Hachimenum N. Amadi, 2026, 14:1
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Performance Analysis of Medium Voltage Feeders in A Distribution Network

[1]Hachimenum N. Amadi, [2]Richeal Chinaeche Ijeoma
Electrical Engineering Department, Rivers State University, Nkpolu - Oroworukwo Port - Harcourt, Nigeria.

Abstract - This paper examines a 33kV medium voltage distribution network for improved performance, and five (5) medium voltage feeders from Port Harcourt mains transmission were analyzed. Simulation was performed in electrical transient analyzer program software (ETAP 19.1) using the Newton-Raphson load flow technique. The results obtained from the base case network simulation show that the following buses violated the statutory limit condition of 0.95-1.05p.u (Aba Road 93.03%, Agip 93.03%, and Okoh Road 93.03%, Federal Government College (FGC) 91.98%, Obi-wali 91.98%, Eligbolo 91.98%, and Rukpokwu 91.98%,). Also, the transformer T-4 (96.80%), T-5 (96.50%), and T1A (104.30%) were overloaded. It was observed that under-voltage experienced is due to the overloading of transformers T-4 and T-5 at the Oporo and Rumuodomaya injection substations. The total real and reactive power losses in the base case were 148.6 kW and 251.2 kvar. However, transformer up-gradation was used as the cost-effective optimization technique to improve the network of Oporo and Rumuodomaya injection substations. The operating values after optimization for the buses and transformers are (Aba Road 98.91%, Agip 98.91%, Okoh Road 98.91%, FGC 98.23%, Obi-wali 98.23%, Eligbolo 98.23%, and Rukpokwu 98.23%,) and transformers loading reduced T-4 (50%), T-5 (58%), and T1A (56.8%). We concluded that the proposed optimization techniques impacted significantly in the improvement of the 33kV medium voltage distribution network.

Keyword - ETAP, Load Flow Technique, Newton-Raphson, Oporo and Rumuodomaya, Port Harcourt Mains Transmission.

I. INTRODUCTION

Electric power distribution networks are the final link in delivering electricity from high-voltage transmission systems to homes, businesses, and industries. How efficiently they operate directly affects the reliability, quality, and affordability of electricity (Amadi, Nwokoegi and Ijeoma, 2025). The implication of power failure leads to loss of income, loss future sales and increase in repairs and maintenance on the utility company and their end users. The cost usually incurred form a small part of the entire cost of the outages. The greater part is borne by the customers, due to the impact on the business. The power failure cost is a precursor of various situations which are deliberated in the sub-sections below. The issue of estimating outage costs is affected by the identified cost of an electric outage, the moment the consumer like to buy electric energy and is unable to do so. The different classes of customer will condone loss of service differently. A private consumer may experience a huge deal of hardship if this outage occurs during hot summer day or while he is engaging in domestic activities but it may be in a little inconvenience to an end user who is forced to close his business until power is restored. Outage might cause a great loss to the end user, if this occurs during production process. Therefore, consumers do not ascertain service interruption to the extent of hardship. The cost depends on availability of the substitute source of power at the time of service interruption. An unexpected outage of electricity might result in great loss on the part of the customer (Ijeoma and Ibinabo, 2019).

Electrical energy is the basic necessity for the economic development of a country due to its importance to human life and occupies the top position in the energy hierarchy. It finds innumerable uses in the home, industry, agriculture, and transport. The demand for electrical power is generally in the increase at a fast rate in economically developing countries like Nigeria. So, the power distribution networks are becoming highly loaded; so, the issue of protection scheme has become a great concern in most of the injection substation power distribution networks. A number of works have been carried out in the area of electric power distribution protection and solutions have been proposed to improve the protection of the distribution network (Ijeoma and Amadi, 2024).

Reliable energy technologies are expected to play a major role in mitigating pressing societal challenges such as climate change and resource depletion, while contributing to domestic energy security. Just as no human being can survive without the flow of blood, no nation or city can develop without reliable electricity (Ibinabo and Ijeoma, 2019).

Its constant and reliable performance is important to the economic stability of a nation and citizens' way of life (Haughton and Heydt, 2010). The electricity situation in Nigeria can be described as epileptic in its present state.

The erratic power supply affects the manufacturing, commercial services, and residential sectors of the economy which in turn affects the nation's economic growth (Sambo et al., 2010). The inconsistent power supply and moribund power sector can be attributed to inadequate and inefficient power plants, poor transmission and distribution facilities, and outdated metering systems used by electricity consumers. In general, the distribution network together with the voltage profile coupled with the imperfection of the billing system is not in a sustainable and manageable condition. Besides, the billing system as it relates to the public needs improvement, and ensuring adequate network coverage and provision of constant and quality power supply are quite relevant to the economic development of a nation. Some of the drawbacks or challenges identified include weak and inadequate network coverage, overloaded transformers, bad feeder pillars, substandard distribution lines, poor billing system, unwholesome practices, poor staff training, poor customer relations, poor maintenance culture and inadequate logistic facilities such as tools, working vehicles, poor and obsolete communication equipment (Sambo et al., 2010). The ever-increasing use of alternative sources like generating sets, power inverters, and solar inverters at the consumer end is an effort to enhance the availability of electric power supply. It is a reality that all these alternatives are more expensive than power utility services.

Various utilities estimate the value of electric services to consumers to measure the benefits of investments to improve reliability. The majority of power outages are caused by weather-related damage to overhead power lines. High winds can cause trees to bridge power lines, and from time to time can cause the breaking of lines and poles. Animal contact, vehicle accidents, equipment failure, and human mistakes also add to power outages.

Generation, transmission, and distribution are the three subsystems of an electric power system. At the generating station, electricity is generated and transmitted through the high-voltage transmission lines to the distribution substations. The distribution substation system considers coverage of the electrical system between the substation fed by the sub-transmission system and the supply line to the consumers' meters i.e. 11kV to 0.415kV transformation (Theraja and Theraja, 2005). The distribution substations are usually situated relatively near the customers for effective delivery, monitoring, and maintenance of the substation and the customer's end is referred to as a secondary distribution substation system. Distribution systems serve as the link from the distribution substation to the customer.

Distribution networks are typically of two types: radial networks and interconnected networks. A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical of long rural lines with isolated load areas. An interconnected network has multiple connection points. These connection points are normally open but allow various configurations by the operating utility by closing and opening switches. Operation of these switches may be by remote control from a control center or by a lineman.

The benefit of the interconnected model is that in the event of a fault or required maintenance, a small area of the network can be isolated and the remainder kept in supply.

Feeders are the power lines through which electricity is transmitted in power systems. The feeder transmits power from the Generating station or substation to the distribution points. In power engineering, a feeder line is part of an electric distribution network, usually a radial circuit of intermediate voltage. Feeders are circuits that carry electric power to substations. Its performance and 24-hour-a-day consistent energy delivery are central to the reliability of electric power distribution systems. The Electric Power Distribution System is a very important infrastructure because it delivers electricity to end-users either domestic or commercial consumers. Its continuous and reliable performance is essential to nation-building and citizens' way of life.

Reliability evaluation and modelling, generating stations have justifiably received more attention than the other systems because they are individually capital-intensive. In addition, in the event of generation inadequacy and generation loss, there are usually widespread catastrophic effects on the environment. It impacts directly on the whole system and even the distribution system will not be able to perform its duty because there will be no electricity to supply to customers.

However, based on published research work and studies, distribution systems have begun to receive moderate attention compared to past decades. In most cases, when there is disturbance in the form of failure which results in outages in the distribution system it affects only the localized territory. Only in a few cases does the fault move up into the system largely as a result of protection failure. Analysis of the customer failure statistics of most electricity companies shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer (Gonen, 2014). In effect, the purpose of establishing generating stations and the hurdles overcome to transmit electricity is defeated when it does not go to the end-users due to distribution system failure. This makes the distribution system to be important.

The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability (Billinton and Jonnavithula, 1996). Meanwhile, the main aim of a power system is to meet the electricity needs of the customers and this can only be achieved when the components making up the system are performing their intended function properly as long as the system is in operation, the demand for electricity and its supply must be properly viewed and included in setting up the system. Therefore, due to its high impact on the cost of electricity and its corresponding effect on customer satisfaction, distribution reliability is important. However, as in any other viable engineering system, some challenges face the power distribution system which tends to make the system unreliable. One of these is the issue of serving its main purpose which is to supply quality electricity with little or no interruptions.

As outlined by Sule and Anyanwu (1994), growth in thermal plants in Nigeria started with the installation of steam thermal plants at Oji river (1956), 4 unit gas thermal plants in Ijora (1966/78), 20 units gas thermal plants in Delta (1966/90), 4 steam thermal plants at Sapele (1978/80), another 18 unit gas thermal plants were installed at Afam (1982) and 6 steam thermal plants at Egbin (1985/87). A total of 6 power stations consist of 55 units capable of producing a total capacity of 5988 MW of electricity.

Nigeria's electricity industry is operating far below its installed capacity and the optimal production level. This reflects the extent of inefficiency in the sector. Total generation capacity throughout 1980–2009 ranged from 783.9 to 4076.2 MW, while the installed capacity ranged from 2507 to 8702.25 MW. There is a wide gap between generation capacity and installed capacity. For over two decades (1980s to 2000s), the generation capacity by PHCN was less than half the installed capacity. The fluctuation of capacity utilization at different times is due to huge energy losses as a result of poor power plant maintenance, fluctuations in water levels powering the hydro plants, resistive and other losses (e.g. unmetered consumption, theft, etc.) in the transmission grid, and distribution lines; more importantly, lack of spinning reserve inbuilt in PHCN power short and long term plans. The above reason accounts for the increasing gap between demand and supply of electricity in addition to about 30–47% losses of electricity generated in transmission due to the old transmission infrastructure of the Power Holding Company of Nigeria (PHCN). Among other factors that could be stated as responsible for the underutilization of the PHCN power plants are the following:

- Frequent major breakdowns, arising from the use of outdated and heavily overloaded equipment.
- Lack of coordination between town planning authorities and PHCN, resulting in poor overall power system planning which in turn leads to over-loading of PHCN equipment.
- Inadequate generation due to operational/technical problems arising from machine breakdown and low gas pressure.
- Poor funding of the organization (PHCN’s sole source of revenue is from tariffs which are the lowest in Africa.
- Inadequate budgetary provision and undue delay in the release of funds to PHCN.
- PHCN’s inefficient billing and collection system.
- High indebtedness to PHCN especially by public sector consumers who are reluctant to pay for electricity consumed as and when due.
- Vandalization and pilfering of PHCN equipment.
- Inability to convert gas flares to a source of electricity.
- Scarcity of relevant manpower for adequate maintenance and general consumer indiscipline.
- Lack of essential spare parts for maintenance of the plants.
- The absence of local manufacturing capabilities and
- Lack of systematic studies of distribution networks to reduce extraordinary losses that usually accompany haphazard system expansion.

The electricity consumption in Nigeria is very low due to inadequate supply. As of 2011, electricity consumption stood at just 149 kWh per head. At 149 kWh per capita, electricity consumption is one of the lowest in the world. Nigeria’s per capita electricity consumption is about 4 times less than the African average (563 kWh per capita) and about 17 times less than the world’s average (2596 kWh per capita). Despite Nigeria’s huge resource endowment in energy and enormous investment in the provision of energy infrastructure, the performance of the power sector has remained poor in comparison with other developing economies.

As of 2010, Nigeria’s electricity sector contributed only 0.32% and 0.22% to economic value added and economic growth respectively. This reflects the poor state of infrastructural development in the country. Notwithstanding the above factors that had rendered public electricity supply in Nigeria unreliable and inefficient, the trend of its utilization has grown significantly over the past years. Public sector electricity utilization by the industrial sector has been fairly static because of the unreliability nature of the public electric supply system in the country.

Thus, many companies had resolved to provide their own power-generating sets for more reliable self-generation of electricity leading to high costs of their products and services. Adebayo and Alake (2012) observed that power distribution to the industrial sector in Nigeria also remains abysmally irregular. The effect of irregular power on the cost of production by manufacturing industries was assessed by Adebayo and Alake (2012). The study observed that the cost of operating on self-power generating sets is higher than the cost of operating on power supply from the national grid by PHCN.

Previous studies have been done on performance analysis of medium voltage feeders in a distribution network, but none has been done on the significance of a reliable distribution system which is hinged on the fact that even if the generation and transmission of a power system are highly reliable, an unreliable distribution system will mean that there will be poor supply of energy to the consumers. Therefore, there must be ways of measuring the reliability of power distribution systems according to given standards to help inform the system engineers on the causes of interruptions. This will in turn help in proffering methods of accomplishing a more reliable distribution system. The network under this analysis is a very large system and the techniques or method of simulation and results orientation will be a load flow-based method using Newton-Raphson load Flow techniques for the simulation in the ETAP environment with the following additional processes, which are: Network (feeder) reconfiguration, Upgrading of transformer rating and tap setting, Integration of the Static Var Compensator and Integration of DG unit micro, small, medium, or large unit into the feeder.

II. MATERIALS AND METHOD

The data used for this study was obtained from Port Harcourt Electricity Distribution Company (PHEDC) Materials:

Table 1: Substation Load Data

Name	Capacity	Feeder ID	Load (MW)
Abuloma	1x15MVA	Abuloma	4.8
		Azuboko	4.8
Okuru	1x15MVA	Odili Rd	2.5
		Okuro Rd	2.0
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

Resistance of line per kilometer

Resistance, $R = \frac{\rho\times1000}{A}\Omega/km$

(1)

Where;

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

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

L= Route length of the feeder (m)

$$R = \frac{2.65\times10^{-8}}{182\times10^{-6}}\times1000 = 0.1456\ \Omega/\text{km}$$

Reactance of line per kilometer

$$r = \sqrt{\frac{A}{\pi}}$$

(2)

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

(3)

$$X = \mu_0\,\text{f}\ln\left(\frac{GMD}{r}\right)\ \Omega/_{m}$$

(4)

Where;

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

r= radius of the conductor

GMD= Geometric mean distance of conductor

D= conductor spacing = 4.1m

μ_0= permeability of free space= $1.257\times10^{-6}H/m$

$$r = \sqrt{\frac{182\times10^{-6}}{3.142}} = 0.0076108\ m$$

$$D_{GMD} = 1.26\times4.1 = 5.166m$$

$$X = \mu_0\,\text{f}\ln\left(\frac{GMD}{r}\right)\ \Omega/_{m}$$

$$X = 1.257x10^{-6}\times50\ln\left(\frac{5.166}{0.0076108}\right)\times1000 = 0.4098\Omega/\text{km}$$

Table 2: Line Characteristics

From	To	L(Km)	R(Ω)	X (Ω)
PH Mains	Abuloma	4.6	0.66976	1.88508
PH Mains	Okuru	4.3	0.62608	1.76214
PH Mains	Okporo	3.7	0.53872	1.51626
PH Mains	Rumuodumaya	4.1	0.59696	1.68018

PH Mains	Woji	2.2	0.32032	0.90156

Description of Existing Medium Voltage Feeder

The medium voltage feeder under study consist of five (5) radiating feeders of voltage level 33kV from PH mains transmission station located at Trans-Amadi Port Harcourt. The installed capacity of the station is 3x60MVA. The five (5) feeders under study are fed from transformer T1A and the medium voltage network under study includes the following injection substations; Abuloma, Okuru, Okporo, Rumuodumaya and Woji respectively.

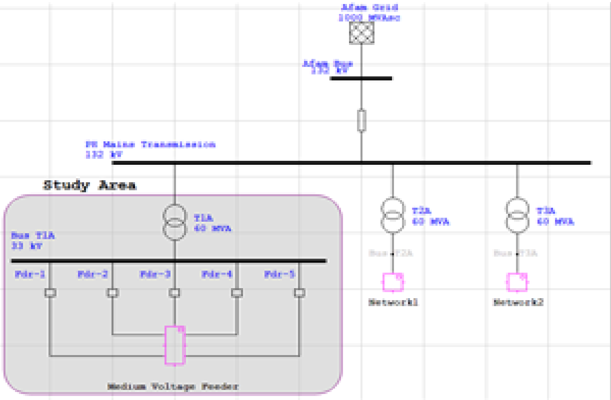


Figure 1: Shows the Single Line Diagram of Port Harcourt Mains (Z2)

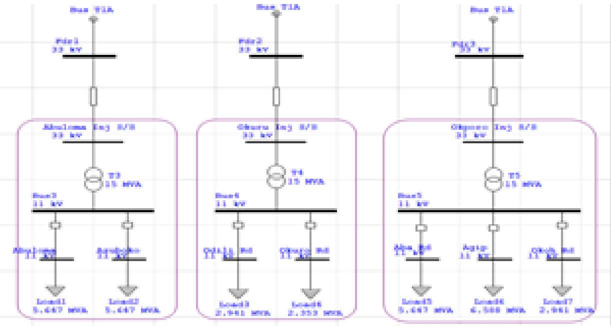


Figure 2: Shows the Single Line Diagram of PH Mains Medium Voltage Feeder 1, 2 & 3

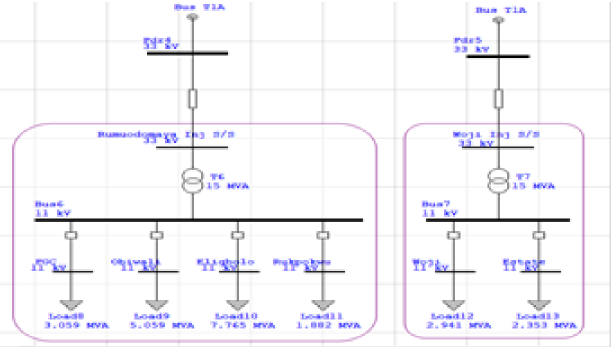


Figure 3: Shows the Single Line Diagram of PH Mains Medium Voltage Feeder 4 & 5

Method:

The Newton-Raphson Power Flow Techniques

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

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

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

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

$$P_i - jQ_i = V_i^*\left(\sum_{k=1}^{n} Y_{ik} V_k\right) \quad (10)$$

$$P_i - jQ_i = V_i^*\left(\sum_{k=1}^{n} Y_{ik} V_k\angle\delta_k + \theta_{ik} - \delta_i\right) \quad (11)$$

$$P_i - jQ_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\left[\cos(\delta_k + \theta_{ik} - \delta_i) + j\sin(\delta_k + \theta_{ik} - \delta_i)\right] \quad (12)$$

Separating (8) into real and imaginary parts we have,

$$P_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\cos(\delta_k + \theta_{ik} - \delta_i) \quad (13)$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\sin(\delta_k + \theta_{ik} - \delta_i) \quad (14)$$

Where,

Y_{ik} = the admittance matrix

P_i = the injected real power

Q_i= the injected reactive power

δ_i= phase angle

Expanding (13) and (14) in Taylors series neglecting higher order terms we have

$$\begin{bmatrix}\Delta P_2^{(k)}\\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)}\end{bmatrix} = \begin{bmatrix} \begin{vmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} \end{vmatrix} & \begin{vmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{vmatrix} \\ \begin{vmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n} \end{vmatrix} & \begin{vmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{vmatrix} \end{bmatrix} \begin{bmatrix}\Delta \delta_2^{(k)}\\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta \left|V_2^{(k)}\right| \\ \vdots \\ \Delta \left|V_n^{(k)}\right|\end{bmatrix}$$

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.

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{16}$$

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

$$\frac{\partial P_i}{\partial \delta_k} = |Y_{ik}||V_{\mathrm{i}}||V_{\mathrm{k}}|\sin(\delta_i + \theta_{ik} - \delta_k) \tag{17}$$

$$\frac{\partial P_i}{\partial \delta_i} = -\sum_{\substack{k=1 \\ k\neq i}} |Y_{ik}||V_{\mathrm{i}}||V_{\mathrm{k}}| \sin(\delta_i + \theta_{ik} - \delta_k) \tag{18}$$

The off-diagonal and diagonal elements of J_2 are

$$\frac{\partial P_i}{\partial V_k} = |Y_{ik}||V_{\mathrm{i}}|\cos(\delta_i + \theta_{ik} - \delta_k) \tag{19}$$

$$\frac{\partial P_i}{\partial V_i} = 2|Y_{ii}||V_{\mathrm{i}}|cos\theta_{ii} + \sum_{\substack{k=1 \\ k\neq i}}^{n} |Y_{ik}||V_{\mathrm{k}}|\cos(\delta_i + \theta_{ik} - \delta_k) \tag{20}$$

The off-diagonal and diagonal elements of J_3 are

$$\frac{\partial Q_i}{\partial \delta_k} = -|Y_{ik}||V_{\mathrm{i}}||V_{\mathrm{k}}|\cos(\delta_i + \theta_{ik} - \delta_k) \tag{21}$$

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{k=1 \\ k\neq i}} |Y_{ik}||V_{\mathrm{i}}||V_{\mathrm{k}}| \cos(\delta_i + \theta_{ik} - \delta_k) \tag{22}$$

The off-diagonal and diagonal elements of J_2 are

$$\frac{\partial Q_i}{\partial V_k} = |Y_{ik}||V_{\mathrm{i}}|\sin(\delta_i + \theta_{ik} - \delta_k) \tag{23}$$

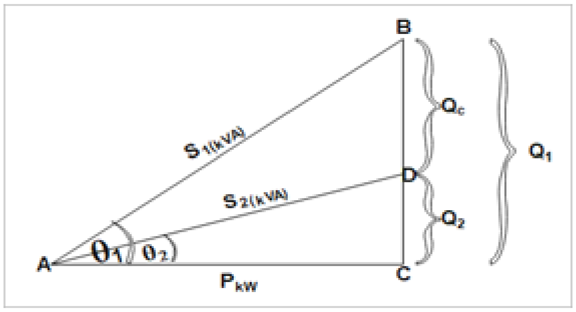
$$\frac{\partial Q_i}{\partial V_i} = 2|Y_{ii}||V_{\mathrm{i}}|sin\theta_{ii} + \sum_{\substack{k=1 \\ k\neq i}}^{n} |Y_{ik}||V_{\mathrm{k}}|\sin(\delta_i + \theta_{ik} - \delta_k) \tag{24}$$

Compute the scheduled error ΔP_i and ΔQ_i for each load

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \tag{25}$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \tag{26}$$

Determination of Capacitor Bank Sizing



Initial Reactive Power

$$pf_1 = \cos\theta_1 \tag{27}$$

$$\theta_1 = \cos^{-1}(pf_1) \tag{28}$$

$$P = S_1 \cos\theta_1 \tag{29}$$

$$Q_1 = P\tan\theta_1 \tag{30}$$

Where;

pf_1: Initial power factor

θ_1: Initial power angle

S_1: Apparent power

P: Real power delivered

Desired Power Factor

$$pf_2 = \cos\theta_2 \tag{31}$$

$$\theta_2 = \cos^{-1}(pf_2) \tag{32}$$

$$Q_2 = P\tan\theta_2 \tag{33}$$

Where;

pf_2: Desired power factor

$\boldsymbol{\theta_2}$: Desired power angle

S_2: Desired apparent power

P: Real power delivered

Capacitor Bank Size

$$Q_c = Q_1 - Q_2 \tag{34}$$

$$Q_c = P\tan\theta_1 - P\tan\theta_2 \tag{35}$$

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

Determination of Transformer Loading

$$API = \frac{Operating\ MVA}{Rated\ MVA} \tag{37}$$

Results and Discussion

Table 3 shows the base case result obtained from load flow simulation performed using ETAP 19.1 software. The result consists of nominal and operating voltage of the system. A quick look at Table 4.1 shows that seven (7) buses (Aba Road 93.03%, Agip 93.03%, and Okoh Road 93.03%, FGC 91.98%, Obi-wali 91.98%, Eligbolo 91.98%, and Rukpokwu 91.98%,) violates the bus voltage statutory limit condition of 0.95p.u-1.05p.u. The under voltage experienced in the above mentioned load centers is as a result of overloading of transformer T5 and T6 at Oporo and Rumuodomaya respectively.

Table 3: Bus Operating Voltage

S/N	Bus ID	Nominal kV	Operating (%)
1	Abuloma	11	96.96
2	Azuboko	11	96.96
3	Odili Rd	11	99.57
4	Okuru	11	99.57
5	Aba Rd	11	93.03
6	Agip	11	93.03
7	Okoh Rd	11	93.03
8	FGC	11	91.98
9	Obi-Wali	11	91.98
10	Eligbolo	11	91.98
11	Rukpokwo	11	91.98
12	Woji	11	99.57
13	Estate	11	99.57

Table 4: Determination of Overloaded Transformers

S/N	Device ID	Rated MVA	Operating MVA	Operating (%)
1	T5	15	13.912	92.7
2	T6	15	16.086	107.2
3	T1A	60	55.679	92.8

Table 4 shows the rated MVA, operating and percentage loading of the distribution transformer obtained from load flow simulation in the base case network condition. Transformers with operating values greater than 90% are considered overloaded. A cursory look at table 4.2 shows that transformer (T5 92.7%, T6 107.2% and 92.8 %) are over loaded transformer in the network. This explains the reason why buses connected to Okpro and Rumuodumaya injection substation are having low voltage.

Table 5: Determination of Line Losses

Line ID	**Power Flow**						**Loss**	
	From	**kW**	**kvar**	**To**	**kW**	**kvar**	**kW**	**kvar**
2	Fdr-1	9091	6438	Abuloma	9062	6390	28.8	48.6
3	Fdr-2	4470	2954	Okuru	4464	2945	6.7	8.2
4	Fdr-3	11259	8313	Okporo	11214	8234	45.5	79
5	Fdr-4	12907	9789	Rumuodumaya	12846	9682	60.9	107.2
6	Fdr-5	4470	2954	Woji	1464	2945	6.7	8.2
							148.6	**251.2**

Table 5 shows the result of line flow and line losses obtained from load flow simulation in the base case network condition. The total real and reactive power loss on the line are 148.6 kW and 251.2 kvar respectively. A quick look at Table 4.3 shows that the highest real and reactive power loss occurred on line 5 followed by line 3. The high real and reactive power loss on line 5 and line 3 is responsible for the under voltage experienced in feeder 4 and feeder 3 supplying power to Rumuodomaya and Okporo injection substation respectively.

Table 6: Bus Operating Voltage

S/N	Bus ID	Nominal kV	Operating (%)
1	Abuloma	11	97.29
2	Azuboko	11	97.29
3	Odili Rd	11	100.49
4	Okuru Rd	11	100.49
5	Aba Rd	11	98.91
6	Agip	11	98.91
7	Okoh Rd	11	98.91
8	FGC	11	98.23
9	Obi-Wali	11	98.23
10	Eligbolo	11	97.65
11	Rukpokwo	11	97.65
12	Woji	11	99.58
13	Estate	11	99.58

Table 6 shows the improve case result obtained from load flow simulation after fortification of the network and the optimization techniques impacted positively and the after bus voltage improved significantly (Aba Rd 98.91%, Agip 98.91%, Okoh Rd 98.91%, FGC 91.98%, Obi-wali 91.98%, Eligbolo 91.98%, and Rukpokwu 91.98%).

Table 7: Transformer Overloading

S/N	Device ID	Rated MVA	Operating MVA	Operating (%)
1	T5	15	10.08	67.2
2	T6	30	17.555	58.5
3	T1A	100	54.229	54.2

Table 7 shows the distribution transformers loading after performing load flow simulation in the improve network condition and that transformer T6 was upgraded to 30MVA and transformer T1A was upgraded to 100MVA. The loading of the transformers are (T5 67.2%, T6 58.5%, T1A 54.229%) respectively after optimization.

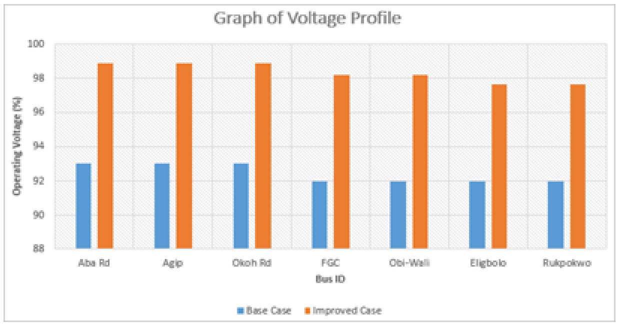


Figure 4: Comparison Plot of Bus Voltage Profile

Figure 4 shows the graph of voltage profile for medium voltage feeder for both existing and improved state. The blue color indicates the operating bus voltage of the base case network condition while the brown colours indicate the operating bus voltage of the improved case network condition, and that the voltage profile of the network improved significantly when capacitor bank was connected to the system.

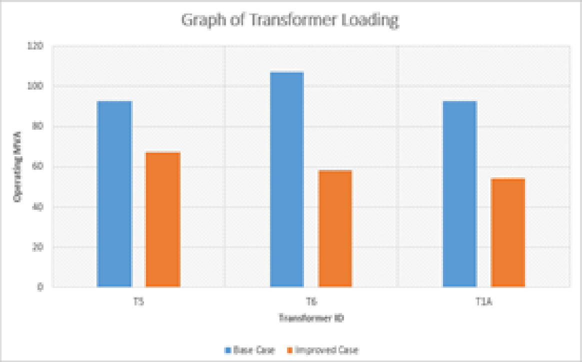


Figure 5: Comparison Plot of Transformer Load Profile

Figure 5 shows the graph of transformer load profile for medium voltage feeder for both existing and improved state. The blue color shows the operating capacity of the over loaded transformers in the network. While the brown colors shows the operating capacity of the improved transformers in the network, and that there was an improvement in transformer loading after upgrading of the transformer.

III. CONCLUSION

This research examined the existing medium voltage feeder of PH mains transmission station located at Trans-Amadi Port Harcourt. The installed capacity of the station is 3x60MVA and five (5) feeders fed from transformer T1A were considered under this study. The medium voltage network under study includes the following injection substations; Abuloma, Okuru, Okpro, Rumuodumaya and Woji respectively. The network was modeled in Electrical Transient Analyzer Program (ETAP 19.1) software. The existing and improved network was tested using Newton-Raphson power flow analysis method. In the base case, buses that violate the voltage statutory limit of 0.95-1.05p.u were identified and distribution substations loaded above 70% were also identified. Transformer upgrading and capacitor bank sizing were used as an effective optimization technique in improving voltage profile of the weak buses, reduce losses and eliminate over loading from the system.

REFERENCES

1. Adebayo, A.A., & Alake, T.J., (2012). The Impact of Irregular Power Supply on the Cost of Production of Selected Manufacturing Industries in Ilorin, Kwara State, Paper presented at National Engineering Conference on 'Strategies for Promotion of Sustainable Technology –Based and Production Driven Economy in Nigeria', Held at Kwara Hotel, Ilorin, Kwara State, Nigeria, December 3rd-7th
2. Amadi, H.N., Nwokoegi, H.P., & Ijeoma, R.C. (2025) Advanced Power Factor Correction for Distribution Efficiency Enhancement: The Case of Port Harcourt Mainstream 33 kV Distribution Network, International Journal of Scientific Research & Engineering TrendsVolume 11(4): 301
3. Billinton, R., & Jonnavithula, S., (1996). A Test System for Teaching Overall Power Systems Reliability Assessment, IEEE Transactions on Power Systems, 11, 1670-1676. https://doi.org/10.1109/59.544626
4. Fubara, I., & Ijeoma, R.C. (2019) Investigating the Reliability and Viability of Embedded Generation to Improve the Power Supply (Eleme, Rivers State as a Case Study), IOSR Journal of Engineering (IOSRJEN), 09(08) 27-37
5. Gonen, T., (2014). Electrical Power Transmission System Engineering, Analysis and Design, CRC Press, New York
6. Haughton, D., & Heydt, G.T., (2010). Smart distribution system design: Automatic reconfiguration for improved reliability, Conference: Power and Energy Society General Meeting, 2010 IEEE, Minneapolis USA, DOI: 10.1109/PES.2010.5589678
7. Ijeoma, R.C., & Amadi, H.N. (2024) Analysis of a Grid-Based Rural Electrification Scheme for Ekpe-Aggah Community in Rivers State, Nigeria. International journal of Engineering and Modern Technology (IJEMT), 10(6), 148-158
8. Ijeoma, R.C., & Fubara, I. (2019). The Effect of Power Failure on Commercial Consumers within Port Harcourt Garden City, Rivers State, Journal of Engineering (IOSRJEN), 09(08) 13-26
9. Sambo, A.S., Garba, B., Zarma, I.H., & Gaji, M.M., (2010). Electricity Generation and the Present

Challenges in the Nigerian Power Sector, https://www.researchgate.net/publication/228399732_Electricity_Generation_and_the_Present_Challenges_in_the_Nigerian_Power_Sector#fullTextFileContent

10. Sule, E.I.K., & Anyanwu, C.M., (1994). An Appraisal of electricity supply in Nigeria and the privatisation option, https://dc.cbn.gov.ng/cbn_occasional_papers/2/
11. Theraja, B.L., & Theraja, A.K., (2005). A Textbook of Electrical Technology - Volume II, S. Chand Publishing, New Delhi