulation software.
iv. Power Transformers
v. Single Line Diagram
vi. Capacitor Bank.

Load Data

Table 2: Load Data

ID	Rating	11kV Feeder	MW
Rumuodomaya	1x15MVA	FGC	2.6
		Obiwali	4.3
		Eligbolo	6.6
		Rukpokwu	1.6
Okporo	1x15MVA	Aba Road	4.8
		Agip	5.6
		Okoh Road	2.5
Woji	1x15MVA	Woji	4.7
		Estate	6.1
Eneka Town Hall	2x15MVA	Igwuruta Rd	5.2
		Elimgbu	7.0
Eliozu	1x15MVA	OPM	4.2
		Shell Estate	3.4
		Pipeline	3.2
Akani	2x15MVA	Rumuorolu	4.3
		Old Aba Rd	6.5
		Rumuogba	6.6
		Rumuibekwe	0.8
		Rumukalagbo	3.2
		Glass factory	5.7
NTA	2x15MVA	Ohakwe	4.93
		Location	7.14
		Mgbuoba	4.00
		Ozuoba	6.63
Choba		Aluu	5.61
	1x15MVA	Choba	4.00
		Rumuekini	1.02
Uniport	1x15MVA	UPTH	0.68

		Unipirt	3.83
Rukpokwu	1x15MVA	Market Rd	6.72
		ADP	5.27
Airport	1X15MVA	Airport	1.02

Line Data

i.Resistance of line per kilometer

Resistance, $R = \frac{\rho}{A}\Omega/m$ (1)

Where;

ρ =Resistivity of Aluminum=$2.65x10^{-8}\Omega m$

A = Area of conductor=$182mm^2$

L= Route length of the feeder (m)

ii.Reactance of line per kilometre

$$r = \sqrt{\frac{A}{\pi}} \quad (2)$$

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

$$X = \mu_0 \left(\frac{GMD}{r}\right)\frac{\Omega}{m} \quad (4)$$

Where

A =Area of conductor

r= radius of the conductor

GMD= Geometric mean distance of conductor

D= conductor spacing =4.1m

μ_0= permeability of free space

$$R = \frac{2.65 \times `10^{-8}}{182 \times 10^{-6}} = 0.0001456\ \Omega/m$$

$$r = \sqrt{\frac{182 \times 10^{-6}}{3.142}} = 0.0076108\ m$$

$$D_{GMD} = 1.26 \times 4.1 = 5.166m$$

Table 3: Line Characteristics

Line ID	From	To	L(km)	R(Ω)	X (Ω)
Line 10	PH Mains	Okporo	4.2	0.61152	1.72116
Line 11	PH Mains	Rumuodomaya	13	1.89280	5.32740
Line 12	PH Mains	Woji	5.2	0.75712	2.13096
Line 13	PH Mains	Eneka Town	2.4	0.34944	0.98352
Line 14	PH Mains	Eliozu	9.4	1.36864	3.85212
Line 15	PH Mains	Akani	7.0	1.01920	2.86860
Line 5	Rumuosi	NTA	3.2	0.46592	1.31136
Line 6	Rumuosi	Choba	2.5	0.36400	1.02450
Line 7	Rumuosi	Uniport	2.4	0.34944	0.98352
Line 8	Rumuosi	Rukpokwu	9.4	1.36864	3.85212
Line 9	Rumuosi	Airport	7.0	1.01920	2.86860

Description of Existing Network

Obio/Akpor is a local government area in the metropolis of Port Harcourt located 4° 48’43” N latitude and 7°2’14” E longitude. It is one of the major centers of economic activities in Rivers State and Nigeria at large and play host to many multinational companies and is considered the richest local government in Nigeria. Power supply to the Obio/Akpor is via two (2) 132kV transmission station namely Port Harcourt mains and Rumuosi 132kV. The Port Harcourt Mains is duly linked to Afam power station while the Rumuosi is linked to Ooku power station.

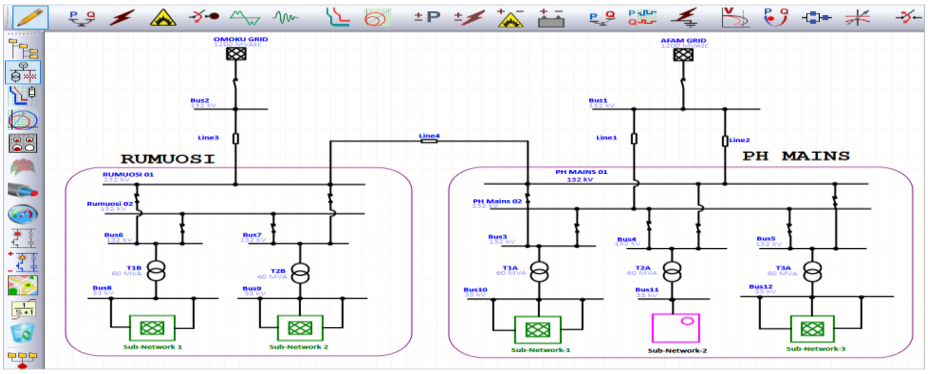


Figure 1 PH Mains and Rumuosi Transmission Substations

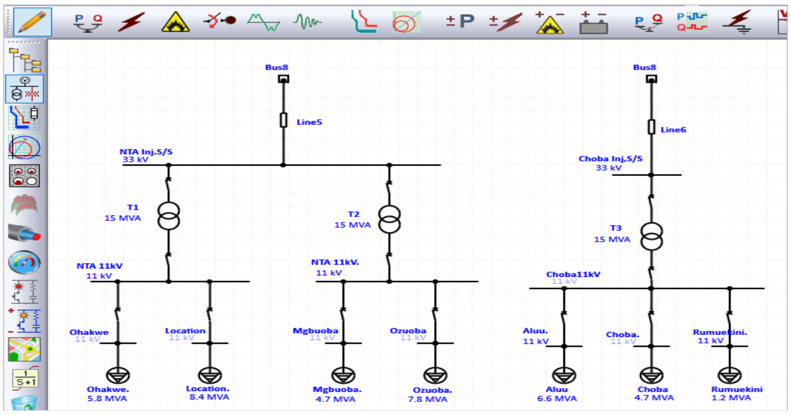


Figure 2 NTA and Choba Injection Substations

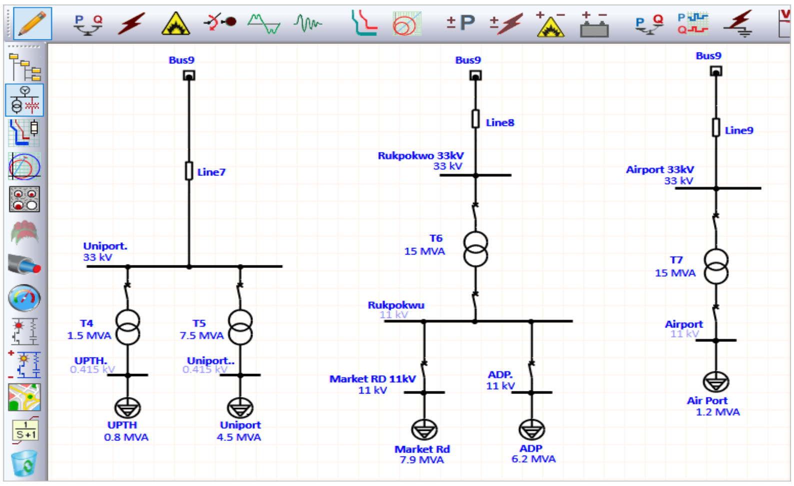


Figure 3 Uniport. Rukpokwu and Airport Injection Substations

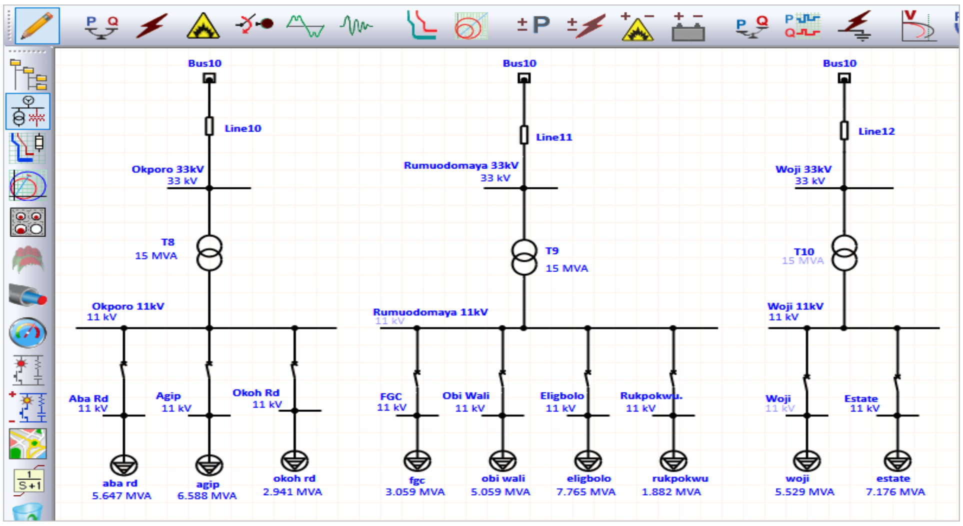


Figure 4 Okporo, Rumuodomaya and Woji Injection Subsation

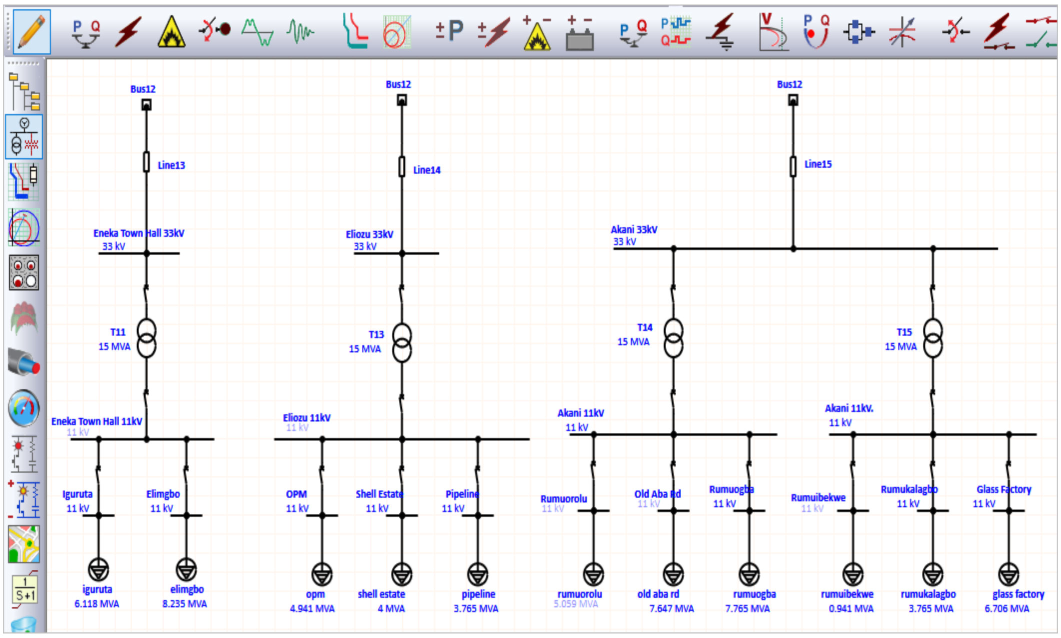


Figure 5 Eneka Town Hall. Eliozu and Akani Injection Subsation

Method Used
Determination of Operating Condition

The Newton-Raphson Power Flow Techniques was used to determine operating condition of the network

For any ith bus,

Let $V_i = V_i\angle\delta_i$ and $V_i^* = V_i\angle-\delta_i$, (5)

For kth bus,

$V_k = V_k\angle\delta_k$ and $Y_{ik} = Y_{ik}\angle\theta_{ik}$ (6)

The real and reactive power injected in the network is given by

$$S_i = V_i I_i^* = P_i + jQ_i \quad (7)$$

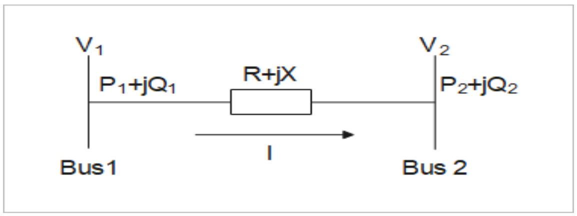
$$I_i = \left(\frac{S_i}{V_i}\right)^* = \frac{P_i - jQ_i}{V_i^*} \quad (8)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} = \sum_{k=1}^{n} Y_{ik}V_k \quad (9)$$

$P_i - jQ_i = V_i^*(\sum_{k=1}^{n} \quad Y_{ik}V_k)$
(10)
$P_i - jQ_i = V_i^*(\sum_{k=1}^{n} \quad Y_{ik}V_k\angle\delta_k + \theta_{ik} - \delta_i)$
(11)
$P_i - jQ_i = \sum_{k=1}^{n} \quad |Y_{ik}||V_i||V_k|[cos\,cos(\delta_k + \theta_{ik} - \delta_i) + j\,sin\,sin(\delta_k + \theta_{ik} - \delta_i)]$
(12)
Separating (3.8) into real and imaginary parts we have,
$P_i = \sum_{k=1}^{n} \quad |Y_{ik}||V_i||V_k|\,cos\,cos(\delta_k + \theta_{ik} - \delta_i)$
(13)
$Q_i = -\sum_{k=1}^{n} \quad |Y_{ik}||V_i||V_k|\,sin\,sin(\delta_k + \theta_{ik} - \delta_i)$
(14)
Where
Y_{ik}= the admittance matrix
P_i= the injected real power
Q_i= the injected reactive power
δ_i= phase angle

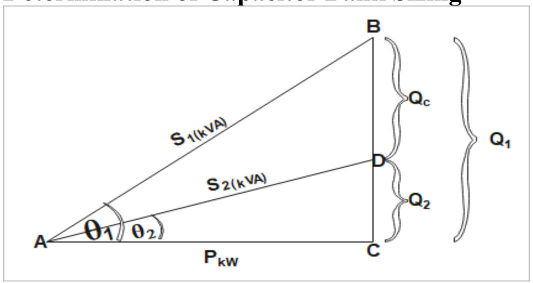
Expanding (3.13) and (3.14) in Taylors series neglecting higher order terms we have
$\left[\Delta P_2^{(k)} \vdots \frac{\Delta P_n^{(k)}}{\Delta Q_2^{(k)} \vdots \Delta Q_n^{(k)}}\right] = \left[\left|\frac{\partial P_2^{(k)}}{\partial \delta_2} \cdots \frac{\partial P_2^{(k)}}{\partial \delta_n} \vdots \ddots \vdots \frac{\partial P_n^{(k)}}{\partial \delta_2} \cdots \frac{\partial P_n^{(k)}}{\partial \delta_n}\right|\left|\frac{\partial P_2^{(k)}}{\partial |V_2|} \cdots \frac{\partial P_2^{(k)}}{\partial |V_n|} \vdots \ddots \vdots \frac{\partial P_n^{(k)}}{\partial |V_2|} \cdots \frac{\partial P_n^{(k)}}{\partial |V_n|}\right|\left|\frac{\partial Q_2^{(k)}}{\partial \delta_2} \cdots \frac{\partial Q_2^{(k)}}{\partial \delta_n} \vdots \ddots \vdots \frac{\partial Q_n^{(k)}}{\partial \delta_2} \cdots \frac{\partial Q_n^{(k)}}{\partial \delta_n}\right|\left|\frac{\partial Q_2^{(k)}}{\partial |V_2|} \cdots \frac{\partial Q_2^{(k)}}{\partial |V_n|} \vdots \ddots \vdots \frac{\partial Q_n^{(k)}}{\partial |V_2|} \cdots \frac{\partial Q_n^{(k)}}{\partial |V_n|}\right|\right]\left[\Delta\delta_2^{(k)} \vdots \frac{\Delta\delta_n^{(k)}}{\Delta\left|V_2^{(k)}\right| \vdots \Delta\left|V_n^{(k)}\right|}\right]$
(15)
The Jacobian matrix gives the linearized relationship between mall changes in voltage angle $\Delta\delta_i^{(k)}$ and magnitude $\Delta\left|V_i^{(k)}\right|$ with small change in real $\Delta P_i^{(k)}$ and reactive power $\Delta Q_i^{(k)}$ respectively.
$[\Delta P\ \Delta Q] = [J_1 J_3 J_2 J_4][\Delta\delta\ \Delta|V|]$
(16)
Where
$J_1,\ J_2, J_3, J_4$ are the elements of the Jacobian matrix
The off-diagonal and diagonal elements of J_1 are
$\frac{\partial P_i}{\partial \delta_k} = sin\,|Y_{ik}||V_i||V_k|sin(\delta_i + \theta_{ik} - \delta_k)$ (17)
$\frac{\partial P_i}{\partial \delta_i} = -\sum_{k=1k\neq i} \quad |Y_{ik}||V_i||V_k|\,sin\,sin(\delta_i + \theta_{ik} - \delta_k)$
(18)
The off-diagonal and diagonal elements of J_2 are
$\frac{\partial P_i}{\partial V_k} = cos\,|Y_{ik}||V_i|cos(\delta_i + \theta_{ik} - \delta_k)$
(19)
$\frac{\partial P_i}{\partial V_i} = 2|Y_{ii}||V_i|cos\theta_{ii} + \sum_{k=1k\neq i}^{n} \quad cos\,|Y_{ik}||V_k|cos(\delta_i + \theta_{ik} - \delta_k)$
(20)
The off-diagonal and diagonal elements of J_3 are
$\frac{\partial Q_i}{\partial \delta_k} = (\delta_i + \theta_{ik} - \delta_k)$ (21)
$\frac{\partial Q_i}{\partial \delta_i} = \sum_{k=1k\neq i} \quad |Y_{ik}||V_i||V_k|\,cos\,cos(\delta_i + \theta_{ik} - \delta_k)$ (22)
The off-diagonal and diagonal elements of J_2 are
$\frac{\partial Q_i}{\partial V_k} = sin\,|Y_{ik}||V_i|sin(\delta_i + \theta_{ik} - \delta_k)$
(23)
$\frac{\partial Q_i}{\partial V_i} = 2|Y_{ii}||V_i|sin\theta_{ii} + \sum_{k=1k\neq i}^{n} \quad sin\,|Y_{ik}||V_k|sin(\delta_i + \theta_{ik} - \delta_k)$
(24)
Compute the scheduled error ΔP_i and ΔQ_i for each load
$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)}$
(25)
$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)}$
(26)

Determination of Line Losses



$P_L = I(R + jX) = (P_1 - P_2) + j(Q_1 - Q_2)$ (27)

Determination of Capacitor Bank Sizing



Initial Reactive Power

$pf_1 = \cos \cos\theta_1$ (28)

$\theta_1 = (pf_1)$ (29)

$P = S_1 \cos \cos\theta_1$ (30)

$Q_1 = P \tan \tan\theta_1$ (31)

Where

pf_1: Initial power factor

θ_1: Initial power angle

S_1: Apparent power

P: Real power delivered

Desired Power Factor

$pf_2 = \cos \cos\theta_2$ (32)

$\theta_2 = (pf_2)$ (33)

$Q_2 = P \tan \tan\theta_2$ (34)

Where

pf_2: Desired power factor

θ_2: Desired power angle

S_2: Desired apparent power

P: Real power delivered

Capacitor Bank Size

$Q_c = Q_1 - Q_2$ (35)

$Q_c = P \tan \tan\theta_1 - P \tan \tan\theta_2$ (36)

$Q_c = P(\tan \tan\theta_1 - \tan \tan\theta_2)$ (37)

3.4.4 Determination of Transformer Loading

$API = \frac{Operating\ MVA}{Rated\ MVA}$ (38)

IV. RESULT AND DISCUSSION

Result Presentation for Pre-Upgrade Simulation

Table 4 Weak Buses

S/N	Bus ID	Nominal kV	Operating kV	% Operating
1	Aba Rd	11	9.835	89.41
2	ADP.	11	9.907	90.06
3	Agip	11	9.835	89.41
4	Eligbolo	11	9.731	88.46
5	Elimgbo	11	9.788	88.98
6	FGC	11	9.731	88.46
7	Iguruta	11	9.788	88.98
8	Location	11	9.882	89.84
9	Market RD	11	9.907	90.06
10	Obi Wali	11	9.731	88.46
11	Ohakwe	11	9.882	89.84
12	Okoh Rd	11	9.835	89.41
13	Old Aba Rd	11	9.449	85.90
14	Rukpokwu.2	11	9.731	88.46
15	Rumuogba	11	9.449	85.90
16	Rumuorolu	11	9.449	85.90

Table 4 shows the result from load flow simulation carried out on the existing Obio/Akor distribution network using ETAP 19.1 software. The system's minimum and operational voltages for the which was before network situation were shown. Table 4.1 reveals that sixteen (16) buses are in violation of the 0. 95p.u. to 1. 05p.u. bus voltage statutory limit requirement. (See appendix A1-A5) for load flow simulation single line diagram of the base case). The cause of the under voltage experienced

Table 5 Determination of Overloaded Transformers

S/N	Device ID	Nominal MVA	Operating MVA	% Operating
1	T1	15	14.51	96.80
2	T6	15	14.48	96.50
3	T8	15	15.64	104.30
4	T9	15	18.50	123.30
5	T11	15	14.72	98.10
6	T14	15	21.59	143.90
7	T3A	60	68.05	113.40

Table 5 shows the nominal, operating and loading of the distribution transformers after performing load flow simulation in the pre-upgrade network condition. In the distribution system, overcrowded transformers are identified using the performance measure of the transformer (PPI), and those with a PPI value more than 70% are regarded as such. A cursory look at table 4.2 shows the over loaded transformer in the network. This explains the cause of the low voltage profile of the buses duly linked to the affected substations.

Table 6 Determination of Line Losses

Line ID	Power Flow						Losses	
	From Bus	kW	Kvar	To Bus	kW	kvar	kW	Kvar
1	1	45721	40577	3	45453	40603.2	268	-26.2
2	1	45721	40577	2	45453	40603.2	268	-26.2
3	23	48616	41570	24	48322.6	41566.25	293.4	3.75
4	2	2876	813.8	24	2875.331	1152.5	0.669	-338.7
5	28	23040	17161	30	22336	16347	703.6	813.5
6	28	10726	7723	33	10618	7606	108.7	116.6
7	29	4559	3213	35	4507.9	3180.3	50.2	32.1

8	29	11748	8812	36	11608	8658	140	32.1
9	29	1010	609.5	37	1006	634.1	2.27	-24.7
10	7	12598	9583	10	12471	9442	127.4	141.7
11	7	14676	11532	11	14566	11408	109.7	123.9
12	7	10877	7812	12	10830	7760	47.8	51.8
13	9	11963	9048	16	11772	8837	191.1	211.2
14	9	10877	7819	17	10821	7758	56.6	61.4
15	9	26735	20951	18	26315	20462	419.8	488.5
							2787.239	**1660.75**

Table 6 shows the result of line flow and line losses obtained from load flow simulation in the pre-upgrade network condition. The total real and reactive power losses are 2787.239 kW and 1660.75 kvar. A quick look at table 4.3 shows that the highest real and reactive power loss occurred on bus 28-30.

Post-Upgrade Result.

Table 7 Improvement of Bus Voltage

S/N	Bus ID	Nominal kV	Operating kV	% Operating
1	Aba Rd	11	10.8	98.18
2	ADP.	11	10.77	97.91
3	Agip	11	10.8	98.18
4	Eligbolo	11	10.8	98.18
5	Elimgbo	11	10.72	97.45
6	FGC	11	10.8	98.18
7	Iguruta	11	10.72	97.45
8	Location	11	10.73	97.55
9	Market RD	11	10.77	97.91
10	Obi Wali	11	10.8	98.18
11	Ohakwe	11	10.73	97.55
12	Okoh Rd	11	10.8	98.18
13	Old Aba Rd	11	10.61	96.45
14	Rukpokwu.	11	10.8	98.18
15	Rumuogba	11	10.61	96.45
16	Rumuorolu	11	10.61	96.45

Table 7 shows the bus voltage of the improved obio/Akpr distribution network with the addition of a 5000kvar capacitor bank on buses 19, 31, and 40. In addition, bus 14 and bus 21 each received a capacitor bank of 6500kvar and 7000kvar, respectively. Table 4.4 quickly reveals that no voltage statutory limit violations occurred at the impacted buses following compensating (See appendix C1-C5 for load flow simulation single line diagram following network fortification).

Table 8 Mitigation of Transformer Overload

S/N	Device ID	Nominal MVA	Operating MVA	% Operating
1	T1	30	12.42	41.383
2	T6	30	12.33	41.093
3	T8	30	13.26	44.203
4	T9	30	15.55	51.823
5	T11	30	12.56	41.870
6	T14	30	18.05	60.167
7	T3A	100	57.67	57.670

Table 8 shows the nominal, operating and loading of the distribution transformers after performing load flow simulation for post-upgrade network condition. The overloaded distribution transformers (T1, T6, T8, T9, T11, and T14) were upgraded from 15MVA to 30MVA while transformer T3A were upgraded from

60MVA to 100MVA. After performing load flow simulation, the performance index obtained shows that no transformer was over loaded in the network.

Table 9 Reduction of Line Losses

Line ID	Power Flow						Losses	
	From Bus	Kw	kvar	To Bus	kW	kvar	kW	Kvar
1	1	46239	24838	3	46041.5	24947.8	197.5	-109.8
2	1	46239	24838	2	46041.5	24947.8	197.5	-109.8
3	23	49025	27707	24	48797.7	27781.5	227.3	-74.5
4	2	2778	2677	24	2776.9	3016	1.1	-339.0
5	28	23184	11585	30	22610	10925	574.0	660.0
6	28	10772	7721	33	10613	7605	159.0	116.0
7	29	4557	3210	35	4509.8	3180.2	47.2	29.8
8	29	12000	3317	36	11902	3213	98.0	104.0
9	29	1015	611.7	37	1013	637.1	2.0	-25.4
10	7	12913	3466	10	12809	2633	104.0	833.0
11	7	15089	4116	11	15015	4034	74.0	82.0
12	7	10866	7807	12	10820	7757	46.0	50.0
13	9	12221	3560	16	12087	3417	134.0	143.0
14	9	10887	7820	17	10832	7761	55.0	59.0
15	9	27159	12736	18	26842	12369	317.0	367.0
							2233.6	1785.3

Table 9 shows the result of line flow and line losses obtained from load flow simulation in the post-upgrade network condition after fortifying the network. The total real power loss after optimization is 2233.6 kW and 1785.3 kvar. Which is an indication that the proposed optimization performed impacted positively on the network.

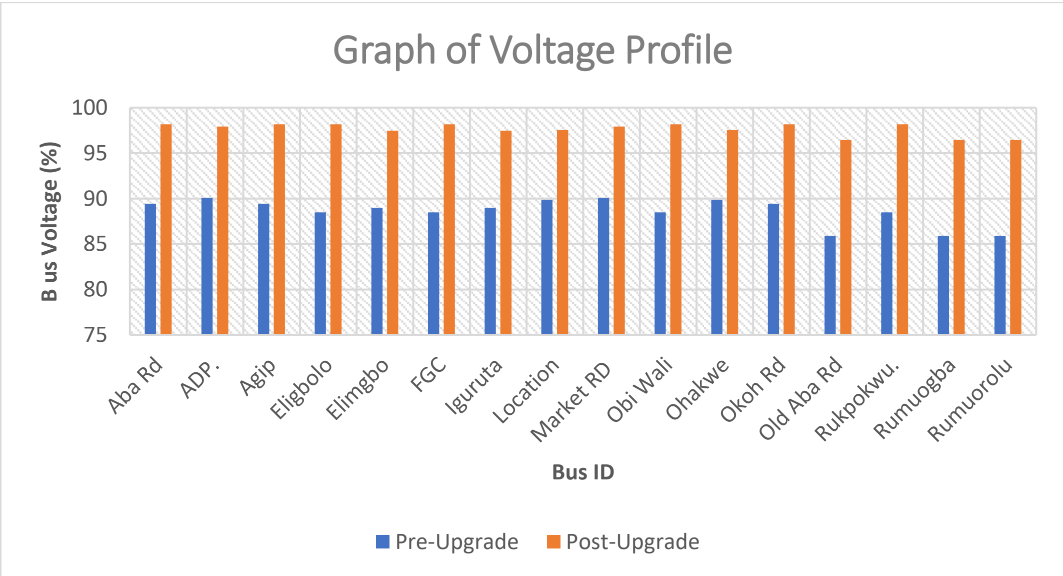


Figure 6: Comparison Plot of Bus Voltage Profile

Figure 6 shows the graph of voltage profile for Obio Akopr distribution network for both existing and improved state. The blue colour shows the existing state when no capacitor bank is connected to the network. Similarly, the brown colours shows the improved state when a capacitor bank is connected to the network. A quick look at the figure4.1 shows that the voltage profile of the network improved significantly when capacitor bank was connected to the system.

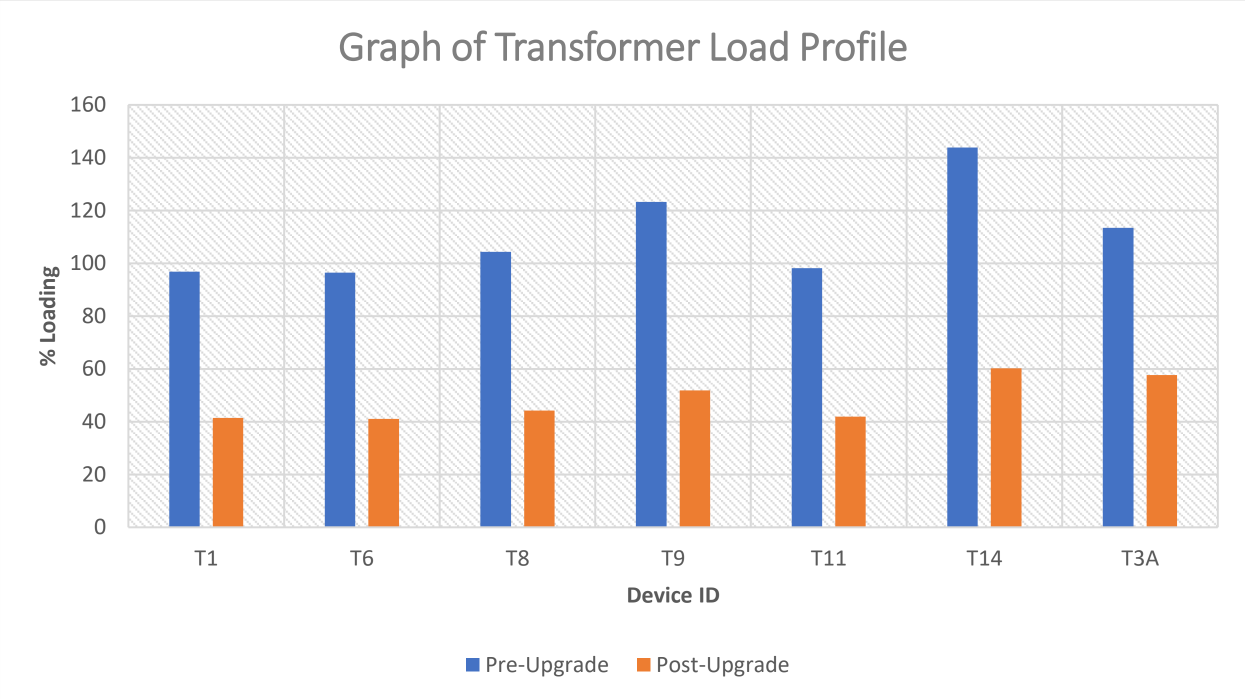


Figure 7: Comparison Plot of Transformer Load Profile

Figure 7 shows the graph of transformer load profile for Obio/Akopr distribution network for both existing and improved state. The blue colour shows the operating capacity of the over loaded transformers in the network. While the brown colours shows the operating capacity of the improved transformers in the network. A quick look at the figure 4.2 shows that there was an improvement in transformer loading when weak or stressed transformers are upgraded.

V. CONCLUSION

The study examined the existing Obio/Akpor distribution network. The distribution network is duly linked to two (2) transmission stations namely Port Harcourt mains and Rumuosi 132kV transmission. The network was modelled in Electrical Transient Analyzer Program (ETAP19.1)software. The existing and improved network were tested using Newton-Raphson power flow analysis method. In the base case, buses that violates the voltage statutory limit of 0.95-1. 05p.u were identified and distribution substations loaded above 70% were also identified. Also, a repeated power flow analysis was performed after improving the network using a cost-effective optimization technique such as transformer upgrading and capacitor bank sizing were effective in reducing losses, reducing the voltage profile of the weaker buses, and eliminating overload.

Contribution to Knowledge

i. This study provides a model for systems engineers in designing and managing an effective power distribution system.
ii. This study has provided vital information to Port Harcourt Electricity Distribution Company on how to improve the electric power supply to Obio/Akpor Distribution Network

Recommendations

The following recommendations are highlighted for optimum performance of Obio/Akor distribution system.

i. The existing 15MVA transformer (T1) at NTA injection substation should be upgraded to 30MVA
ii. The existing 15MVA transformer (T6) at Rukpokwu injection substation should be upgraded to 30MVA
iii. The existing 15MVA transformer (T8) at Okporo injection substation should be upgraded to 30MVA
iv. The existing 15MVA transformer (T9) at Rumuodomaya injection substation should be upgraded to 30MVA
v. The existing 15MVA transformer (T11) at Eneka Town Hall injection substation should be upgraded to 30MVA
vi. The existing 15MVA transformer (T14) at Akani injection substation should be upgraded to 30MVA
vii. The existing 60MVA transformer (T3A) at PH mains should be upgraded to 100MVA
viii. A capacitor bank of 5000kvar should be installed at bus 13 Okporo injection substation
ix. A capacitor bank of 6500kvar should be installed at bus 14 Rumuodomaya injection substation

x. A capacitor bank of 5000kvar should be installed at bus 19 Eneka Town Hall injection substation
xi. A capacitor bank of 7000kvar should be installed at bus 21 Akani injection substation
xii. A capacitor bank of 5000kvar should be installed at bus 31 NTA injection substation
xiii. A capacitor bank of 5000kvar should be installed at bus 40 Rukpokwo injection substation.

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