Assessment of STATCOM Impact on Power Loss Reduction and Efficiency Improvement in Semi-Urban Distribution System

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Abstract
The semi-urban distribution systems often grapple with power loss and inefficiency, primarily due to the growing demand for electricity and the aging infrastructure. STATCOM (Static Synchronous Compensator) has emerged as a promising solution to address these issues by enhancing voltage stability, reducing power losses, and improving overall system efficiency. This study aims to assess the impact of STATCOM on power loss reduction and efficiency improvement in semi-urban distribution systems. By analyzing the semi-urban distribution ***system*** *and simulation data, the research will provide insights into the effectiveness of STATCOM in mitigating power distribution challenges and contributing to a more reliable and sustainable power supply. A comprehensive benefit for the Assessment of STATCOM Impact on Power Loss Reduction and Efficiency Improvement in Semi-Urban Distribution Systems are well addressed. Data collected includes: Station equipment, conductor size, step-up transformer, step-down transformer, and bus parameters. Again, Power losses, bus voltage magnitude and there ones were realized for evaluation. Critical buses were recorded at bus 9 for optimal sizing of about 2500KVAr. A load flow analysis showed that the active power loss and reactive power loss in the existing network were 85.63kW and 193.7167KVAr respectively. When STATCOM were introduced active power loss and reactive power were reduced from the values of 67.03kW and 143.71KVAr. The results obtained, when STATCOM was penetrated into the network, many of the bus voltage magnitude falls within IEEE statutory limit, hence electric power supply to the study area has improved.*

Keywords*: Reactive Power Loss, Real Power Loss, Electrical Transient Analysis Program, KVAR, STATCOM.*

INTRODUCTION

The semi-urban distribution systems often grapple with power loss and inefficiency, primarily due to the growing demand for electricity and the aging infrastructure. STATCOM (Static Synchronous Compensator) has emerged as a promising solution to address these issues by enhancing voltage stability, reducing power losses, and improving overall system efficiency. This study aims to assess the impact of STATCOM on power loss reduction and efficiency improvement in semi-urban distribution systems. By analyzing the **semi-urban distribution system** and simulation data, the research will provide insights into the effectiveness of STATCOM in mitigating power distribution challenges and contributing to a more reliable and sustainable power supply. The implementation of STATCOM (Static Synchronous Compensator) in semi-urban distribution systems significantly enhances both technical and economic aspects of the power infrastructure. Technically, STATCOM reduces power losses by providing dynamic reactive power compensation, stabilizing voltage, and improving power factor, leading to a more efficient power delivery system. Economically, these technical improvements translate to substantial cost savings through reduced energy losses and maintenance costs, as well as extending the operational life of distribution equipment. Additionally, the enhanced reliability and stability of the power supply boost customer satisfaction and support economic development by attracting and sustaining businesses. Consequently, STATCOM not only optimizes the current infrastructure but also fosters long-term economic growth and sustainability in semi-urban areas**.** The power supply system consists of generation, transmission and distribution sub systems [1].

Distribution system are associated with high resistance to reactance ratio ,large number of nodes and radial structure because of structural nature of the networks, there exists real and reactive losses which consequently reduces the efficiency of the power system. Power loss reduction is the only solution to enhance efficiency and improve the voltage profile. One of the methods of reducing power losses in distribution systems is by the injection of appropriate shunt capacitor banks in the residential area distribution network when economic cost and easy maintenance is of paramount consideration [2].

Transmission and distribution lines represent a very important link between the generation stations and the electricity users as power from generating stations due to economic reasons is usually transmitted at high voltages over long distances to high load centers and then distributed to different substations at different locations and localities via distribution lines [3].The conventional method of distribution line upgrading is highly capital demanding with limited expansion in power capacity. The problem of losses can be minimized by appropriate kVAR management scheme through the deployment of sizable electronic controllers like Static Compensator (STATCOM) which is the main concern of this study, as it delivers effective reactive power coupled with better ability to provide fast and continuous response during inductive and capacitive mode compensation [4]. Researchers have since shown that it is more economical to transmit power at high voltages to reduce power losses while distribution is usually implemented at low voltages for customer user [5].

II RELATED WORKS

There is high demand on the distribution network in the recent years and therefore several study have explored different approach on the challenges. Electricity supply through assessment and mitigation of power losses and voltage deviation in power system network. Some researchers have used analytical technique to size the KVAR compensating device while some others have used either heuristic or evolutionary algorithm techniques.

According to [6], they presented a paper on the utilization of analytical technique to determine the numbers and sizes of relief transformers needed to reduce power losses of the subjected network. Newton Raphson power flow method embedded in Dig silent (15.1) Power factory was used for simulation.

According to [7], they presented a paper on the usage cuckoo search algorithm to determine the optimal size of DG and DSTATCOM to reduce power losses of study case network. To determine the location of DG and DSTATCOM, a loss sensitivity factor and Voltage stability index were applied.

According to [8], they carried out a study on the power loss reduction and voltage profile improvement on a distribution network using analytical method to determine the size of capacitor bank to penetrate for reactive power compensation. Electrical Transient Analyzer program (ETAP) was used for the simulation.

According to [9], they presented a paper on the utilization of Particle Swarm Optimization for optimal sitting and sizing of D-STATCOM to minimize power loss maximize voltage profile in radial distribution network. Voltage stability index was used to identify suitable placement of the D-STATCOM.

According to [10], they examine the application of static synchronous compensator (STACOM) on the Nigeria distribution network in order to reduce system losses and stabilize the system voltage thereby providing additional capacities for the consumers.

III MATERIALS AND METHODS

Materials

Study Area

The research focuses on a semi-urban distribution system, characterized by a mix of residential, commercial, and light industrial loads. The selected area exhibits typical challenges of semi-urban power distribution, including voltage instability and significant power losses.

Data Collection

Data for this study were collected from the local utility provider, including historical power loss data, load profiles, and system configuration details. Additional data were gathered through field measurements of voltage levels, power factor, and load demand across different parts of the distribution network. Also, the following were considered route length, conductor size, station equipment's, step-up transformer, step-down transformer, and bus parameters which were obtained from Port Harcourt Electricity Distribution Company.

STATCOM Implementation

A STATCOM device was modeled and integrated into the simulation. Parameters for the STATCOM, including its reactive power capacity and control settings, were based on typical specifications used in similar semi-urban settings. The STATCOM was strategically placed at critical nodes within the distribution system to maximize its impact on voltage stabilization and loss reduction.

Simulation Model

A detailed simulation model of the semi-urban distribution system was developed using Electrical Transient Analysis Program (ETAP) software. The model included all relevant components such as transformers, transmission lines, and load centers.

Table 1: Transformer and Load Data at Okwuzi(Omoku) at 0.8 PF

BUS ID	TRANSFORMER (MVA)	INPUT/OUTPUT (KV)	UNIT	LOAD (MVA)
2-3	15	33/11	1	2.6
5-6	1	11/0.415	1	0.325
7-8	0.75	11/0.415	1	0.325
9-10	0.5	11/0.415	1	0.325
9-11	0.5	11/0.415	1	0.325
9-12	0.5	11/0.415	1	0.325
9-13	0.5	11/0.415	1	0.325
9-14	0.5	11/0.415	1	0.325
9-15	0.5	11/0.415	1	0.325

Source: First Independent Power Limited (2023)

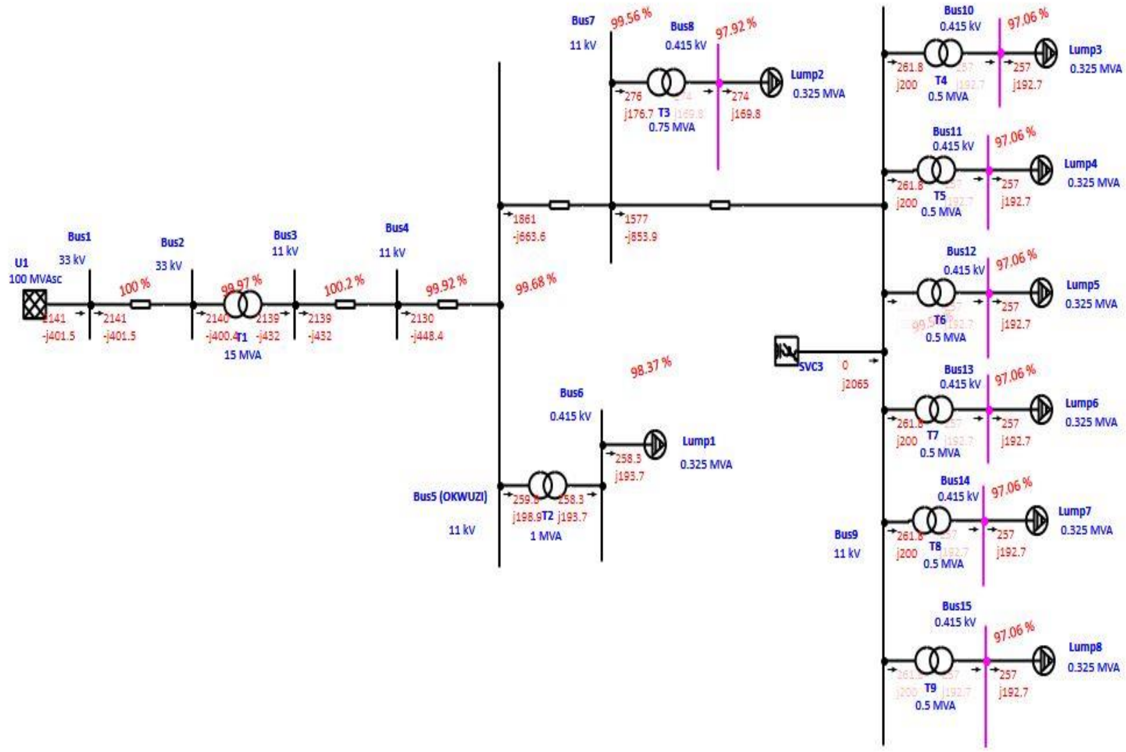


Fig 1: One Line Diagram of the Distribution Network with STATCOM Injection.

Method of Analysis and Reactive Power

Newton Raphson's Method of Power Flow Analysis

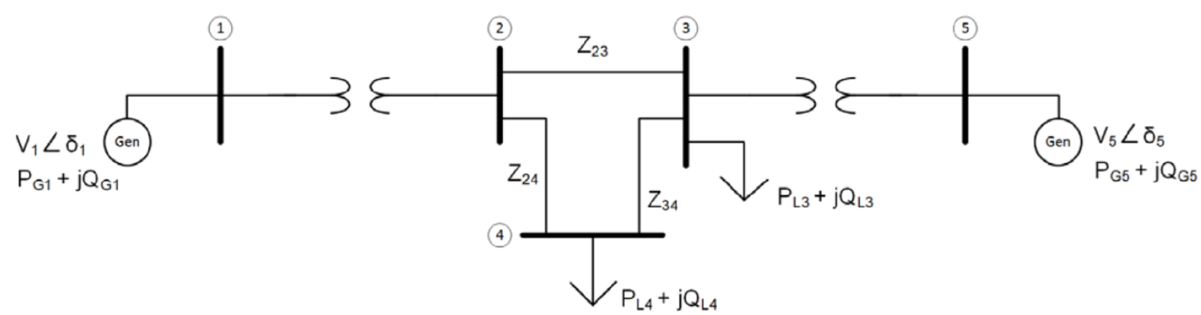


Fig 2: A Typical Power System One Line Diagram

The current received at bus i from the generator or power grid is given as;

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + \ldots + Y_{ik}V_K = \sum_{i,k=1}^{n} Y_{ik}V_k \qquad (1)$$

Considering magnitude and phase angle, the voltage and admittance will be given as;

$V_k = V_K \angle \delta_k$ (Voltage at the bus k) (2)

$Y_{ik} = Y_{ik} \angle \theta_{ik}$ (Admittance between bus i and bus k) (3)

Substitute equations (2) and (3) into equation (1)

$$I_i = \sum_{i,k=1}^{n} Y_{ik} \angle \theta_{ik} V_k \angle \delta_k \quad (4)$$

δ_i, δ_k *are phase angles of* bus i and k, while θ_{ik} is the angular difference between bus i and k.

Conjugate of the injected current at bus i will be;

$$I_i^* = \sum_{i,k=1}^{n} Y_{ik} \angle -\theta_{ik} V_k \angle -\delta_k \quad (5)$$

Apparent power available at bus i will be;

$$S_i = V_i I_i^* = P_i + jQ_i \quad (6)$$

Substitute equation (12) into equation (13), considering the magnitude and angle of V_i

We have;

$$P_i + jQ_i = V_i \angle \delta_i \sum_{i,k=1}^{n} Y_{ik} \angle -\theta_{ik} V_k \angle -\delta_k \quad (7)$$

Rearranging equation (3.7) gives;

$$P_i + jQ_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \angle (-\theta_{ik} + \delta_i - \delta_k) \quad (8)$$

But,

$$\delta_{ik} = \delta_i - \delta_k \quad (9)$$

$$-\theta_{ik} = \theta_{ki} \quad (10)$$

Substitute the relations in equations (9) and (10) into equation (8)

$$P_i + jQ_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \angle (\theta_{ki} + \delta_{ik}) \quad (11)$$

From the equation (3.18), the active real and imaginary power will be;

$$P_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \cos(\theta_{ki} + \delta_{ik}) \quad (12)$$

$$Q_i = \sum_{i,k=1}^{n} Y_{ik} V_i V_k \sin(\theta_{ki} + \delta_{ik}) \quad (13)$$

Equations (12) and (13) are used to obtain calculated values of real and reactive power.

Note that when a bus generates electricity, it is called an electric bus other than the bus loading; a loose bus is also needed to install (suction) excess flow. Line flow may also be expressed as changes in the bus and values are defined as follows:

$$\Delta P_i = \left|P_i^{sp} - P_i^{cal}\right| \tag{14}$$

Where,

P_i^{sp}= the specified real bus powers at power exchange sequence i, and

P_i^{cal}= the computed real bus powers at power exchange sequence i, using equation 12

Similarly, the reactive power changes may be expressed as:

$$\Delta Q_i = \left|Q_i^{sp} - Q_i^{cal}\right| \tag{15}$$

Where,

Q_i^{sp}= the specified reactive bus powers at power exchange sequence i, and

Q_i^{sp}= the computed reactive bus powers at power exchange sequence i, using equation 21.

Typically, the admittances, line power demand and generations are given while the bus voltages and angles are obtained by making an initial guess and solving using a load-flow program.

The net power balance is then expressed as the sum over all bus power sequence exchanges as:

$$\Delta P_{net} = \sum_i^n \Delta P_i^2 \tag{16}$$

and,

$$\Delta Q_{net} = \sum_i^n \Delta Q_i^2 \tag{17}$$

Equations 1 to 21 are the fundamental power flow equations and its solution is facilitated using the traditional Newton Raphson solution algorithm in ETAP.

Problem Formulation, Objective Functions and Constraints.
STATCOM was used to minimize the total power loss in the distribution network with voltage profile improvement.
Min f = Min (PT loss) **(**18**)**

Constraints:
The reactive power injected by STATCOM to the system is limited by upper and lower boundary given:

$$Q_{min} \ll STATCOM \ll Q_{max} \tag{19}$$

The system voltage in all buses should be within an acceptable limit.

$$\boldsymbol{V_{min}} \ll V_i \ll V_{max} \tag{20}$$

V_i is the voltage of ith bus and i bus varies from 1 to number of buses
The expression for Voltage Stability Index is given by:

$$V.S.I = \frac{4ZQ}{V^2X} \tag{21}$$

Where,
Z= Impedance
X= Reactance
Q= Reactive power
V= Bus Voltage

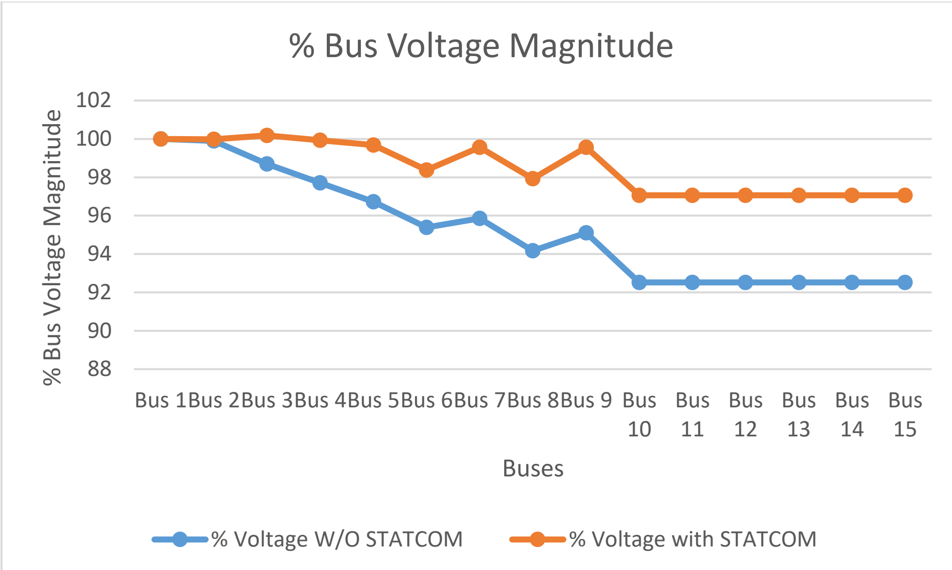
IV RESULTS AND DISCUSSION

The results realized from the load flow are indicated in the Table 2-3 for Bus Voltage Magnitude Before and After Compensation and Line Losses Before and After Compensation. Then Plot 1-3 indicates plot for Comparison of Bus Voltage Profile with and without Compensation, Plot of Active Power Losses versus Line Branches and Plot of Reactive Power Losses versus Line Branches.

Table 2: Bus Voltage Magnitude Before and After Compensation

Bus id	Nominal Voltage (kV)	% Voltage W/O STATCOM	% Voltage with STATCOM
Bus 1	33	100	100
Bus 2	33	99.89	99.97
Bus 3	11	98.70	100.18
Bus 4	11	97.71	99.92
Bus 5	11	96.72	99.68
Bus 6	0.415	95.38	98.37
Bus 7	11	95.85	99.56
Bus 8	0.415	94.17	97.92
Bus 9	11	95.1	99.56
Bus 10	0.415	92.52	97.06
Bus 11	0.415	92.52	97.06
Bus 12	0.415	92.52	97.06
Bus 13	0.415	92.52	97.06
Bus 14	0.415	92.52	97.06
Bus 15	0.415	92.52	97.06

Source: Transmission Company of Nigeria (TCN) 2023.



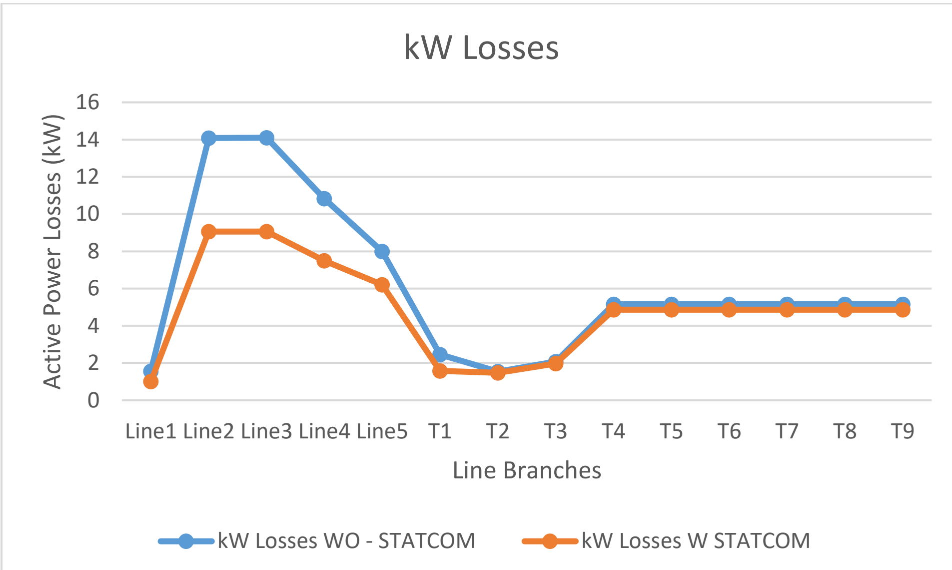
Plot 1: Comparison of Bus Voltage Profile with and without Compensation

Table 3: Line Losses Before and After Compensation

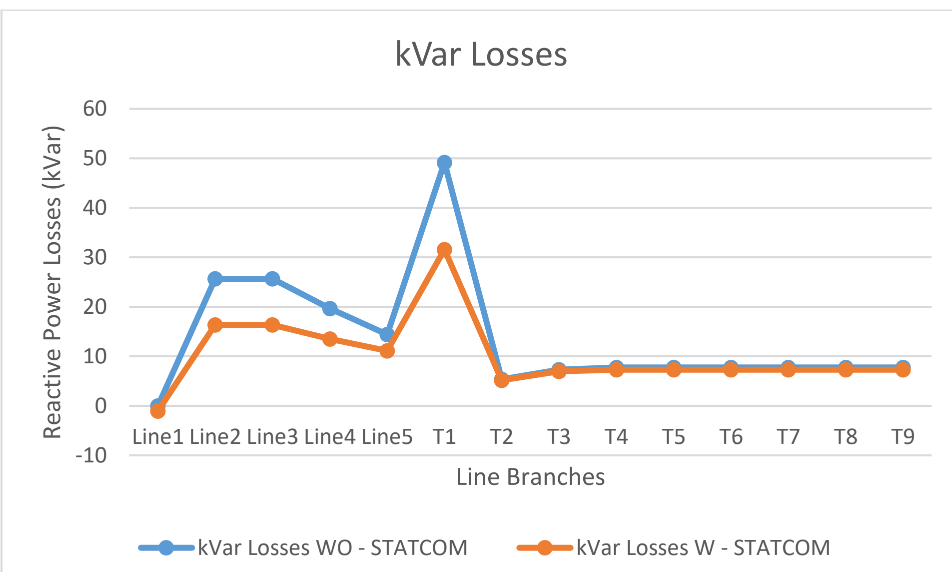
ID	kW Losses WO-STATCOM	kvar Losses WO-STATCOM	kW Losses W STATCOM	kvar Losses W-STATCOM
Line1	1.56	-0.0233	1.01	-1.05
Line2	14.09	25.65	9.06	16.36
Line3	14.1	25.66	9.06	16.36
Line4	10.84	19.67	7.5	13.49
Line5	8	14.44	6.2	11.09
T1	2.46	49.15	1.58	31.59
T2	1.54	5.38	1.48	5.18
T3	2.08	7.29	1.98	6.95
T4	5.16	7.75	4.86	7.29
T5	5.16	7.75	4.86	7.29
T6	5.16	7.75	4.86	7.29
T7	5.16	7.75	4.86	7.29

T8	5.16	7.75	4.86	7.29
T9	5.16	7.75	4.86	7.29
	Total = 85.63	Total = 193.7167	Total = 67.03	Total = 143.71

Source: First Independent Power Limited (2023)



Plot 2 : Plot of Active Power Losses versus Line Branches



Plot 3: Plot of Reactive Power Losses versus Line Branches

V CONCLUSION

To a Large extent the study emphasizes on the Assessment of STATCOM Impact on Power Loss Reduction and Efficiency Improvement in Semi-Urban Distribution Systems. Static Synchronous Compensator (STATCOM) was used to reduce active power loss and reactive power loss and improve voltage profile to the values of 67.03kW and 143.71KVAr. Power losses and voltage deviation assessment could help in improving power supply to the study area, boost revenue generation for the utility through customer satisfaction. Power losses and bus voltage profiles were assessed through load flow analysis of the 33kv distribution network using Electrical Transient Analyzer Program (ETAP) was the simulation tool used. PSO algorithm embedded in ETAP, the optimal location and KVAr capacity was determined with Static Synchronous Compensator. The voltage profile of all the buses was found within the IEEE-315 standard limits.

REFERENCES

[1] Ikuobase, E., Olusegun, D. S., Mgbemena,C. O. & Adeyeri, M K. (2018). Electric Power Generation Crisis in Nigeria. A Review of Causes and Solutions. *International* Journal *of Integrated Engineering*, 10(1), 47 – 56.

[2] Ekeriance, D. E., & Wokoma, B. A., (2024) Assessment of 11KV Distribution Network for Minimization using Analytical Technique for capacitor sizing. *International Journal of Innovation Research in Electrical, Electronic, Instrumentation and Engineering*. 12(2): 1-6.

[3] Gupta, J. B. (2009). Transmission & Distribution of Electrical Power. SK Kataria and Sons.

[4] Kazmi, S. A. A., Khan, U., Ahmad, H. N. & Shin, D. R. (2020). A Techno-Economic Centric Integrated Decision Making Planning Approach for Optimal Assets Placement in Meshed Distribution Network across the Load Growth. *Energies*, 13(6), 1444-1456.

Gupta, J. B. (2009). Transmission & Distribution Of Electrical Power. SK Kataria and Sons.

[5] Badran, O. & Jalland, J. (2023). Active and Reactive Power Loss Minimization Along with Voltage Profile Improvement for Distribution Reconfiguration. *Journal of Electrical and Computer Engineering,* 14(10), 1193 – 1201.

[6] Ale, T. O. (2015). Electrical and Electronics Engineering Lecture Note. Federal University of Technology Akure, Ondo State.

[7] Igbogidi, O. N., Amadi, H. N., & Ekeriance, D. E., (2024). Analysis of High Voltage Direct Current Transmission Line Bus Voltage Using Load and Component Sizing Method. Journal of Recent Trend In Electrical Power Systerm,7(1) 1-9.

[8] Ighalo, G. I., & Williams, A. A. (2012). Simulating Power Distribution Network in Nigeria. The Ikpoba-Hill District Network as A case Study. *International Journal of Scientific Technology Research*, 1(9), 1-8.

[9] Ekeriance, D. E., Dumkhana., L., Philip-Kpae. F. O. & Aferonkhai, J.E (2024). Improvement of Electricity Supply to a Semi Urban Community Using STATCOM. *International Journal of Engineering and Modern Technology (IJEMT)*,10 (4), 53-64

[10] Ekeriance D. E., Dumkhana L., & Philip-Kpae F. O. (2024), Analysis of Transient Instability on a 132KV Transmission grid Power System Using 4th Order Runge kutta Technique. *African Journal of Electrical and Electronics Research*, 6(1), 17-32.