International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 22, Issue 8 (August 2026), PP 53-60

Capacitor Banks Assisted Load Flow in Power Systems using Shunt Compensation Method

Ajakaiye, Moses Saturday[1*], Orie, Eze Kenneth[2] & Okoroma, Prince Eze[3]
Department of Electrical and Electronics Engineering, Rivers State University, Port Harcourt, Nigeria
Corresponding Author: Ajakaiye, Moses Saturday

Abstract
A robust and efficient power system, designed to meet demand, is worth relying on. A prototype power system compliant with IEEE standards was used in this study. To achieve the aim of this research, a power system consisting of nine 11 kV feeders was used to conduct load flow studies in the Electrical Transient Analyzer Program (ETAP) software with and without capacitor banks to determine the stability, transfer, and loading capability of the power system. Shunt compensation method was used to integrate capacitor banks to achieve more stable and efficient power transfer. The study was conducted in two scenarios: with and without capacitor banks. The branch losses report showed a percentage drop in voltage magnitude improvement from 0.66% to 0.28% on the transmission line, and from 8.26%, 8.13%, and 7.62 % to 1.12%, 1.41%, and 0.52%, respectively, on the transformers, as capacitor banks were installed at the appropriate buses. The method used kept the line voltage at 100.3% and improved bus voltage from 91.1%, 91.2%, and 91.7% to 99.2%, 98.9%, and 99.8% on T1A, T2A, and T3A respectively with increased loading from 68.3%, 67.3%, and 66.5% to 78.1%, 77.3%, and 83.9% on T1A, T2A, and T3A, respectively. Voltage improvement from installing capacitor banks enabled more efficient power transfer in the system. This scenario has sufficiently improved the power system's load flow, a requirement for efficient operation.

Keywords: *Voltage limits, Load flow, Capacitor banks, Shunt compensation, Power system, Adaptive Newton-Raphson.*

Date of Submission: 05-08-2026 Date of acceptance: 17-08-2026

I. INTRODUCTION

Benefits derived from capacitor banks include power factor correction, voltage support, loss reduction, and increased system capacity. In power factor correction, they reduce reactive power and energy losses. In providing voltage support, capacitor banks improve voltage stability and reduce voltage drops. Energy losses in transmission and distribution lines are reduced, and system capacity is increased by reducing reactive power flow.

Capacitor banks, if well utilized play significant roles in industrial power systems, transmission and distribution systems, and renewable energy systems in providing solutions to system voltage and power problems. Improved system efficiency is obtained by reducing energy losses. Also, reduced costs may be achieved by improving the power factor and reducing losses. Capacitor banks can improve system reliability by providing voltage support and reducing the risk of power outages. Shunt compensation is a technique used in power systems to improve voltage stability, reduce power losses, and enhance overall system performance. Shunt compensation devices, such as shunt capacitors, provide reactive power support to maintain voltage levels within acceptable limits. Shunt compensation can enable higher power transmission capacity by reducing the system's reactive power burden.

In a nutshell, capacitor banks play a crucial role in maintaining power system stability, efficiency, and reliability. The genetic algorithm is an essential and very popular technique for the optimization of transmission and distribution systems. Its objective function could be to minimize power losses, optimize transformer loading, or maximize system reliability. This indicates that the objective function will consider the percentage loading of each transformer, the allocation of feeders to transformers, and the power flow through each transformer and feeder. The genetic algorithm always selects the fittest solutions to reproduce.

II. RELATED WORKS

Very important information realized from load flow analysis is the magnitudes and phase angles of load bus voltages, reactive powers, and voltage phase angles at generator buses, real and reactive power flows on transmission lines, alongside power at the reference bus (Efe, 2026). FACTS devices are highly relevant in power networks, especially in developing countries, for improving network efficiency, given the enormous challenges inherent in the system, as in Nigeria, where deregulation/unbundling in the electricity market is in place (Amaize et al., 2017). Operational challenges, vandalism, poor funding, and ageing infrastructure are factors that impede efficient electricity delivery in Nigeria (Tebepah, Amadi, & Igbogidi). Nigeria's power transmission system requires continuous upgrading and expansion to meet the ever-growing power demand (Ebune, Ezechukwu, & Aneke, 2018). Overstressed transmission and distribution networks with high rates of power failure is a challenge in Nigeria's power system (Igbogidi & Dike, 2023).

Improving voltage control and reactive power support is difficult because they are strongly influenced by random load fluctuations. Enhancing reactive power support and voltage control applications in Nigeria's transmission and distribution systems using FACT controllers is a novel concept and a new, emerging smart technology. It can be regarded as a major reinforcement project and a remedial action in the transmission network to avert several instances of voltage collapse due to overloading and congestion in recent times (Ebune, Ezechukwu, & Aneke, 2018). There is therefore a need to develop an effective and efficient technique for maintaining the required balance between the active and reactive power consumed and generated in a network, using FACTS devices and capacitor banks to ensure voltage stability (Iyidobi, & Eneh, 2018). The resultant effect of having the transmission lines' voltages operating outside the allowable limit, insufficient and inadequate power flow, high line losses, and damping oscillation can be put to rest by the installation of new transmission lines, changing of transmission line conductors or terminal equipment, increasing the transmission line operating voltage, and the addition of reactive power compensation devices (Olulope, 2018).

In the absence of a new grid, improvement of the existing lines and substations can be accomplished using FACTS and capacitor banks, which will enhance system stability and availability, power transmission capability, power quality, load sharing between parallel circuits, improve voltage stability in the grid, reduce environmental impact, transmission losses, etc. (Al-Masud et al., 2019). Similarly, any nation facing energy challenges and striving for sustainable development will attest to the importance of renewable energy (Amadi, Bakare, & Igbogidi, 2024). The only known option available to prevent voltage collapse is to either reduce reactive power demand or increase reactive power before reaching the voltage collapse point (Ajenikoko & Ojeyinka, 2019). The addition of compensation modifies the line's electrical impedance, thereby increasing the power flow across the line. This can be an effective and economical means of increasing the transmission and distribution capabilities, provided transmission lines are not loaded to their thermal limits (Oleka, Ndubisi, & Ijemaru, 2016). The challenge faced by the utility is how to maximize service with limited amounts of capital available for plant and equipment (Igbogidi & Dahunsi, 2020).

Shunt compensation successfully reduces voltage drop and power loss in the network under steady load conditions by reducing current flow in areas of installation (Adeniji & Mbamaluikem, 2017). It could also be a series arrangement in which the compensating device is connected in series with the circuit to be compensated. Whereas shunt compensation reduces the current flow in areas of installation, series compensation acts directly on the series reactance of the line. It reduces the transfer reactance between the supply point and the load, thereby reducing the voltage drop (Adeniji & Mbamaluikem, 2017).

III. MATERIALS AND METHODS

3.1 Materials

Relevant data pertaining to transmission and distribution networks were considered in this research for the actualization of a more stable, reliable, and efficient power system using capacitor banks. Also, the Electrical Transient Analyzer Program (ETAP) software was used for the implementation of the simulations.

3.2 Methods

Adaptive Newton-Raphson and shunt compensation methods were used in the optimal placement of the capacitor banks and load flow in the Electrical Transient Analyzer Program (ETAP) software for the actualization of a more efficient flow of power in this research. The procedure considered two scenarios, which include and exclude capacitor banks, and it followed the sequence of power system modeling as indicated below.

3.2.2 Modeling of Capacitor Banks

Consequently, the capacitance of C farads if connected to an AC source,

$$V = V_m \, Sin \, \omega t \tag{1}$$

$$I = \frac{CdV}{dt} \, \omega C \, V_m \, Cos \, \omega t \tag{2}$$

$$I = \omega C \, V_m \, Sin \, (\omega t + \pi/2) \tag{3}$$

$$I = I_m \, Sin \, (\omega t + \pi/2) \tag{4}$$

Where,

$$I_m = \omega C \, V_m \tag{5}$$

Or $I = \omega$CV (6)

The quantity $\frac{1}{\omega C}$ is the capacitive reactance denoted by X_C. Thus,

$$X_C = \frac{1}{\omega c} = \frac{1}{2\pi f c} \quad (7)$$

and $I = \frac{V}{X_C}$ (8)

For the powers in the system,

$$MVA^2 = MW^2 + MVA_r^{\,2} \quad (9)$$

$$MVA_r^{\,2} = MVA^2 - MW^2 \quad (10)$$

$$MVA_r = \sqrt{(MVA^2 - MW^2)} \quad (11)$$

Where,

$MVA = Complex\ power$

$MW = Active\ power$

$MVA_r = Reactive\ power$

Power factor, $pf = \frac{Active\ power}{Complex\ power} = \frac{MW}{MVA}$ (12)

If base value and base voltage are known, then:

$$Per\ Unit\ Value, P_{P.U} = \frac{MW}{Base\ Value} \quad (11)$$

$$Per\ Unit\ Value, Q_{P.U} = \frac{MVAr}{Base\ Value} \quad (12)$$

Upon getting secondary data, the values are used as input data in the Electrical Transient Analyzer Program software for the load flow studies and improvements using capacitor banks.

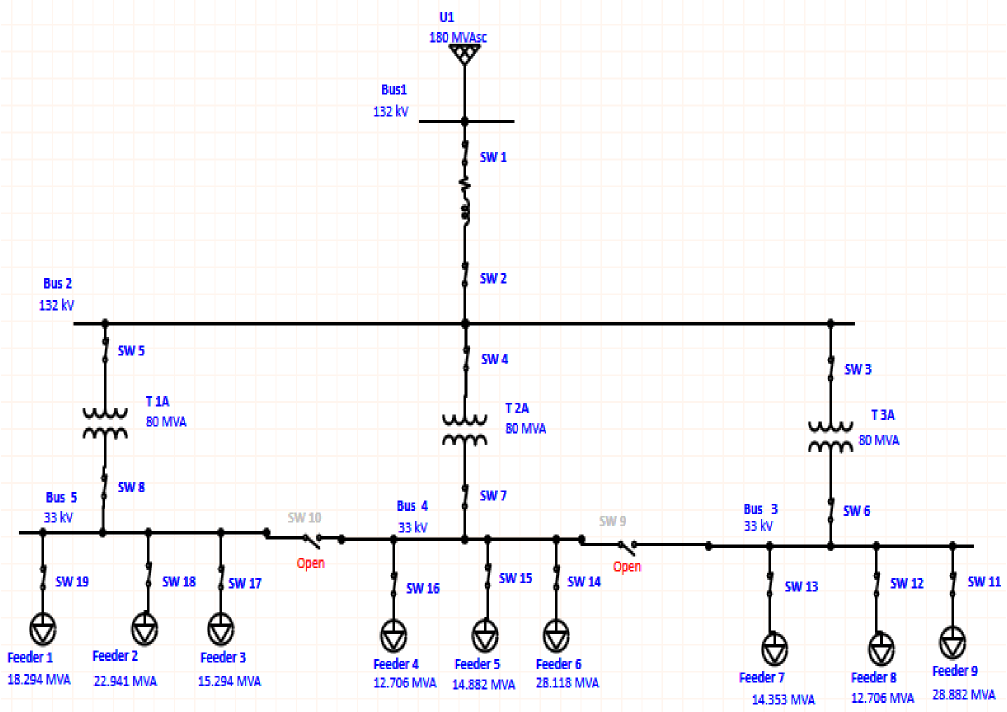

Figure 1: Single Line Diagram of the Prototype Power System

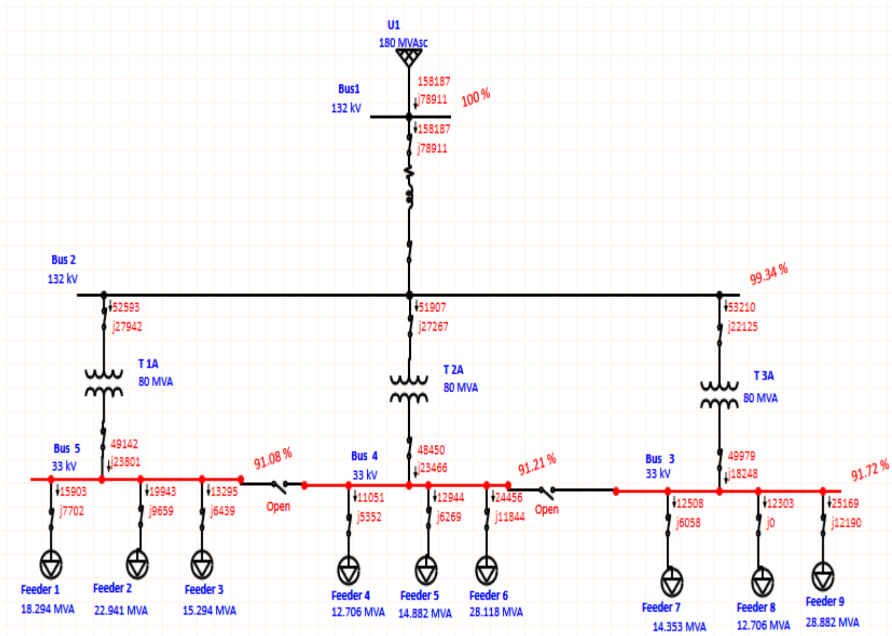

Figure 2: Single Line Diagram of the Prototype Power System without Capacitor Banks

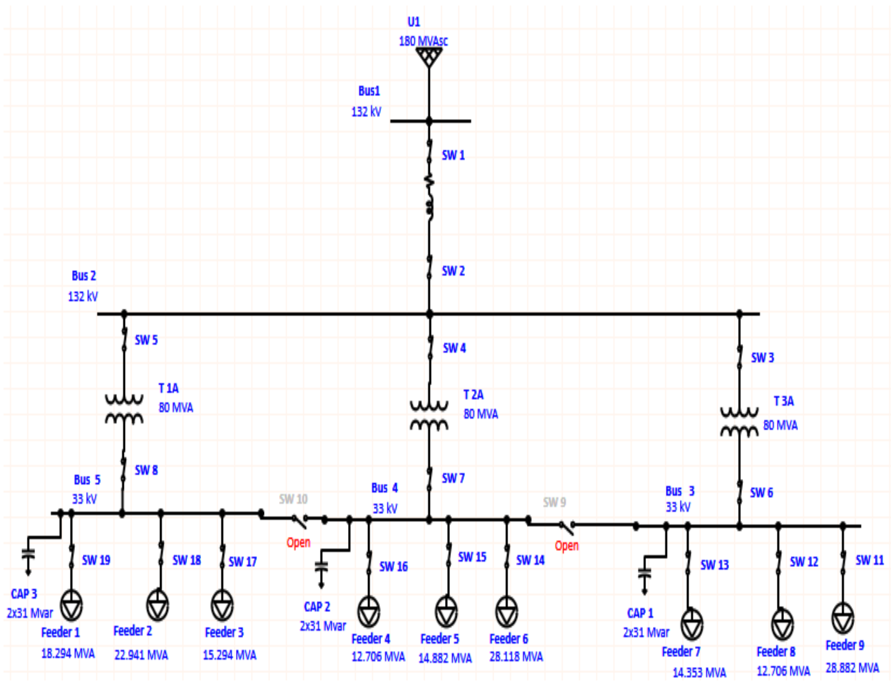

Figure 3: Single Line Diagram of the Prototype Power System with Capacitor Banks

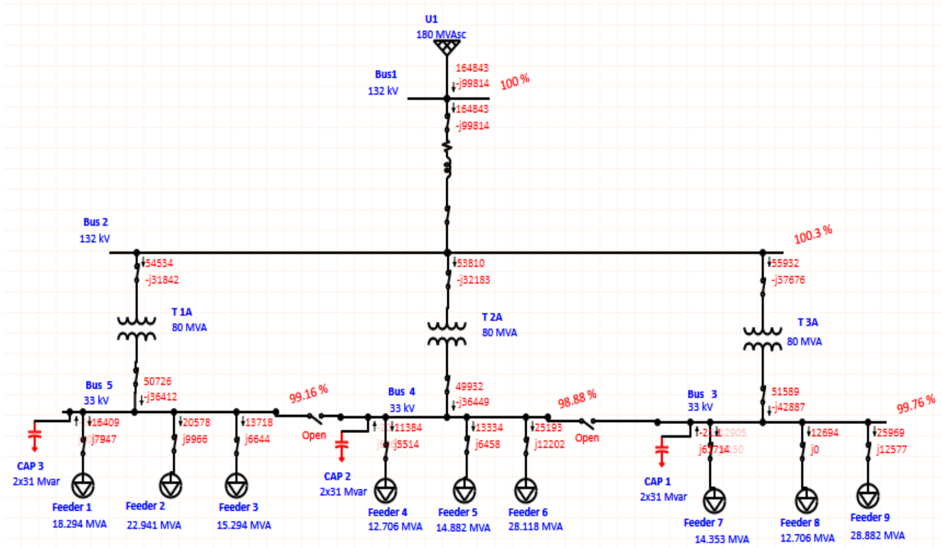

Figure 4: Single Line Diagram of the Prototype Power System with Capacitor Banks

IV. RESULTS AND DISCUSSION

4.1 Bus Percentage Loading

Figure 5 shows bus loading, branch loading, and losses under two operating conditions: buses 1 and 2 had the lowest loading of 18.4 MW, bus 5 had the highest loading of 65.6 MW, and no capacitor was installed. With the inclusion of capacitor banks, the load on buses 1 and 2 rose to 20.1 MW, while the load on bus 3 rose from 63.4 to 88.2 MW, the highest, compared to bus 5, which rose from 65.6 to 87.5 MW.

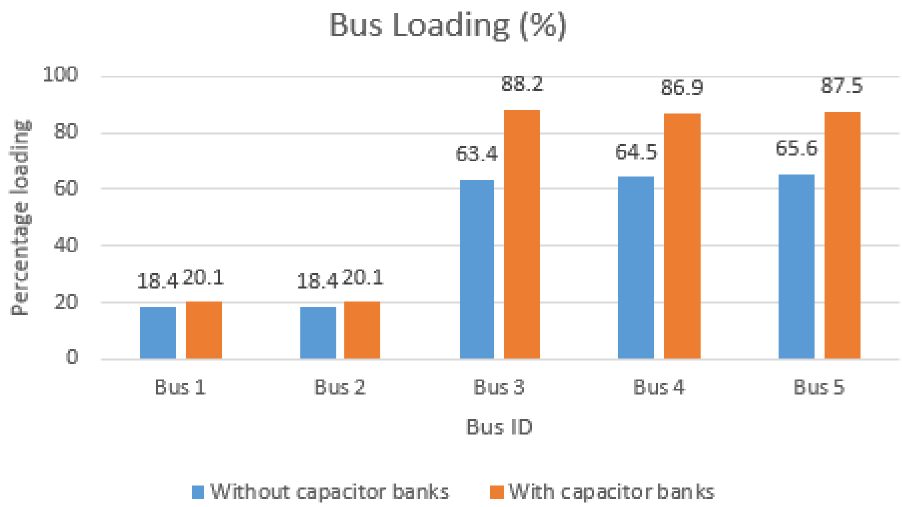

Figure 5: Bus Percentage Loading with and without Capacitor Banks

4.2 Transformer Percentage and MVA Loading

The load analysis of the transformers with and without a capacitor is shown in Figures 6 and 7. The base case shows that T3A is the least loaded at 66.5% and 53.206 MVA, while T1A is the most loaded at 68.3% and 54.602 MVA. Figure 6 also shows that T2A had the lowest loading at 77.3% and 61.820 MVA, while T3A was the most loaded at 83.9% and 67.088 MVA when capacitors were connected in the circuit.

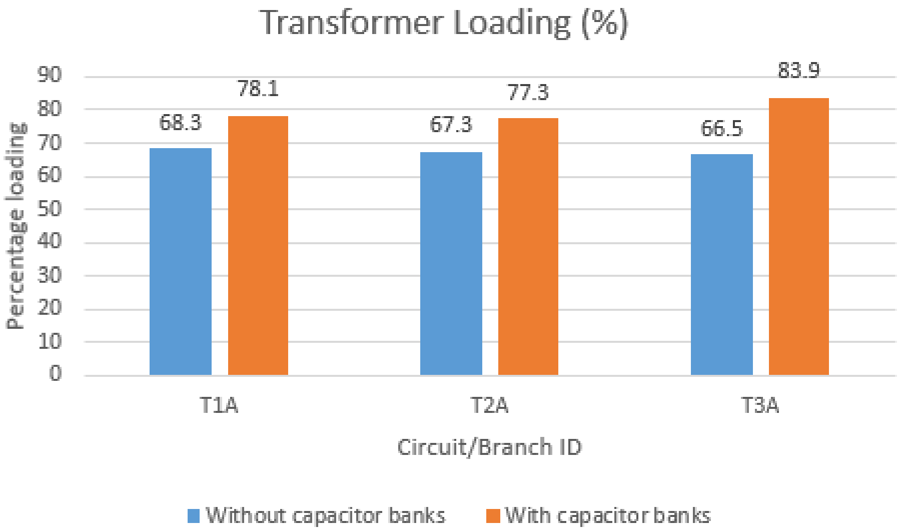

Figure 6: Transformer Percentage Loading with and without Capacitor Banks

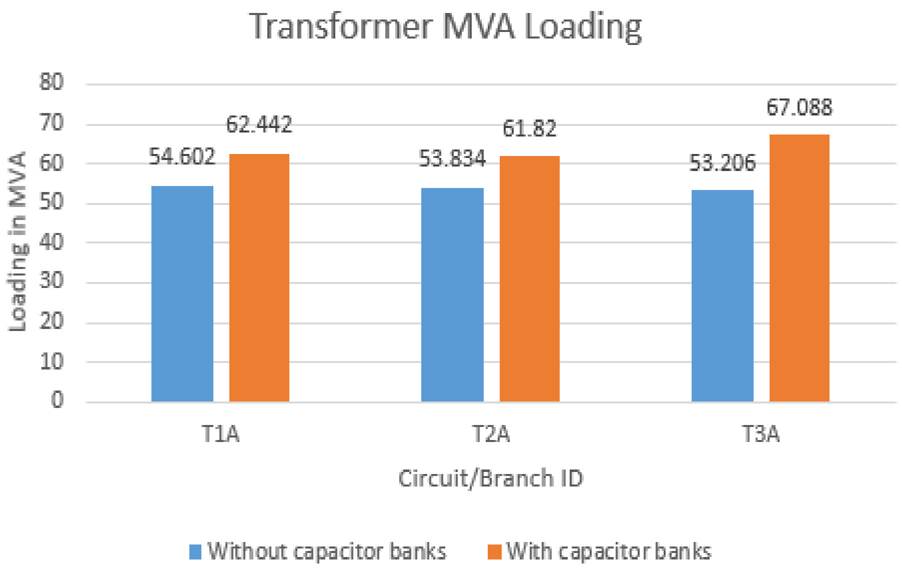

Figure 7: Transformer MVA Loading with and without Capacitor Banks

4.3 Branch Losses

Figures 8 and 9 show the branch losses under with and without capacitor scenarios. The least voltage drops of 0.28% occurred on the line while capacitor was connected and 0.66% voltage drops when capacitor was not connected. The least voltage drops of 0.52% occurred on T3A when capacitor was connected and a maximum of 7.62% when capacitor was disconnected.

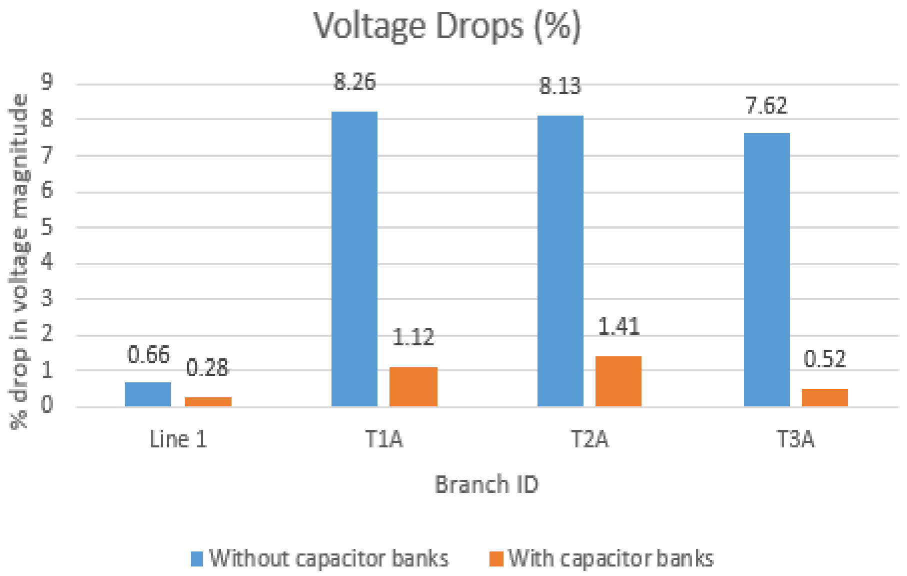

Figure 8: Percentage Voltage Drops with and without Capacitor Banks

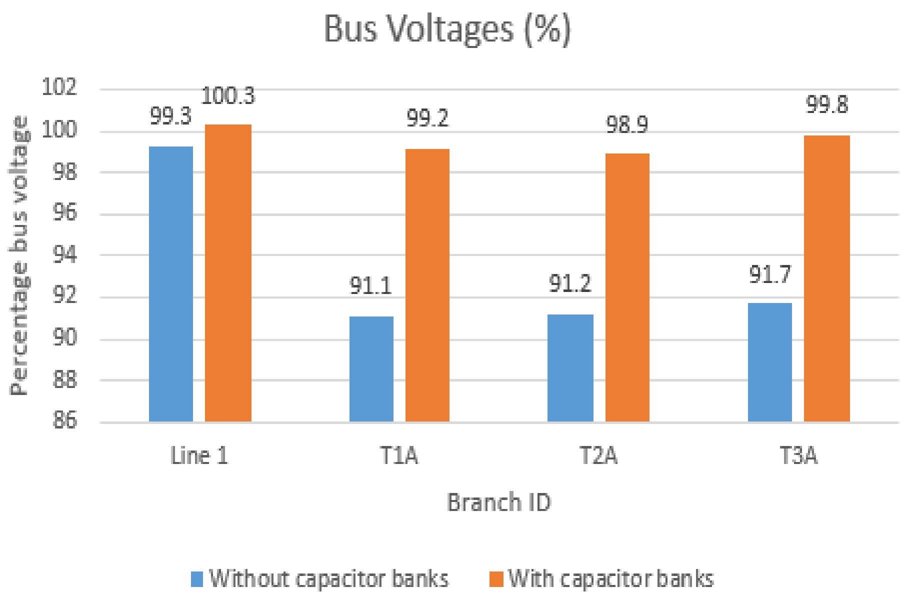

Figure 9: Bus Voltages in (%) with and without Capacitor Banks

V. CONCLUSION

From the findings, bus percentage loading was higher with capacitor banks and lower without them. In all forms, loading on each transformer increased with the introduction of capacitor banks compared with the baseline scenario.

The branch losses summary report showed that the least voltage drops occurred when capacitor banks were installed in the system. Voltage drops in the various buses were higher when capacitor banks were not installed. Voltage improved with the addition of capacitor banks, as all buses had voltages sufficient to support enhanced loading. Reduced voltage drops across buses, aided by capacitor banks, led to higher bus voltages, resulting in efficient load flow in the power system. Enhancing bus voltages with capacitor banks has mitigated increased voltage drops, thereby enabling efficient load flow in the system. Load flow in transmission and distribution networks is guaranteed with the inclusion of capacitor banks of appropriate sizes at appropriate locations.

REFERENCES

[1] Adeniji, O. A., & Mbamaluikem, P. O. (2017). Voltage Stability Enhancement and Efficiency Improvement of Nigerian Transmission System Using Unified Power Flow Controller. American Journal of Engineering Research, 6(1), 37-43.

[2] Al-Masud, M. R., Islam, M. M., Hasan, M. S., & Podder, P. (2019). Capacity Enhancement and Voltage Stability Improvement of Power Transmission Line by Series Compensation. European Alliance for Innovation Endorsed Transactions on Energy Web, 6(23), 1-10.

[3] Ajenikoko, G. A., & Ojeyinka, O. A. (2019). Loss Minimization and Voltage Profile Improvement in Power System: A Review. World Journal of Engineering Research and Technology, 5(3), 387-405.
[4] Amadi, H. N., Bakare, B. I., & Igbogidi, O. N. (2024). Renewable Energy for Sustainable Development in Nigeria: A Comprehensive Review. Ist International Conference of the Faculty of Environmental Sciences, Nnamdi Azikiwe University, 116-135.
[5] Amaize, P., Adoghe, A., Awosope, C., & Airoboman, A. (2017). A Review of the Application of FACTS Devices on Nigerian 330kV Transmission System. Journal of Engineering and Applied Science,12(20), 5182-5185.
[6] Ebune, R. U., Ezechukwu, O. A., & Aneke, J. I. (2018). Improvement of Reactive Power and Voltage Control with D-FACTS Devices in Nigeria Super Grid System. Iconic Research and Engineering Journals, 2(4), 87-93.
[7] Efe, S. B. (2016). Power Flow Analysis of a Distribution System Under Fault Conditions. International Journal of Energy and Smart Grid, 1(1), 22-27.
[8] Igbogidi, O. N., & Dahunsi, A. A. (2020). Load Forecasting using Quadratic Regression Model for Energy Management in Distribution Networks. International Research Journal of Engineering and Technology, 7(9), 3167-3174.
[9] Igbogidi, O. N., Dike, B., & Idoniboyeobu, D. C. (2023). Determination of Energy Not Supplied in Power System. American Journal of Engineering Research, 12(2), 108-117.
[10] Iyidobi, J. C., & Eneh, I. I. (2018). Enhancing the Voltage Stability of the Nigerian 330kV 28 Bus Power Network Using Unified Power Flow Controller (UPFC) and High Voltage Direct Current (HVDC) During Contingency of Three Phase Fault. International Journal of Engineering & Scientific Research, 6(8), 86-96.
[11] Oleka, E. U., Ndubisi, S. N., & Ijemaru, G. K. (2016). Electric Power Transmission Enhancement: A Case of Nigerian Electric Power Grid. American Journal of Electrical and Electronic Engineering, 4(1), 33-37.
[12] Olulope, P. K., (2018). Optimizing Power Loss on Nigerian Weak Transmission Line Using FACTS Devices and Genetic Algorithm. Journal of Electrical and Electronics Engineering, 13(3), 07-16.
[13] Tebepah, E. A., Amadi, H. N., & Igbogidi, O. N. (2024). Electric Power Transmission Upgrade in Nigeria: The Present Status. International Journal Of Engineering Research And Development. Journal of Recent Trends in Electrical Power System, 20(4), 128-133.