Optimum Placement of Facts Devices on an Interconnected Power Systems Using Particle Swarm Optimisation Technique

Uduyok, Awajinwon Charles., Akaninyene B. Obot., Kufre M. Udofia

Department of Electrical and Electronics Engineering, Faculty of Engineering, University of Uyo, Nigeria

DOI: https://doi.org/10.51244/IJRSI.2025.120800189

Received: 10 Aug 2025; Accepted: 16 Aug 2025; Published: 19 September 2025

ABSTRACT

The increasing demand for electrical power has led to significant challenges in maintaining voltage stability and meeting reactive power requirements in modern power systems, particularly in Nigeria. This study investigates the optimal placement of STATCOM (Static Synchronous Compensator) devices in the Gombe 132 kV, 12-Bus transmission network using the Particle Swarm Optimization (PSO) technique. The power network is modelled and simulated in MATLAB/SIMULINK with the Power System Analysis Toolbox (PSAT) to assess the impact of STATCOM placement on voltage profile enhancement. The results demonstrate the effectiveness of STATCOM in mitigating voltage drops and enhancing reactive power control across the network. The study optimizes Bus-12 as the optimal location for STATCOM placement, resulting in improved voltage levels within the IEEE standard limits of $0.95 \leq V \leq 1.05$ p.u. The findings highlight the potential of PSO-based optimization for enhancing power system stability and reducing transmission losses, offering valuable insights for improving the reliability of the Nigerian power grid.

Keyword- STATCOM, Particle Swarm Optimization (PSO), Voltage Stability, MATLAB/SIMULINK, Transmission Network

INTRODUCTION

Modern power systems are increasingly stressed due to escalating electricity demands, leading to significant challenges in maintaining stable voltage profiles and managing reactive power [1], [2]. Nigeria's national grid is particularly vulnerable to voltage instability, characterized by frequent power outages and unreliable service. Voltage sags, swells, and harmonic distortions are pervasive issues that disrupt the smooth operation of the grid, especially in areas where transmission networks are overburdened [3]. Despite recent investments in power generation, the transmission infrastructure has not kept pace with rising demand. As a result, the grid often operates beyond its designed capacity, contributing to power quality issues [4].

To address these challenges, the integration of Flexible Alternating Current Transmission Systems (FACTS) has emerged as a promising solution. Specifically, Static Synchronous Compensator (STATCOM) devices have shown considerable potential in enhancing voltage regulation and improving the capacity for power transfer in transmission systems. STATCOMs use advanced power electronics to control reactive power, stabilizing voltage levels, and mitigating transmission losses [5]. However, the effectiveness of STATCOMs is highly dependent on their optimal placement within the grid, as improper location selection can lead to suboptimal results [6].

Recent studies have demonstrated the utility of particle swarm optimization (PSO) in optimizing the placement of FACTS devices in power networks. PSO is recognized for efficiently finding optimal solutions in complex, nonlinear systems by minimizing voltage deviations and improving system stability [7]-[10]. Despite these advancements, there remains a gap in applying PSO-based optimization techniques to Nigeria's 330 kV transmission network, particularly the Gombe 132 kV, 12-Bus power system, which suffers from poor voltage stability [4], [11].

This study aims to address this gap by evaluating the effectiveness of STATCOM devices in improving the voltage profile of the Gombe 132 kV, 12-Bus power network. Using PSO for optimal STATCOM placement, this research will provide insights into improving voltage regulation, reducing transmission losses, and enhancing the overall reliability of Nigeria's power grid.

MATERIAL AND METHODS

Materials

This section outlines the materials and methods used to analyse the effectiveness of STATCOM devices in improving the voltage profile of the Gombe 132 kV, 12-Bus power network. The study employed simulation tools and optimization techniques to evaluate the impact of STATCOM placement within the transmission network.

1) *Software and Simulation Tools*

The power network analysis and simulations were conducted using the Power System Analysis Toolbox (PSAT) in the MATLAB/SIMULINK environment. The PSAT command-line version, compatible with GNU Octave, was employed for network modelling. At the same time, SIMULINK interface was used for a more visual representation of the system and the placement of FACTS devices.

2) Gombe 132 kV Transmission Network

The study focused on the Gombe 132 kV, 12-Bus power network, part of Nigeria's North East region. The single-line diagram of the network, provided by the Jos Electricity Distribution Company (JEDCO), served as the basis for the simulations. The transmission network's parameters, such as line impedance, transformer ratings, and power generation data, were sourced from Transmission Company of Nigeria (TCN). The network design was carried out within the PSAT MATLAB environment using the graphical user interface (GUI), which allows for the easy inclusion of transmission lines, Buses, generators, and other essential components. Table I shows the transmission line parameters in per unit (p.u.) on a 100 MVA base, detailing line voltage, length, resistance, reactance, and half-line charging susceptance. Table II provides the power network Bus data, including Bus voltage, average load, and each Bus's real and reactive power.

Table I Transmission Line Parameters In P.U. On 100mva Base

S/N	Name of Branch	Length (km)	Rated Voltage (kV)	Current Limit (A)	R (p.u)	X (p.u)	B (p.u)
1	Jos-Gombe	265	330	1360	0.0095	0.051	1.010
2	Jos-Bauchi	118	132	400	0.140	0.280	0.057
3	Bauchi-Gombe	146	132	306	0.172	0.344	0.042
4	Gombe-Biu	126	132	400	0.221	0.311	0.059
5	Biu-Damboa	92	132	400	0.162	0.227	0.042
6	Gombe-Ashaka Junction	84	132	400	0.098	0.197	0.041
7	Ashaka/junction-Factory	10	132	306	0.118	0.024	0.005
8	Ashaka -Potiskum	94	132	306	0.110	0.221	0.046
9	Gombe-Savannah	95	132	306	0.166	0.233	0.044

10	Savanah-Numan	85	132	306	0.149	0.211	0.039
11	Numan-Yola	50	132	306	0.087	0.123	0.023
12	Damboa-Maiduguri	85	132	400	0.149	0.209	0.039

Source: [12]

Table Ii Bus Data Of The Transmission Network

Bus No.	Bus Name	Bus Voltage (kV)	Average load on Bus (MW)	Real Power P (MW)	Reactive Power Q (MVAR)
1	Jos	330	98.30	50.00	20.00
2	Gombe	132	23.40	20.01	16.01
3	Biu	132	4.80	1.50	1.20
4	Damboa	132	11.90	1.21	0.98
5	Maiduguri	132	76.60	32.50	26.01
6	Ashaka junction	132	30.00	9.10	6.00
7	Potiskum	132	28.00	15.5	8.90
8	Ashaka Cement Factory	132	3.51	1.40	2.40
9	Savannah	132	3.60	2.81	2.20
10	Numan	132	3.60	2.80	2.30
11	Yola	132	41.80	9.00	3.60
12	Bauchi	132	30.00	30.00	24.02

Source: [12]

3) STATCOM Device

The STATCOM device, a key component in this study, is modelled to enhance the network's voltage stability and reactive power control. The device is represented in the simulation environment with adjustable parameters, allowing for placement at different Buses within the transmission network. This study focuses on the placement of single STATCOM and double STATCOM devices, with the optimal location determined using the Particle Swarm Optimization (PSO) technique.

4) PSO Optimization Technique

The PSO algorithm is applied to optimize the placement of STATCOM devices in the network. The algorithm minimizes voltage deviation by iterating through possible placements of STATCOM at various Buses. The PSO parameters, including inertia weight, acceleration constants, and particle velocity, were carefully tuned to ensure convergence to the optimal solution. The objective function used for optimization was based on minimizing voltage deviations from the nominal values across all Buses in the network.

5) Simulation Data

The simulation requires several key datasets, including:

i. Transmission line parameters: The lines' resistance, reactance, and susceptance.

ii. Bus data: Voltage levels, load capacities, and generation data for each Bus in the system.

iii. Transformer and load data: Specifications of the transformers and load characteristics at each Bus.

Fig. 1 gives the single line diagram of the studied network.

METHODOLOGY

The methodology for this study involved modelling and simulating the Gombe 132 kV, 12-Bus power network to evaluate the impact of STATCOM devices on voltage stability. The following steps outline the power flow analysis and optimization of STATCOM placement using PSO algorithm. Fig. 2 illustrates the methodology employed for the study.

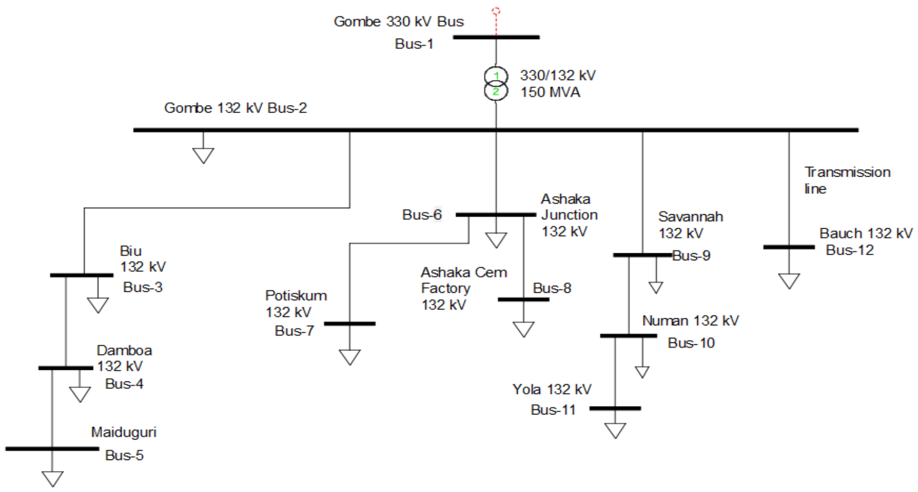

Fig. 1 Single Line Diagram of Gombe 132 kV Power Network [12]

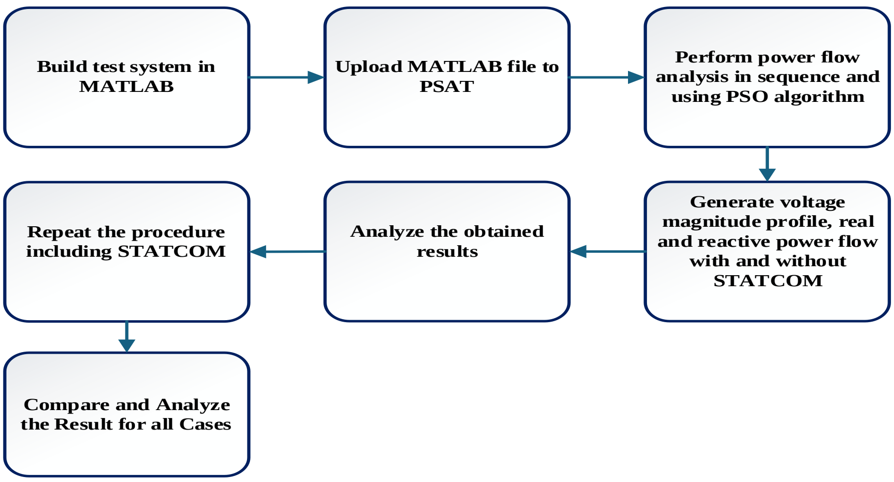

Fig. 2 Methodology Block Diagram

1) Power Flow Analysis without STATCOM (Base Case)

The first step in the methodology is to simulate the existing power network without any compensation devices. This served as the base case, providing the baseline data for voltage magnitudes, real and reactive power

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

generation, and system losses across all Buses. This simulation helps establish the network's voltage profile and identify areas of potential voltage instability (Li et al., 2023). The power flow equations used in this step are given in (1) and (2).

$$P_i = \sum_{j=1}^{N} V_i V_j \left(G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j) \right) \quad (1)$$

$$Q_i = \sum_{j=1}^{N} V_i V_j \left(G_{ij} \sin(\theta_i - \theta_j) + B_{ij} \cos(\theta_i - \theta_j) \right) \quad (2)$$

where P_i and Q_i are the real and reactive power injections at Bus i, V_i and θ_i are the voltage magnitude and angle at Bus i, G_{ij} and B_{ij} are the conductance and susceptance between Buses i and j, and N is the total number of Buses in the system.

2) Power Flow Analysis with STATCOM

In the second step, STATCOM devices were introduced to enhance voltage regulation and reactive power control. The STATCOM's reactive power injection is modelled as given in (3):

$$Q_{STATCOM} = \pm V_{STATCOM} (i_{STATCOM} . X) \quad (3)$$

where $Q_{STATCOM}$ is the reactive power provided by the STATCOM, $V_{STATCOM}$ is the voltage magnitude at the STATCOM's location, $I_{STATCOM}$ is the current injected or absorbed by the STATCOM and X is the reactance of the STATCOM device.

Each scenario involved placing a single STATCOM at various Buses (2–12, excluding the slack and PV Buses) to observe their effect on voltage magnitudes. The objective was to optimize the location to ensure the best voltage regulation.

Optimal Placement Using Particle Swarm Optimization (PSO)

The PSO algorithm was employed to determine the optimal placement for the STATCOM devices. PSO is a swarm intelligence-based optimization technique that searches for the optimal solution by simulating the social behaviour of particles (Kennedy & Eberhart, 1995). The objective function J to be minimized in this case is the voltage deviation from the nominal voltage (1.0 p.u.) at all Buses as expressed in (4):

$$J = \sum_{i=1}^{N} (V_i - 1)^2 \quad (4)$$

where V_i is the voltage magnitude at Bus i and 1 is the nominal voltage. The goal is to minimise this deviation and improve voltage in the process.

The steps for PSO are as follows:

1. Initialization: A population of particles (potential STATCOM placements) is initialized randomly within the search space (the set of Buses).
2. Fitness Evaluation: The fitness of each particle is evaluated using the objective function J.
3. Update Velocity and Position: Each particle updates its velocity and position based on its best-known position (pbest) and the best-known position in the swarm (gbest):

$$V_i^{k+1} = wV_i^k + c_1 r_1 \left(pbest_i - x_i^k \right) + c_2 r_2 \left(gbest_i - x_i^k \right) \quad \ldots (5)$$

$$x_i^{k+1} = x_i^k + V_i^{k+1} \quad (6)$$

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

where V_i^{k+1} and V_i^k are the new and current velocity of particles i, c_1 and c_2 are acceleration constants, r_1 and r_2 are random numbers between 0 and 1, $pbest_i$ and $gbest_i$ are the best positions of particle i and the swarm, respectively.

4. Termination Condition: The algorithm terminates after a predefined number of iterations (10 for a single STATCOM and 30 for double STATCOM placement), returning the optimal placement of STATCOM.

Fig. 3 gives the flowchart of the PSO algorithm.

Simulation Setup and Parameters

The PSO algorithm used the following parameters:

i. Inertia Weight (w): A constant that decreases from 0.9 to 1.0 during the search process.

ii. Acceleration Constants ($c_1 = 2.6, c_2 = 1.4$): These constants influence the effect of individual and global best positions on particle velocity updates.

iii. Particle Population: The number of particles is set to 5, with random initial placements for the STATCOM.

iv. Iterations: The algorithm runs 10 iterations for single STATCOM placement and 30 for double STATCOM placement.

The single-line diagram of the Gombe 132 kV, 12-bus power network, shown in Fig. 1, was first modelled in the PSAT/SIMULINK environment by dragging and placing components such as buses, generators, and transmission lines. Transmission line parameters from Table 1 and bus data from Table 2 were input accordingly. The completed power network model, developed using the PSAT GUI, is shown in Fig. 4.

3) Placement of STATCOM at Bus-2

A STATCOM was installed at Bus-2 (Fig. 5) and a power flow analysis was conducted to assess system performance under compensation. The resulting report quantified key metrics at Bus-2—including voltage magnitude, real/reactive power generation, losses, and total output—with the STATCOM operational. This placement and analysis procedure was repeated for Buses 3, 4, and 6–12.

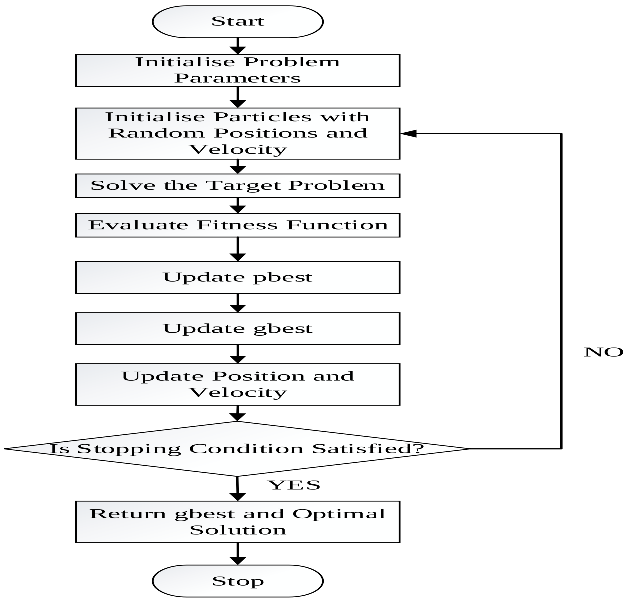

Fig. 3: PSO algorithm flowchart

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

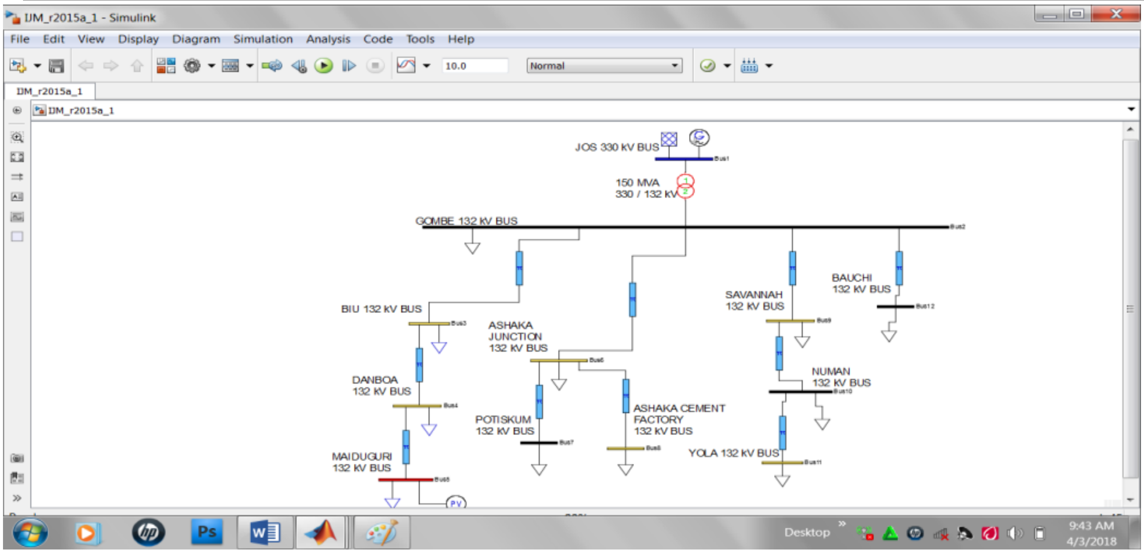

Fig. 4: Network Model without STATCOM in PSAT MATLAB Environment

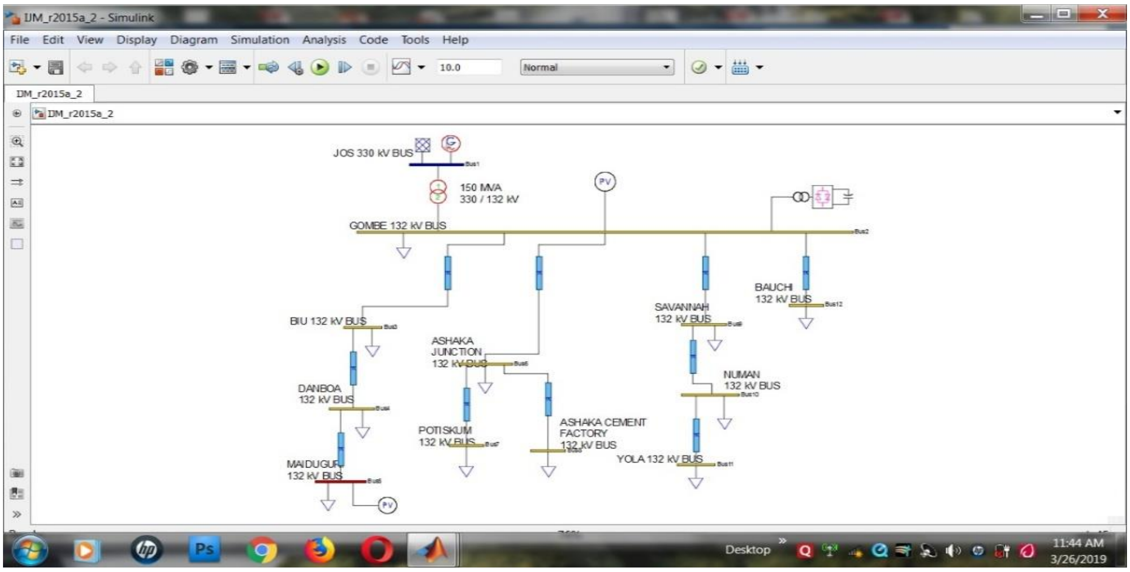

Fig. 5: Network model with STATCOM at Bus-2 in PSAT MATLAB environment

For each scenario—using a single STATCOM and using two STATCOMs—the power network was simulated using the PSO algorithm in MATLAB. The results were compared against the base case (without compensation) to evaluate the impact of STATCOM integration. At each bus where a STATCOM was installed and power flow analysis was performed using PSAT, the real/reactive power generation and power losses were recorded and tabulated. The effectiveness of the STATCOM was assessed by comparing the results with and without compensation.

RESULTS

This section presents the simulation results for integrating a STATCOM into the Gombe 132 kV, 12-bus power network. The STATCOM was placed on individual buses one at a time, and PSO algorithm was employed to determine its optimal location for enhancing bus voltage magnitudes. The simulation results, with and without STATCOM compensation using PSAT, were both tabulated and plotted.

A. Baseline Power System Performance (Without STATCOM)

For the system without STATCOM compensation, Table 3 presents the power flow results, including voltage profiles and real and reactive power generation. A bar graph of bus voltage magnitudes versus bus numbers is shown in Fig. 6. Bus voltages vary across the network, with Bus-12 (Fig. 6) recording the lowest voltage magnitude, and adjacent buses also experiencing low voltage levels. Most bus voltages fell outside the acceptable range of 0.95 p.u. to 1.05 p.u. Bus-1 and Bus-5 exhibited higher voltage levels than the others. Bus-1 is the slack bus that serves as the system reference with a predefined voltage magnitude and angle. At the same time, Bus-5 is a PV bus where both real power and voltage are specified.

B. Results for Location of a Single STATCOM

This study explored the optimal placement of STATCOM across the buses to evaluate its power enhancement capability. The STATCOM was placed at each bus individually (excluding the slack Bus-1 and PV Bus-5) to identify the most effective location for improving bus voltage levels within the network.

C. Optimizing Voltage Regulation: A Comparison of STATCOM Placement at Buses 2 to 12

The results for placing a STATCOM at Bus-2, shown in Fig. 7, indicate an improvement in voltage levels compared to the uncompensated system; however, this placement does not achieve optimal voltage regulation. While the voltage magnitudes at most buses were enhanced, many still remained outside the acceptable range of 0.95 p.u. to 1.05 p.u. This suggests that Bus-2, while offering some improvement, is not the ideal location for optimal voltage stabilization within the network. In comparison, the placement of the STATCOM at Bus-6, illustrated in Fig. 7, demonstrates a more significant voltage improvement across all buses, with the voltages at buses 1 through 8 remaining within the desired voltage range. Although buses 9, 10, 11, and 12 still showed voltage levels below the lower bound of 0.95 p.u., their values were improved compared to the base case, showing that Bus-6 provided a better overall voltage regulation than Bus-2.

Table Iii Voltage Magnitude Without Statcom (Base Case)

Bus No	V m (p.u)	Phase (Deg.)	P gen (p.u)	Q gen (p.u)	P Load (p.u)	Q Load P.u)
1	1.06400	0.00000	0.67389	0.89448	0.00000	0.00000
2	0.95096	-4.75580	0.00000	0.00000	0.20000	0.16000
3	0.99012	-4.41180	0.00000	0.00000	0.01500	0.01200
4	0.99730	16.42700	0.00000	0.00000	0.01200	0.00980
5	1.06000	21.82700	0.80000	0.25553	0.32500	0.26000
6	0.88295	-8.65600	0.00000	0.00000	0.08900	0.05000
7	0.83760	-10.97660	0.00000	0.00000	0.15500	0.08900
8	0.86422	-9.74990	0.00000	0.00000	0.08900	0.05000
9	0.85091	-6.85091	0.00000	0.00000	0.02800	0.02200
10	0.77530	-10.26650	0.00000	0.00000	0.03005	0.08453
11	0.75582	-11.46870	0.00000	0.00000	0.08033	0.03213
12	0.74462	-8.74370	0.00000	0.00000	0.25990	0.20792

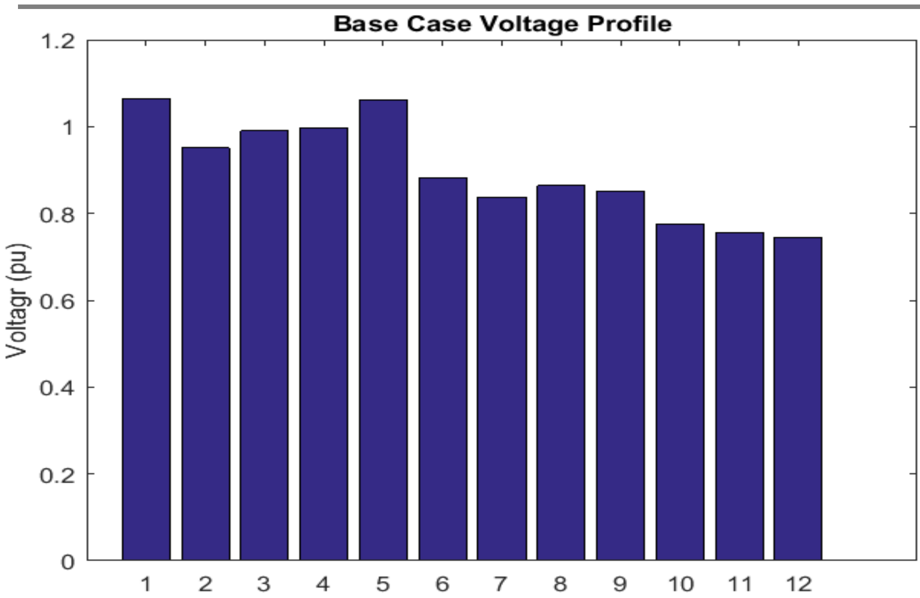

Fig. 6 Voltage Magnitude Without STATCOM (Base Case)

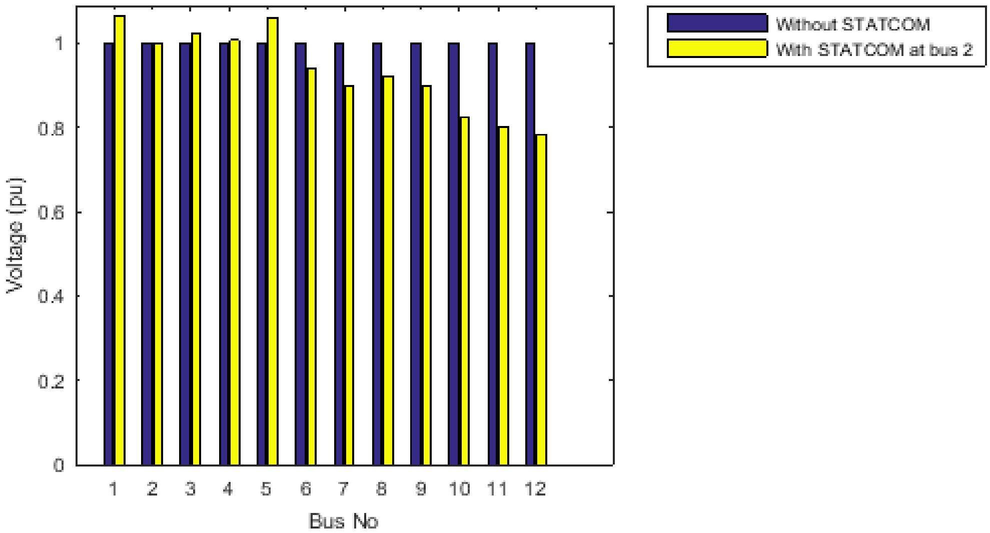

Fig. 7: Voltage Magnitude with Single STATCOM at Bus-2

In Fig. 8, the addition of STATCOM at Bus-7 significantly enhances the voltage profile of the network, especially when compared to the base case scenario. Most buses within the system, particularly buses 1 to 8, remain within the defined voltage range, illustrating a more stable and improved voltage regulation. The results suggest that Bus-7 is a superior location for placing the STATCOM, providing better overall performance across the network, as opposed to Bus-2. Although the voltage improvement for buses 9, 10, 11, and 12 does not fully meet the 0.95 p.u. lower limit, their enhancement over the uncompensated scenario marks Bus-7 as the preferred location for achieving more consistent voltage levels throughout the system.

D. Results for Location of STATCOM for Real and Reactive Power Control

Table IV presents the results of reactive power generation by the power system with the STATCOM positioned at each bus, with the corresponding plot shown in Fig. 9. As demonstrated in Table 2 and Fig. 2, the reactive power generation varies depending on the location of the STATCOM. Notably, the reactive power increases at the buses where the STATCOM was installed, indicating that the device effectively supplies the required reactive power to the specific points in the system where it is needed. Table V give a general comparative analysis of the proposed study with some existing works.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

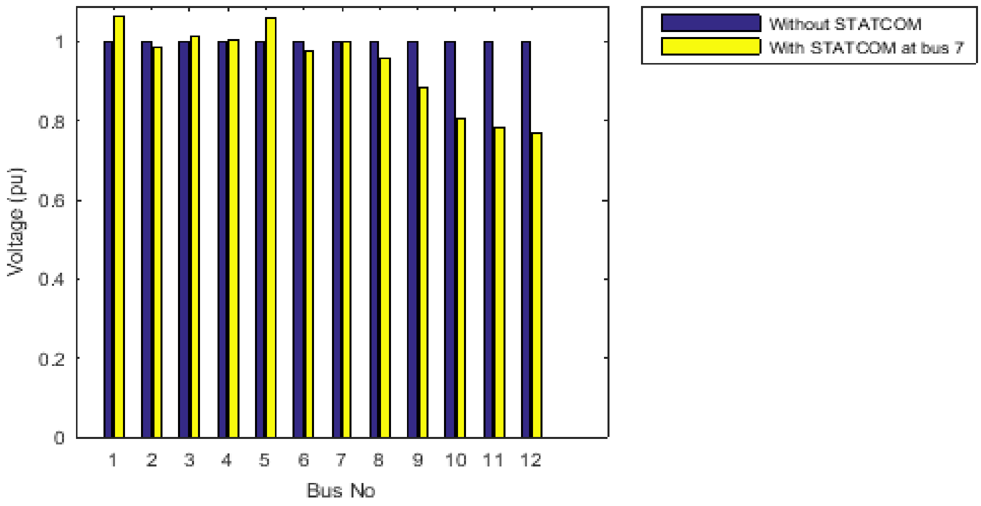

Fig. 8: Voltage Magnitude with a Single STATCOM at Bus-7

Table Iv Total Power Generation On The Network With Statcom

STATCOM at Buses	Total real power generation (p.u)	Total reactive power generation (p.u)
2	1.407	1.158
3	1.475	1.142
4	1.474	1.148
6	1.509	1.088
7	1.503	1.100
8	1.501	1.105
9	1.505	1.088
10	1.497	1.086
11	1.498	1.093
12	1.507	1.043

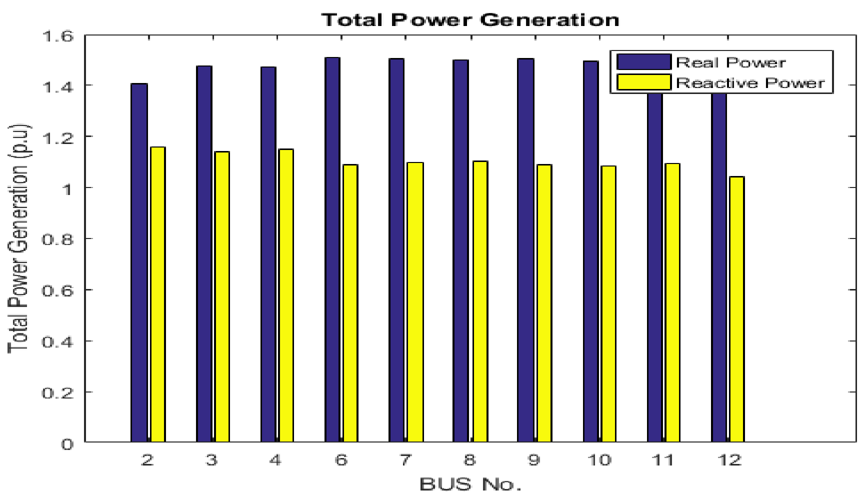

Fig. 9: Total Real and Reactive Power Generation with Single STATCOM at Each Bus

Table V Comparative Performance Analysis

Reference	Method Used	Result Obained	Research Gap
[13]	Particle Swarm Optimization-based power flow control in power systems.	Demonstrated effective power flow control in systems using PSO, showing improvements in voltage regulation and stability.	Limited application to real-world, large-scale systems. Needs more focus on complex power systems with dynamic conditions and the integration of multiple FACTS devices.
[14]	Optimization of FACTS devices for voltage stability in power grids using PSO.	Found that optimized placement of FACTS devices improves voltage stability and reduces transmission losses.	Lack of detailed analysis for specific regions, particularly in the Nigerian context. Further research needed on PSO applications in 132 kV transmission networks.
[15]	Power flow optimization using Particle Swarm Optimization.	Applied PSO to optimize power flow, achieving significant improvements in voltage stability and network performance.	Research did not focus on specific network designs or detailed case studies of Nigerian power systems, especially smaller, regional networks.
[16]	Evaluated STATCOM performance in mitigating voltage instability.	Identified STATCOM's effectiveness in voltage regulation, showing improvements in reactive power control across the network.	Research focused mainly on theoretical models with limited application to actual Nigerian power grid conditions, including 132 kV networks.
[17]	Particle Swarm Optimization algorithm for optimization in power systems.	Introduced PSO as an optimization technique, demonstrating its ability to find optimal solutions in complex, nonlinear systems.	Need for more focused applications in power system optimization and performance assessment, particularly in developing country grids like Nigeria's.
[18]	Analysis of transmission infrastructure and power quality issues in Nigeria.	Identified key power quality issues including voltage instability and proposed solutions involving FACTS devices.	Lacks a detailed focus on PSO or optimization methods applied to Nigerian 132 kV networks for real-world solutions, particularly regarding STATCOM placement.
[19]	Focused on voltage instability and mitigation strategies in Nigerian power systems.	Showed that integrated solutions with FACTS devices could stabilize voltage and reduce outages in Nigerian grids.	More in-depth research is needed on the use of optimization algorithms for FACTS device placement within Nigeria's complex 132 kV transmission networks.
[20]	Voltage Instability Prediction of Nigerian 330kV Network Using Arithmetic Moving Average and Predictive Optimizer Technique.	Applied a predictive optimization technique to identify voltage instability in the Nigerian 330kV network, using a combination of moving averages for improved	Limited focus on optimization techniques like PSO for predicting and mitigating voltage instability in large, interconnected power systems. Further research is needed on integrating PSO with predictive models for voltage stability

INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

		accuracy.	enhancement.
[21]	Optimal placement of STATCOM devices using genetic algorithms.	Found that genetic algorithms can successfully optimize STATCOM placement to improve voltage stability and power flow control.	Limited focus on PSO as an alternative optimization method for FACTS device placement. Further research needed on the comparison of PSO and genetic algorithms in voltage regulation in transmission systems.
[22]	PSO-based optimization for voltage regulation in transmission networks.	Confirmed PSO's effectiveness in optimizing voltage regulation by minimizing voltage deviations across the network.	More research needed to explore the use of PSO in optimizing the placement of multiple STATCOMs and other FACTS devices in large, interconnected networks. Further analysis is needed for Nigerian transmission systems.
[23]	Optimizing Power Losses and Voltage Profiles through Simultaneous Distribution Network Reconfiguration and DG Placement Using a Hybrid CDOA-PSO Algorithm.	Optimized power losses and voltage profiles in a Nigerian distribution network.	Research primarily focused on distribution networks, lacking integration with FACTS devices for voltage regulation. Further research needed on hybrid optimization algorithms for both distribution and transmission networks.
[24]	A Novel Combination of Genetic Algorithm, Particle Swarm Optimization, and Teaching-Learning-Based Optimization for Distribution Network Reconfiguration in Case of Faults.	Applied a hybrid approach combining PSO and genetic algorithms for fault-tolerant distribution network reconfiguration.	Limited exploration of PSO's potential in enhancing voltage regulation in power transmission systems like Nigeria's 132 kV networks
Proposed Study (2025)	The study evaluated the effectiveness of STATCOM devices for voltage profile enhancement in the Gombe 132 kV, 12-Bus power network, using PSO to determine the optimal placement.	Optimized placement of STATCOM at Bus-12 significantly improves voltage levels, maintaining them within the IEEE standard limits ($0.95 \leq V \leq 1.05$ p.u.). Enhanced reactive power control and real power generation were observed across all buses.	Limited research specifically applying PSO to optimize STATCOM placement in Nigeria's 132 kV, 12-Bus network, highlighting the need for further studies on real-world applications in the Nigerian grid.

CONCLUSION

The study analysed voltage enhancement in the Gombe 132 kV power network using STATCOM and optimized its placement across 12 buses. A single STATCOM was sequentially placed at each bus, and PSO algorithm was employed to determine the optimal siting of one or two STATCOMs. The results, comparing scenarios with and without STATCOM, reveal that proper placement of STATCOM at the optimal location significantly improves voltage levels within the operating range of $0.95 \leq V \leq 1.05$ p.u., effectively controlling both real and reactive power flows. The best network performance was achieved by placing a single STATCOM at Bus-1wA2, and the implementation of STATCOM contributed to enhanced real power generation.

REFERENCES

1. Padhi, S., & Swain, S. (2018). A review on the power system stability enhancement using FACTS controllers. Journal of Engineering Research and Application, 8(10), 124–133.
2. Verma, V. S., & Diwan, R. (2020). Review of power system stability enhancement using FACT controller. International Journal of Scientific Research & Engineering Trends, 6(2), 863–870.
3. Usiade, R., & Ufuah, C. (2024). Smart grid technology integration in Nigeria's power system. Greekline Journal of Communication and Advance Technology, 1(2), 42–50.
4. Abioye, A., & Buba, A. (2025). Power system stability enhancement of 132kV North-East power transmission network using STATCOM and SVC hybrid flexible alternating current transmission system. African Journal of Advances in Science and Technology Research, 18, 54–73. https://doi.org/10.62154/ajastr.2025.018.010684
5. Badrudeen, T. U., Ariyo, F. K., & Nwulu, N. (2025). Performance evaluation of STATCOM placement in real-world power system through DOA-NVSP algorithm for congestion management and stability improvement. Scientific Reports, 15, 26399. https://doi.org/10.1038/s41598-025-11232-2
6. Ojo, E. K., Akinremi, O. I., Adeleke, A. H., Adewale, O. A., Ajibola, C. D., & Ogunkeyede, O. Y. (2023). An optimal placement of STATCOM controller on 14-bus IEEE standard test transmission network using particle swarm optimization. FUOYE Journal of Engineering and Technology, 8(1).
7. Okelola, M. O., Ayanlade, S. O., & Ogunwole, E. I. (2021). Particle swarm optimization for optimal allocation of STATCOM on transmission network. Journal of Physics: Conference Series, 1880, 012035.
8. Shehata, A., Refaat, A., Ahmed, M., & Korovkin, N. V. (2021). Optimal placement and sizing of FACTS devices based on autonomous groups particle swarm optimization technique. Archives of Electrical Engineering, 70, 161–172. https://doi.org/10.24425/aee.2021.136059
9. Khan, A., Hizam, H., bin Abdul Wahab, N. I., & Othman, M. L. (2020). Optimal power flow using hybrid firefly and particle swarm optimization algorithm. PLoS ONE, 15(8), e0235668. https://doi.org/10.1371/journal.pone.0235668
10. Lima, D., & Vieira, J. (2023). Improving voltage regulation in distribution systems using PSO-based optimization in the presence of renewable energy resources. In ISGT Latin America 2023 (pp. 190–194). https://doi.org/10.1109/ISGT-LA56058.2023.10328268
11. Wadhai, B., & Bhasme, N. (2021). Performance analysis of STATCOM based power system for the transient stability improvement. In International Conference on Electrical Systems and Technologies (ICEST-2021).
12. 2016 Report from Jos Electricity Distribution Company Gombe State Chapter 2016.
13. Yahya, K. (2023). Analysis of 132–33 KVA grid sub-transmission line along Gombe to Yola power system of Nigeria. International Journal for Research in Applied Science and Engineering Technology, 11, 1122–1129. https://doi.org/10.22214/ijraset.2023.53497
14. Ahgajan, V. H., & Tuaimah, F. M. (2020). Optimal power flow for a power system under particle swarm optimization (PSO) based. International Journal of Computer Applications, 177(33), 56–62. https://doi.org/10.5120/ijca2020919757
15. Zeitawyeh, R., & Faza, A. (2025). Optimal reactive power planning using FACTS devices for voltage stability enhancement in power transmission systems. Energy Science & Engineering, 13, 2720–2756. https://doi.org/10.1002/ese3.70064
16. Dennis, O., Ogboh, V., & Nwoye, A. (2024). Voltage stability improvement in power system using STATCOM and SVC. [Journal name missing], 5, 33–46.
17. Kennedy, J., & Eberhart, R. (1995, November). Particle swarm optimization. In Proceedings of the IEEE International Conference on Neural Networks (Vol. 4, pp. 1942–1948). http://dx.doi.org/10.1109/ICNN.1995.488968

18. Al Butti, O. S. T., Burunkaya, M., Rahebi, J., & Lopez-Guede, J. M. (2024). Optimal power flow using PSO algorithms based on artificial neural networks. IEEE Access, 12.
19. Inyang, P., Nkan, I., & Okpo, E. (2024). Voltage stability improvement in the Nigerian southern 330kV power system network with UPFC FACTS device. American Journal of Engineering Research, 13, 27–33.
20. Ehimhen, E., Ahiakwo, C., Braide, S., & Amadi, H. (2024). Voltage instability prediction of Nigerian 330kv network using arithmetic moving average and predictive optimizer technique. [Journal name missing], 19, 16–33.
21. Srinivasa Rao, V., & Rao, R. (2017). Optimal placement of STATCOM using two stage algorithm for enhancing power system static security. Energy Procedia, 117, 575–582. https://doi.org/10.1016/j.egypro.2017.05.151
22. Alshehri, M., & Yang, J. (2024). Voltage optimization in active distribution networks—Utilizing analytical and computational approaches in high renewable energy penetration environments. Energies, 17(5), 1216. https://doi.org/10.3390/en17051216
23. Hadaeghi, A., & Abdollahi Chirani, A. (2025). Optimizing power losses and voltage profiles through simultaneous distribution network reconfiguration and DG placement using a hybrid CDOA-PSO algorithm. International Journal of Scientific Research in Science, Engineering and Technology, 12, 460–476. https://doi.org/10.32628/IJSRSET25122157
24. Linh, N. T. (2024). A novel combination of genetic algorithm, particle swarm optimization, and teaching-learning-based optimization for distribution network reconfiguration in case of faults. Engineering, Technology & Applied Science Research, 14(1), 12959–12965.