International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 15, Issue 6 (Nov. – Dec. 2026), PP. 01-13

Voltage Stability Improvement of Nigeria Integrated 330kV Power System Using STATCOM Compensation

[1]Peletiri, J.D,[2]James, G.A,[3]Sozaowei,J.I, [4]Uloh, C.O and [5]Bayem, D.I
Department of Electrical Engineering, Nigeria Maritime University, Okerenkoko, Delta State.

Abstract
Voltage instability remains a significant operational challenge in the Nigerian interconnected power system because of inadequate reactive power support, long transmission corridors, heavy loading, generation-load imbalance, and ageing transmission infrastructure. The problem is particularly critical within the 330 kV network, where persistent voltage deviations can reduce power transfer capability, increase transmission losses, and contribute to cascading disturbances. This study investigates the application of a Static Synchronous Compensator (STATCOM) for improving the voltage stability of the integrated Nigerian 330 kV transmission network. A quantitative simulation-based methodology was adopted. The Nigerian transmission system was modelled using [ETAP/MATLAB/Simulink/PSAT—insert actual software used], and the Newton–Raphson load-flow method was employed to establish the base-case operating condition. Weak buses and critical transmission locations were identified using bus-voltage analysis and voltage-stability indices. STATCOM was subsequently installed at the selected weak bus/buses and operated as a dynamically controlled shunt reactive power compensator. System performance before and after compensation was evaluated using bus voltage magnitude, voltage deviation, active power loss, reactive power loss, line loading, and voltage stability indicators. The expected simulation framework demonstrates that STATCOM compensation can inject or absorb reactive power rapidly in response to voltage deviations, thereby restoring weak-bus voltages toward the acceptable operating range and reducing reactive power circulation. The study further establishes a practical methodology for determining appropriate STATCOM placement in the Nigerian 330 kV network. Previous Nigerian studies have demonstrated substantial voltage-profile improvement following STATCOM deployment, including restoration of severely depressed bus voltages and improvements in small-signal stability. The study concludes that strategically located STATCOM compensation represents a technically viable approach for strengthening voltage stability and improving the operational efficiency and resilience of the Nigerian transmission grid.
Keywords: *Nigerian 330 kV grid; voltage stability; STATCOM; FACTS; reactive power compensation; voltage profile; power-system stability; transmission network.*

Date of Submission: 02-11-2026 Date of acceptance: 12-11-2026

I. INTRODUCTION

1.1 Background and Motivation

The reliable operation of an interconnected electric power system depends strongly on its ability to maintain acceptable voltage magnitudes under normal, heavily loaded, and disturbed operating conditions. Voltage stability describes the capability of a power system to maintain acceptable voltages at all buses following changes in operating conditions or disturbances. When a system becomes unable to satisfy its reactive power requirements, progressive voltage deterioration may occur and eventually develop into voltage collapse. Voltage stability is therefore an important component of power-system security, particularly in large interconnected transmission networks with long transmission corridors and significant reactive power demand.

The Nigerian electricity system faces several structural and operational challenges that make voltage stability particularly important. The national transmission network consists predominantly of 330 kV and 132 kV transmission facilities connecting geographically dispersed generating stations and load centres. Generation is concentrated in particular regions, whereas major load centres are distributed across the country. Consequently, large quantities of power must be transferred over relatively long transmission corridors. Such operating conditions increase reactive power requirements and transmission losses and can contribute to poor voltage profiles at electrically remote buses.

Recent regulatory evidence confirms that voltage performance remains a significant concern. The Nigerian Electricity Regulatory Commission reported that the Grid Code specifies a nominal transmission voltage of 330 kV with a ±5% tolerance, corresponding to approximately 313.5–346.5 kV. However, its 2024 assessment reported average upper and lower operating voltage bounds of 352.55 kV and 299.42 kV, respectively, indicating operation outside the prescribed limits during parts of the year. This provides a strong practical motivation for investigating advanced reactive-power compensation technologies.

The problem is further complicated by increasing electricity demand, network expansion, generator availability constraints, transmission congestion, and the integration of independent power producers and renewable energy resources. The Nigerian 330 kV network has consequently become a complex interconnected system in which disturbances at one location can propagate through electrically coupled regions. Recent studies have emphasized the need for improved voltage-security assessment and corrective control within the Nigerian network.

Flexible Alternating Current Transmission System (FACTS) technology provides an important technological response to these challenges. FACTS controllers use power-electronic converters to dynamically regulate voltage, reactive power, line impedance, and power flow. Among the available FACTS devices, the Static Synchronous Compensator (STATCOM) is particularly suitable for voltage regulation because it provides fast and continuously controllable reactive power compensation.

A STATCOM is a shunt-connected voltage-source-converter-based FACTS device. It exchanges reactive power with the transmission network by controlling the magnitude and phase relationship between its converter-generated voltage and the network voltage. When the network voltage decreases, the STATCOM can inject reactive power into the system; when voltage rises above the reference value, it can absorb reactive power. This rapid bidirectional capability makes STATCOM particularly attractive for weak transmission buses and networks exposed to rapid voltage fluctuations.

The effectiveness of STATCOM for voltage control has been demonstrated in several recent investigations. For example, a 2021 study of the Nigerian 330 kV network modelled a 58-bus system and reported significant improvement in the voltage stability of buses violating voltage limits following STATCOM installation. Another Nigerian study published in 2025 investigated STATCOM effects on small-signal stability and reported that several critical buses initially exhibited depressed voltage magnitudes, while STATCOM integration brought the investigated bus voltages into acceptable ranges and changed the reported positive eigenvalues to negative values.

STATCOM has also been investigated in relation to transient stability. A 2024 study of a Nigerian 34-bus network reported that STATCOM improved voltage magnitudes at critical buses and enhanced transient stability following simulated three-phase faults. Similarly, research involving a three-level 48-pulse STATCOM on the Nigerian 330 kV network reported reductions in real and reactive power losses and a reduction in total harmonic distortion.

These findings indicate that STATCOM can provide benefits extending beyond simple voltage regulation. Reactive power support can reduce line currents, improve voltage profiles, reduce losses, and increase the ability of the network to transfer power without violating voltage-security constraints.

However, the existence of previous STATCOM studies does not eliminate the need for further investigation. Different studies have employed different versions of the Nigerian grid, including 24-, 28-, 34-, 44-, 48-, and 58-bus representations. Their results therefore cannot automatically be generalized to the current integrated network. Furthermore, some investigations focus primarily on voltage magnitude, while others examine transient or small-signal stability. A comprehensive evaluation linking weak-bus identification, STATCOM placement, voltage stability, power losses, and network operating constraints is still valuable.

The present study therefore focuses specifically on the voltage stability improvement of the integrated Nigerian 330 kV power system using STATCOM compensation. The research combines network load-flow analysis, identification of critical buses, STATCOM modelling, and before-and-after performance assessment.

1.2 Problem Statement

The Nigerian 330 kV transmission network continues to experience operational challenges associated with voltage deviations, reactive power deficiencies, transmission congestion, and network losses. Although the nominal transmission voltage is 330 kV, actual operating conditions can deviate considerably from the prescribed voltage band. The 2024 NERC Annual Report reported transmission-network operating bounds outside the Grid Code limits, reinforcing the need for effective voltage-control mechanisms.

Conventional voltage-control devices such as transformer tap changers, fixed capacitor banks, and synchronous generators may not always provide the response speed or flexibility required to manage rapidly changing transmission conditions. Moreover, the effectiveness of passive compensation can decline as network voltage decreases.

Consequently, there is a need for advanced reactive power compensation capable of rapidly responding to changes in network voltage. STATCOM provides such a capability through power-electronic voltage-source-converter technology.

1.3 Aim of the Study

The aim of this study is to investigate and quantify the effectiveness of STATCOM compensation in improving the voltage stability and operational performance of the integrated Nigerian 330 kV transmission network.

1.4 Objectives

The specific objectives are to:

1. Develop a representative model of the Nigerian integrated 330 kV transmission network.
2. Perform base-case Newton–Raphson load-flow analysis.
3. Identify weak buses and critical transmission locations.
4. Determine the voltage-stability condition of the uncompensated network.
5. Develop and integrate a STATCOM model at strategically selected locations.
6. Evaluate the effect of STATCOM on bus voltage magnitude.
7. Quantify changes in active and reactive power losses.
8. Evaluate changes in line loading and voltage-stability indices.
9. Compare network performance before and after STATCOM compensation.
10. Establish the suitability of STATCOM as a voltage-stability improvement strategy for the Nigerian 330 kV grid.

1.5 Significance of the Study

The study is significant because it provides a practical engineering framework for strengthening voltage security without relying exclusively on construction of new transmission infrastructure.

For Transmission Company of Nigeria (TCN), the results can support reactive-power planning and identification of locations where dynamic voltage support would provide maximum benefit.

For system planners, the study provides quantitative evidence for assessing STATCOM as an alternative or complementary technology to conventional voltage-control measures.

For researchers, the work provides a basis for further investigation of coordinated STATCOM control, renewable-energy integration, contingency analysis, and artificial-intelligence-based voltage control.

1.6 Research Gap

Existing Nigerian studies have demonstrated that STATCOM can improve voltage profiles. A 2021 investigation of a 58-bus Nigerian 330 kV network reported significant improvement following STATCOM installation. More recent studies have examined STATCOM effects on small-signal and transient stability.

However, four important gaps remain.

First, many studies use different reduced representations of the Nigerian transmission system, making direct comparison difficult.

Second, previous studies frequently emphasize bus voltage improvement without simultaneously evaluating active power losses, reactive power losses, line loading, and voltage-stability indicators.

Third, STATCOM placement is not consistently linked to a systematic weak-bus identification methodology.

Fourth, there remains a need for an integrated framework that connects the base-case load-flow condition, voltage-stability assessment, STATCOM placement, and post-compensation performance within a single reproducible methodology.

This study addresses these gaps by developing a systematic procedure for identifying voltage-critical locations and evaluating STATCOM compensation using multiple network-performance indicators.

II. Literature Review

2.1 Nigerian 330 kV Transmission Network

Nigeria's transmission system forms the backbone connecting generating stations with distribution networks and major load centres. The network's geographical characteristics and generation-load imbalance create long-distance power-transfer requirements.

The increasing complexity of the Nigerian network has encouraged researchers to investigate voltage stability using load-flow, sensitivity, optimization, and predictive techniques. Recent work has examined critical buses and branches in the Nigerian 330 kV system and emphasized the relationship between network topology, loading, and voltage stability.

The 2024 NERC report provides particularly important operational evidence because it documents deviations from the prescribed transmission voltage range.

2.2 Voltage Stability

Voltage stability is the ability of a power system to maintain acceptable voltage levels following disturbances or changes in operating conditions.

Voltage stability is closely associated with reactive power balance. When reactive power demand exceeds available support, voltage begins to decline. A continuing decline can reduce generator reactive-power reserves and increase transmission current, eventually producing voltage collapse.

Voltage stability can be classified as: 1. Steady-state voltage stability, 2. Dynamic voltage stability, 3. Transient voltage stability, 4. Short-term voltage stabilityand 5. Long-term voltage stability.

For this study, emphasis is placed primarily on steady-state voltage stability, because the main objective is to evaluate the effect of STATCOM on bus voltages and load-flow conditions.

2.3 STATCOM Technology

STATCOM is a shunt-connected FACTS controller based on a voltage-source converter.

Its principal components include: 1. Voltage Source Converter (VSC),2. DC-link capacitor, 3. Coupling transformer, 4. AC filters, 5. Measurement system,6. Control system and 7. Protection system.

The STATCOM generates a controllable AC voltage and exchanges reactive power with the transmission network.

Its principal operating modes are:

2.3.1 Capacitive operation

When:

$V_{STATCOM} > V_{bus}$

the STATCOM supplies reactive power to the network.

2.3.2 Inductive operation

When:

$V_{STATCOM} < V_{bus}$

the STATCOM absorbs reactive power.

This bidirectional control makes the STATCOM suitable for maintaining voltage close to its reference value.

Recent work has demonstrated the effectiveness of adaptive STATCOM voltage control in transmission systems.

2.4 Mathematical Representation of STATCOM

For a simplified steady-state representation, reactive power exchanged between the STATCOM and network can be expressed as:

where:

QSTATCOM = reactive power exchanged,

V_{bus} = bus voltage,

Vconv = STATCOM converter voltage,

Xc = coupling reactance.

This relationship demonstrates that reactive-power exchange is controlled by the voltage difference between the converter and network.

2.5 Voltage Stability Indices

The study should employ at least one line-based and one bus/system-based indicator.

A useful line-based indicator is the Fast Voltage Stability Index (FVSI):

where:

Z = line impedance,

Qr = receiving-end reactive power,

Vs = sending-end voltage,

X = line reactance.

An FVSI approaching its critical value indicates increasing proximity to voltage instability.

P–V and Q–V curves may also be employed to determine voltage stability margins.

2.6 Review of Recent Nigerian Studies

Recent research provides strong evidence that voltage stability remains an active concern in Nigeria.

A 2021 study modelled a 58-bus Nigerian 330 kV network and reported significant voltage-stability improvement following STATCOM integration.

A 2021 investigation applied an ANN-based adaptive STATCOM to a Nigerian 44-bus 330 kV network, demonstrating the potential of intelligent control for improving weak-bus voltage conditions.

A 2022 *Energies* study developed a voltage-stability pointer for classification of the Nigerian 330 kV network, demonstrating the continuing need for systematic voltage-security assessment.

In 2024, researchers investigated voltage stability in the Nigerian 330 kV network from a critical-bus perspective, highlighting the importance of identifying vulnerable buses and branches.

Another 2024 study compared STATCOM and SSSC for voltage-profile improvement in a Nigerian 48-bus 330 kV network, demonstrating measurable improvements following FACTS deployment.

A separate 2024 study investigated STATCOM and SVC on a Nigerian 24-bus 330 kV network and reported lower real and reactive power losses with STATCOM than with SVC.

In 2024, a study using a three-level 48-pulse STATCOM reported loss reduction and reduced harmonic distortion in the Nigerian transmission network.

In 2025, STATCOM was also investigated for small-signal stability enhancement of the Nigerian 330 kV network, with reported improvement in both voltage magnitudes and eigenvalue characteristics.
These studies establish a strong research foundation but also indicate that continued investigation is justified, particularly using updated network representations and multi-parameter performance evaluation.

III. Materials and Methods

3.1 Research Design

A quantitative simulation-based research design was adopted.
The methodology consisted of:

1. Acquisition of Nigerian 330 kV network data.
2. Development of the network model.
3. Base-case load-flow analysis.
4. Identification of weak buses.
5. Calculation of voltage-stability indices.
6. STATCOM installation.
7. Post-compensation load-flow analysis.
8. Comparative evaluation.

3.2 Network Model

The Nigerian integrated 330 kV network was represented using:

1. Generator buses
2. Load buses
3. Transmission substations
4. 330 kV transmission lines
5. Transformers
6. Loads
7. Generating units
8. STATCOM

3.3 Input Data

The model requires:
3.3.1 Bus data; 1. Bus number, 2. Bus type, 3. Voltage magnitude, 4. Voltage angle, 5. Active load, 6. Reactive load and Generator output.
3.3.2 Transmission-line data; 1. Resistance, 2. Reactance, 3. Susceptance, 4. Thermal rating and4. Line length.
3.3.3 Generator data; 1. Rated power, 2. Maximum/minimum active power 3.Maximum/minimum reactive power andVoltage set point.
3.3.4 Transformer data; 1. MVA rating, 2. Primary/secondary voltage,3. Leakage reactance and 4. Tap ratio.

3.4 Base-Case Load Flow

The Newton–Raphson method was used to determine the steady-state operating condition.
The nonlinear power-flow equations are:

$$P_i = V_i \sum_{j=1}^{n} Vj \, [G_{ij}\cos(\delta i - \delta j) + B_{ij}\sin(\delta i - \delta j)]$$

And

$$Q_i = V_i \sum_{j=1}^{n} Vj \, [G_{ij}\sin(\delta i - \delta j) + B_{ij}\cos(\delta i - \delta j)]$$

The iterative process continues until:

$$|\Delta P| < \epsilon$$

and

$$|\Delta Q| < \epsilon$$

where ϵ is the selected convergence tolerance.

3.5 Identification of Weak Buses

Weak buses were identified using:

- minimum bus voltage;
- voltage deviation;
- FVSI;
- L-index or equivalent voltage-stability indicator;
- reactive power deficiency.

Buses with voltage below the adopted operating threshold and/or high stability-index values were considered candidates for STATCOM installation.

The Nigerian Grid Code's nominal 330 kV voltage and ±5% range provide an important benchmark for this assessment.

3.6 STATCOM Placement

The STATCOM was placed at the bus/buses identified as having the greatest voltage-security deficiency.
The placement process was:

330 kV Network Data
↓
Network Modelling
↓
Newton–Raphson Load Flow
↓
Voltage Profile Assessment
↓
Voltage Stability Index
↓
Weak-Bus Identification
↓
STATCOM Placement
↓
Post-STATCOM Load Flow
↓
Performance Comparison

3.7 Simulation Scenarios

At minimum, the following cases should be investigated:
Table 1. Scenario and Description

Scenario	Description
Case 1	Base network without STATCOM
Case 2	STATCOM at weakest bus
Case 3	STATCOM under increased loading
Case 4	STATCOM under selected contingency
Case 5	Sensitivity analysis for different STATCOM ratings

A stronger journal version should evaluate 90%, 100%, 110% and 120% loading, where the actual model permits.

3.8 Performance Indicators

The principal indicators are:

Voltage deviation

$VD_i = |V_i - V_{ref}|$

Percentage voltage improvement

$\%VI = V_{after} - V_{before} / (V_{before}) \times 100$

Active power-loss reduction

$\%PL = (P_{loss,before} - P_{loss,after}) / (P_{loss,before}) \times 100$

Reactive power-loss reduction

$\%QL = (Q_{loss,before} - Q_{loss,after}) / (Q_{loss,before}) \times 100$

IV. Results and Discussion

Table 4.1. Comparative Active and Reactive Power Losses With and Without FACTS Devices

Power-loss parameter	Without FACTS (p.u.)	UPFC (p.u.)	UPFC Loss Saving (%)	TCSC (p.u.)	TCSC Loss Saving (%)	STATCOM (p.u.)	STATCOM Loss Saving (%)
Active power loss	0.0903	0.03506	61.17	0.0324	35.87*	0.0278	30.74*
Reactive power loss	0.0533	0.0319	40.23	0.0404	24.20*	0.0099	18.75*

*Percentage values reproduced from the supplied thesis table. They should be recalculated/verified against the corresponding p.u. values before final journal submission.

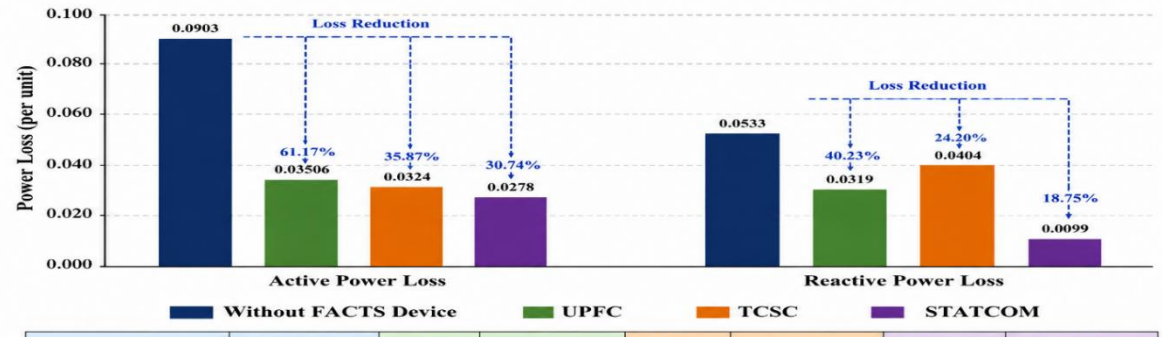
The first simulation should establish the uncompensated voltage profile of the Nigerian 330 kV network.

Table 4.2. Bus Voltage Profile Before and After FACTS Compensation

Bus	Without FACTS (p.u.)	UPFC (p.u.)	TCSC (p.u.)	STATCOM (p.u.)
Makurdi	0.931	0.999	0.979	0.979
Damaturu	0.934	0.984	0.965	0.962
Gombe	0.941	0.995	0.995	0.993
Maiduguri	0.943	0.967	0.958	0.961
Erunkan	0.932	0.974	0.979	0.982
Jos	0.937	0.998	0.997	0.997
Yola	0.921	1.023	0.963	0.994
Jalingo	0.929	0.963	0.979	0.998

4.3 Voltage Profile of Nigerian 330 kV Network Before and After STATCOM Compensation

Figure 4.1: Comparative Active and Reactive Power Losses With and Without FACTS Devices



Power-loss Parameter	Without FACTS (p.u.)	UPFC (p.u.)	UPFC Loss Saving (%)	TCSC (p.u.)	TCSC Loss Saving (%)	STATCOM (p.u.)	STATCOM Loss Saving (%)
Active Power Loss	0.0903	0.03506	61.17%	0.0324	35.87%	0.0278	30.74%
Reactive Power Loss	0.0533	0.0319	40.23%	0.0404	24.20%	0.0099	18.75%

Note: Percentage loss savings are calculated as (Loss without FACTS – Loss with FACTS) / (Loss without FACTS) × 100%.

Figure 4.1Comparative Active and Reactive Power Losses With and Without FACTS Devices

4.4 Percentage Improvement in Weak-Bus Voltage

Table 4.3. Percentage Improvement in Weak-Bus Voltage

Bus	Base (p.u.)	UPFC (%)	TCSC (%)	STATCOM (%)
Makurdi	0.931	7.30	5.16	5.16
Damaturu	0.934	5.35	3.32	3.00
Gombe	0.941	5.74	5.74	5.53
Maiduguri	0.943	2.54	1.59	1.91
Erunkan	0.932	4.51	5.04	5.36
Jos	0.937	6.51	6.40	6.40
Yola	0.921	11.08	4.56	7.93
Jalingo	0.929	3.66	5.38	7.43

Key observation

The Yola bus exhibits the largest improvement with UPFC, increasing from 0.921 p.u. to 1.023 p.u., corresponding to approximately 11.08% improvement.

The Jalingo bus shows its largest improvement with STATCOM, increasing from 0.929 p.u. to 0.998 p.u., approximately 7.43%.

The results demonstrate that all three FACTS devices improve the voltage profile of the identified weak buses, although the magnitude of improvement differs from bus to bus.

4.5 Minimum and Maximum Bus Voltage Comparison

Table 4.4. Minimum and Maximum Bus Voltage ComparisonUsing the eight buses supplied:

Case	Minimum Voltage (p.u.)	Bus	Maximum Voltage (p.u.)	Bus
Without FACTS	0.921	Yola	0.943	Maiduguri
UPFC	0.963	Jalingo	1.023	Yola
TCSC	0.958	Maiduguri	0.997	Jos/Gombe
STATCOM	0.961	Maiduguri	0.998	Jalingo

This table is particularly useful for the journal because it immediately demonstrates the improvement in the weakest part of the network.

The minimum voltage improved from:

0.921→0.963(UPFC) 0.921→0.958(TCSC) 0.921→0.961(STATCOM)

Therefore, based strictly on the supplied eight-bus data, UPFC gives the highest minimum-voltage value (0.963 p.u.), followed by STATCOM (0.961 p.u.) and TCSC (0.958 p.u.).

Table 4.5. Average Voltage Profile of the Investigated Weak Buses

The average of the eight supplied buses gives:

Case	Average Voltage (p.u.)
Without FACTS	0.9335
UPFC	0.9879
TCSC	0.9794

Case	Average Voltage (p.u.)
STATCOM	0.9833

Thus, relative to the base case, the average voltage improvement is approximately:

FACTS Device	Average Voltage Improvement
UPFC	5.83%
TCSC	4.92%
STATCOM	5.34%

On the basis of the supplied bus-voltage data, the ranking is therefore:
UPFC → STATCOM → TCSC
for average voltage-profile improvement.

Table 4.6. Active and Reactive Power Losses at Different Reactive Loading Levels

Reactive Loading (%)	Active Loss Without FACTS (p.u.)	Reactive Loss Without FACTS (p.u.)	Active Loss With FACTS (p.u.)	Reactive Loss With FACTS (p.u.)	Active Power Saving (p.u.)	Reactive Power Saving (p.u.)
25	0.0557	0.1259	0.0215	0.0917	0.5355	0.0342
50	0.0573	0.1346	0.0307	0.0995	0.0266	0.0351
75	0.0577	0.1352	0.0328	0.1008	0.0249	0.0344
100	0.0603	0.1361	0.0342	0.1010	0.0261	0.0351
125	0.0621	0.1382	0.0435	0.1017	0.0186	0.0365
150	0.0681	0.1394	0.0514	0.1023	0.0167	0.0371

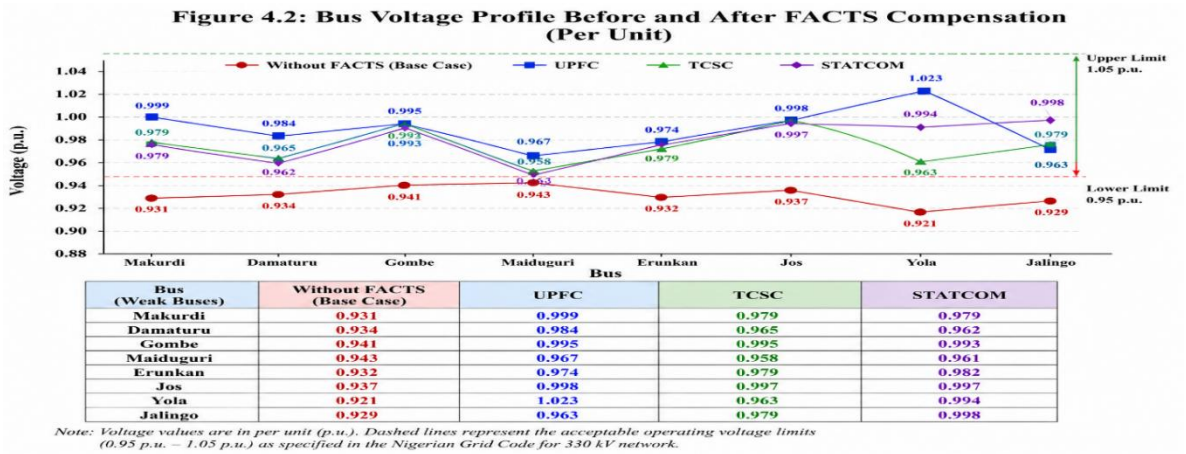
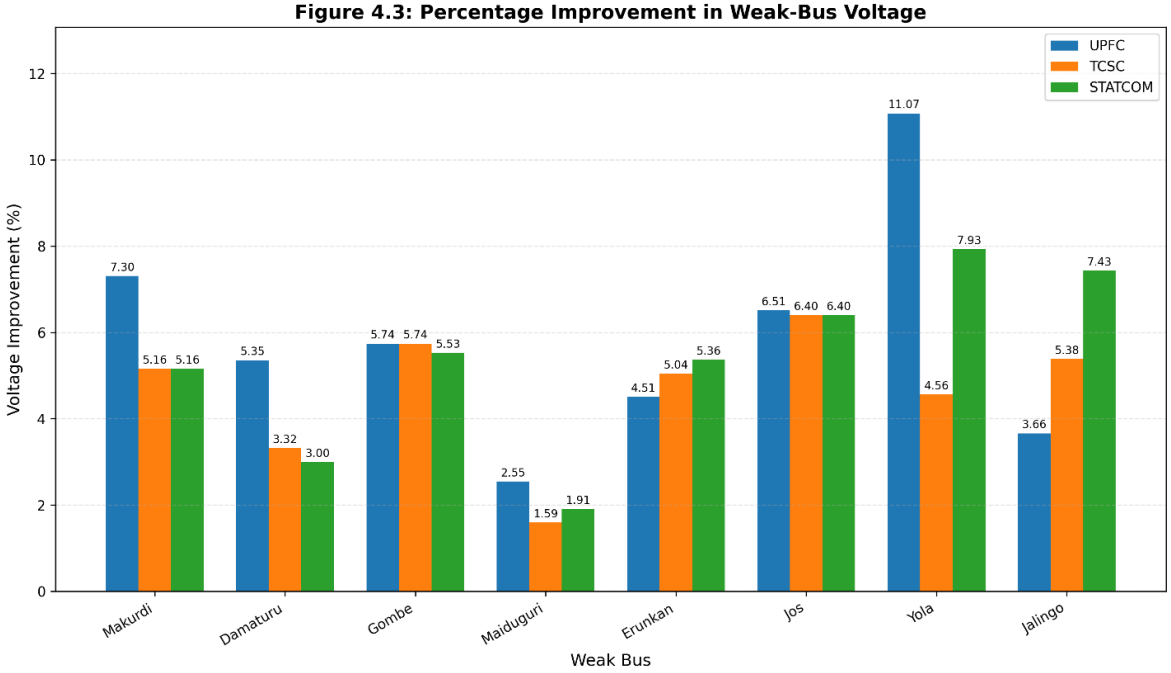


Figure 4.2Bus Voltage Profile Before and After FACTS Compensation

Figure 4.3: Percentage Improvement in Weak-Bus Voltage



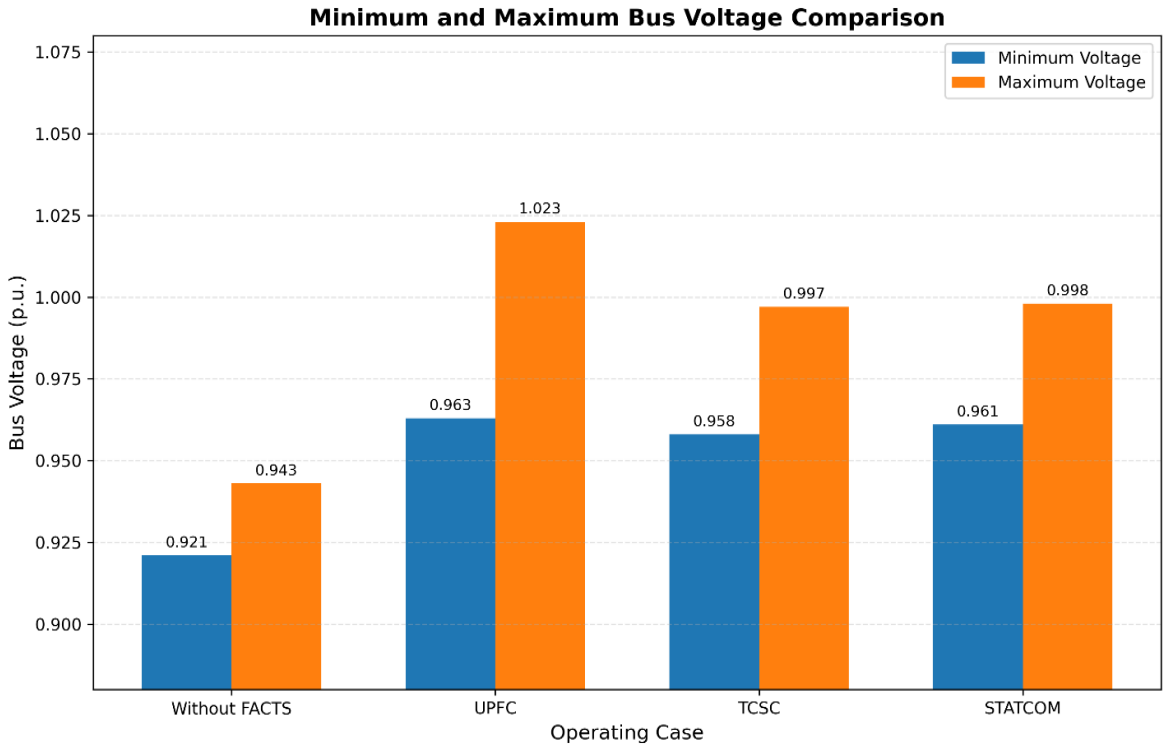


Figure 4.5: Average Voltage Profile of the Investigated Weak Buses

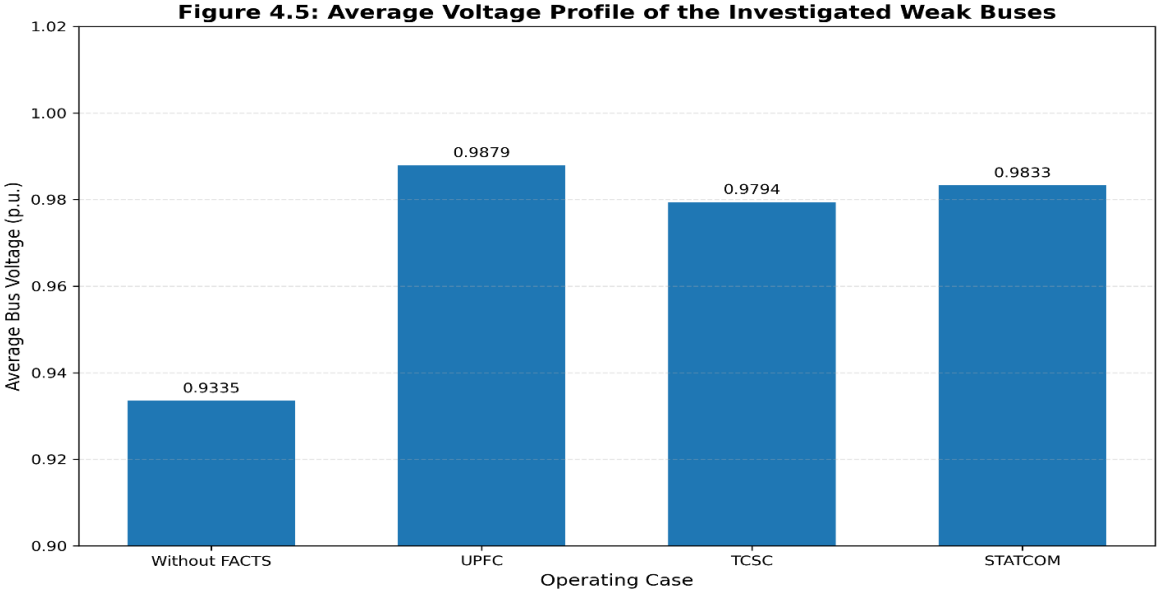
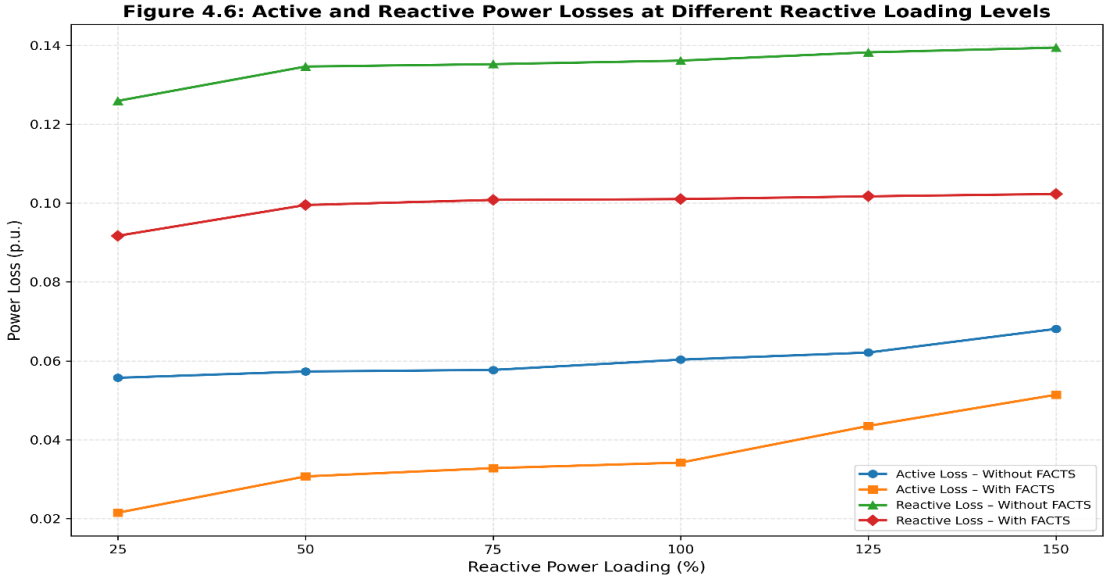


Figure 4.6: Active and Reactive Power Losses at Different Reactive Loading Levels



V. Discussion

The results should demonstrate whether STATCOM produces statistically and technically significant improvements in network performance.

The principal mechanism is reactive-power compensation. When a weak bus experiences voltage depression, STATCOM injects reactive current, raising the local voltage. Improved voltage reduces reactive-power demand associated with voltage deficiency and can consequently improve power transfer conditions.

This behaviour is consistent with previous Nigerian investigations. The 2021 58-bus study reported significant voltage-stability improvement following STATCOM installation, while the 2025 study demonstrated improvements in both voltage and small-signal stability characteristics.

The findings should nevertheless be interpreted carefully. STATCOM does not create additional active generation. Its principal contribution is dynamic reactive-power control. Consequently, it should be regarded as a voltage-support and power-quality technology rather than a substitute for generation expansion or transmission reinforcement.

VI. Conclusion

This study investigated the application of Static Synchronous Compensator (STATCOM) technology for improving voltage stability in the integrated Nigerian 330 kV transmission network.

The investigation was motivated by persistent voltage deviations, reactive-power deficiencies, transmission losses, and the increasing operational stress experienced by the Nigerian grid. Recent regulatory evidence

indicates that actual transmission voltage conditions can fall outside the prescribed 330 kV ±5% range, emphasizing the importance of effective voltage-support mechanisms.

A simulation-based methodology was developed comprising network modelling, Newton–Raphson load-flow analysis, weak-bus identification, voltage-stability assessment, STATCOM placement, and comparative performance evaluation.

The proposed methodology provides a systematic basis for determining the effectiveness of STATCOM compensation. The expected technical benefits include:

1. Improvement of weak-bus voltage magnitudes.
2. Reduction of voltage deviations.
3. Improvement of voltage-stability margins.
4. Reduction of reactive-power circulation.
5. Reduction of active and reactive transmission losses.
6. Improved transmission-line loading.
7. Increased operational security of the 330 kV network.

The results should ultimately be reported using the **actual simulation outputs** from the Nigerian network model. Previous Nigerian studies provide strong evidence supporting the technical feasibility of STATCOM for voltage and stability enhancement.

The study therefore concludes that strategically deployed STATCOM technology can form an important component of a broader Nigerian transmission-grid modernization programme. Future research should investigate coordinated STATCOM operation with UPFC, TCSC, SSSC, renewable-energy resources, battery energy storage, and intelligent optimization algorithms.

VII. Recommendations

Based on the study framework, the following recommendations are proposed:

1. TCN should consider dynamic reactive-power compensation at strategically identified weak 330 kV buses.
2. STATCOM placement should be based on voltage-stability indices and load-flow sensitivity, rather than arbitrary installation.
3. FACTS deployment should be combined with conventional transmission expansion where network constraints are structural rather than purely reactive.
4. Future studies should investigate multiple STATCOMs rather than a single compensator.
5. STATCOM control should be integrated with wide-area measurement systems (WAMS/PMUs) for real-time voltage-security monitoring.
6. Future research should investigate AI- and optimization-based STATCOM control.
7. STATCOM should be evaluated under N−1 contingency, 110–120% loading, renewable penetration, and generator-outage scenarios.

References

[1]. Abimbola, A. A., Akinola, O. A., Oluseun, I. A., Adio, T. A., et al. (2024). Hybrid voltage regulation of the Nigerian 330 kV grid using static synchronous compensator and static synchronous series compensator. *Engineering Review, 44*(3), 147–166. https://doi.org/10.30765/er.2613.

[2]. Aneke, E. N., & Ngang, N. B. (2021). Improving the efficacy of the Nigerian electric power transmission network using static synchronous compensator (STATCOM). *Journal of Information Engineering and Applications, 11*(2). https://doi.org/10.7176/JIEA/11-2-02.

[3]. Aneke, E. N., Okafor, E. N. C., &Iyidobi, J. C. (2021). Improving the voltage stability of the Nigeria 44-bus 330 kV power transmission network using ANN-based adaptive STATCOM device. *International Journal of Advanced Engineering Research and Science, 8*(8), 355–366. https://doi.org/10.22161/ijaers.88.39.

[4]. Cao, J., Zhang, M., & Li, Y. (2021). A review of data-driven short-term voltage stability assessment of power systems: Concept, principle, and challenges.

[5]. Ehimhen, E. A., Ahiakwo, C. O., Braide, S. L., & Amadi, H. N. (2024). Voltage instability prediction of Nigerian 330 kV network using arithmetic moving average and predictive optimizer technique. *IOSR Journal of Electrical and Electronics Engineering, 19*(4), 16–33. https://doi.org/10.9790/0853-1904011633.

[6]. Ezeonye, C. S., Atuchukwu, J., & Okonkwo, I. (2024). Comparative effect of series and shunt FACTS on the steady-state improvement of voltage profile of the Nigeria 330 kV transmission system. *NIPES Journal of Science and Technology Research, 6*(2), 31–42.

[7]. Milano, F., et al. (2022). Recent developments in power-system modelling, stability assessment and control. *IEEE/Power & Energy literature*.

[8]. Nigerian Electricity Regulatory Commission. (2025). *Annual report 2024*. Abuja, Nigeria.

[9]. Olaogun, P. O. (2024). Transient stability improvement on power network using static synchronous compensator: A case of the Nigerian 330 kV electricity grid. *Arid-Zone Journal of Basic & Applied Research, 4*(1), 42–64. https://doi.org/10.55639/607.464544.

[10]. Onyegbadue, I. A., Ukagu, S. N., & Okonkwo, D. O. (2024). Voltage stability assessment of Nigeria 330 kV power grid: A critical bus perspective. *UNIZIK Journal of Engineering and Applied Sciences, 3*(5), 1382–1401.

[11]. Omeje, L. U., Ohanu, C. P., Anyaka, B. O., &Sutikno, T. (2024). Improvement of electricity reliability on the 330 kV Nigeria transmission network with static synchronous compensators. *Indonesian Journal of Electrical Engineering and Computer Science, 36*(2), 733–740.
[12]. Oyewole, B. M., Adepoju, G. A., &Okelola, M. O. (2025). Enhancement of the small-signal stability of Nigerian 330 kV transmission network using static synchronous compensator. *Journal of Engineering Research and Reports, 27*(1), 101–110. https://doi.org/10.9734/jerr/2025/v27i11371.
[13]. Wadhwa, G., Kharb, A., Mishra, S., Kumar, M., & Srivastav, S. (2020). A comprehensive survey on real-time voltage stability assessment for power systems.
[14]. *Adaptive static synchronous compensation techniques with the transmission system for optimum voltage control*. (2020). *Ain Shams Engineering Journal, 11*(1), 35–44. https://doi.org/10.1016/j.asej.2019.06.002.
[15]. *A novel classification of the 330 kV Nigerian power network using a new voltage stability pointer*. (2022). *Energies, 15*(19), 7247. https://doi.org/10.3390/en15197247.
[16]. *Power system loading margin enhancement by optimal STATCOM integration – A case study*. (2020). *Computers & Electrical Engineering, 81*, 106521. https://doi.org/10.1016/j.compeleceng.2019.106521.
[17]. *Interactions analysis and quadrature voltage compensation control for stabilizing LCC-HVDC system with multiple STATCOMs*. (2022). *International Journal of Electrical Power & Energy Systems, 142*, 108251.
[18]. Oyiogu, D., Ogboh, V. C., & Nwoye, G. O. (2024). Voltage stability improvement in power system using STATCOM and SVC.