

Power System Stability Enhancement of 132kV North-East Power Transmission Network Using STATCOM & SVC Hybrid Flexible Alternating Current Transmission System

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Abstract

Among other issues that is affecting the power supply, the Nigerian power system is linked to epileptic supply, low system stability, large losses, weak bus voltages, line overloads, improper generating station placement, and lengthy transmission lines. This impacted overall power quality. Demands for additional electricity are growing daily, and the transmission and distribution networks must meet these demands while also ensuring improved power quality, reduced costs, and minimal environmental impact. Either alone or in combination, Flexible Alternating Current Transmission System (FACTS) devices are used to increase the stability of the power system. The impact of hybrid FACTS devices on the voltage and power stability of the 132kV power transmission network in North Eastern Nigeria is examined in this study. Ant colony optimization techniques were used to deploy the FACTS devices on the network after they were modelled. The network behaviours were examined when no FACTS devices were connected, when only Single FACTS was connected, and when hybrid FACTS was connected to the network. The simulations were conducted using hybrid FACTS devices—static var compensator (SVC) and static synchronous compensator (STATCOM)—in MATLAB's Power System Analysis Toolbox (PSAT). The results show that adding STATCOM alone to the network improves voltage profile by 9%, while adding combination of SVC and STATCOM together improves voltage profile by 12%. When STATCOM and hybrid (SVC & STATCOM) are linked to the network, the actual power loss decreased from 16% to 10%, respectively.

Keywords: FACTS, Power Stability, Ant Colony Optimization, PSAT, Newton-Raphson Load Flow, Voltage Stability.



Introduction

Global need for dependable and high-quality energy is rising quickly. Power quality issues have unavoidably increased as a result of the rapid development of energy output, primarily due to the expanding distance between generation and load centres. Around the world, this

has caused severely pressured power networks to experience voltage collapse (Chremk & Medhaffar, 2024). In order to optimize the current network, alternative power system stability enhancement techniques have become necessary due to the significant capital investment needed for new power infrastructure and the increasing strain on land. FACTS devices offer a great way to increase a power system's rotor, voltage stability, and power transfer capabilities because of their adaptability, high speed control, and flexibility. Due to their high initial installation and maintenance costs, flexible alternating current transmission system (FACTS) devices must be used and located optimally for the system restrictions (Olabisi & Ayeni, 2023). Previous studies on the use of FACTS devices to improve voltage and rotor angle stability have mostly focused on the effects of FACTS devices on the stability of the Nigerian power system, either examining the stability of either voltage or rotor angle separately or comparing two or more devices. Research on the coordinated use of a hybrid of FACTS devices to simultaneously explore the enhancement of rotor angle stability and voltage has not been conducted. Both parameters are applied simultaneously in a genuine power system. This is one of the reasons this study is being conducted.

The ability of the power system to maintain balance under all operating circumstances is known as stability (Atuchukwu, A. J, Okonkwo, I. I., Okoye, 2022). Power electronic-based devices known as flexible alternating current transmission systems (FACTS) allow for the management of one or more power system characteristics, hence improving system stability and controllability (Mbae & Nwulu, 2022). This is accomplished by appropriately adjusting the voltage, angle, and impedance factors. FACTS devices are categorized according to several factors, such as: i) how they are connected to the electrical system, ii) how old they are, and iii) switching technology. A thyristor-controlled reactor and a capacitor make up the static var compensator (SVC) (Adebisi et al., 2018).

It is a variable impedance device used for voltage control and damping of undesirable electromechanical oscillations (Bihari et al., 2021). For a SVC connected at bus k , the reactive power is expressed in (1):

$$Q_{svc} = Q_k = -V_k^2 Q_{svc} V_k \quad (1)$$

where

Q_{svc} = SVC reactive power output

Q_k = Reactive power injected at bus k

V_k = Voltage at bus k

Q_{svc} = Susceptance of the SVC

The system voltage is inversely proportional to the SVC's maximum compensating current (Nguyen & Mohammadi, 2020). They become less beneficial when a power system needs them the most since their maximal reactive power is an inverse function of voltage (Singh & Kumar, 2020). Numerous studies have been conducted on the usage of the SVC to increase rotor angle stability (Gouvêa, 2017) and the voltage stability of a power system both normally and during system disruptions like line faults and outages (Atuchukwu, Okonkwo, Okoye, 2022). The DC-AC switching converter serves as the foundation for the static synchronous compensator (STATCOM). It generates/absorbs reactive power by the

use of capacitor and reactors for voltage control and damping of system oscillations as shown in (2), (3) (Chawda & Member, 2020):

$$P = VV_o / X \sin \delta \quad (2)$$

$$Q = V(V - V_o \sin \delta) / X \quad (3)$$

where

V = Power system voltage

V_o = Voltage generated by the voltage source converter

X = Reactance of the connecting transformers and filters

Equation (2) and (3) demonstrate that the converter produces reactive (capacitive) power for the power system if the maximum displacement of the STATCOM voltage exceeds that of the system. Otherwise, it draws inductive reactive power from the system. The fact that the STATCOM offers complete reactive power adjustment independent of system voltage is a significant benefit over the SVC (Mosheer A D, Karrar M Alanbary, Sadiq AlKafaji M S, 2020). For stability improvement in voltage and rotor angle, the STATCOM has been thoroughly studied (Abas et al., 2020). When the SVC and STATCOM were compared, the latter outperformed the former in terms of improving transient stability and system voltage profiles (Ahmad & Sirjani, 2020).

By adjusting the frequency of the thyristor-controlled series capacitor (TCSC) capacitor using the thyristor firing angle, the series reactance is changed to increase or decrease the active power flow through the line (Khalili et al., 2022). As a source/sink of reactive power, it offers built-in protection against overvoltage. Investigating the degree of stability or power transfer capability increase at the usage of FACTS on the Gombe 132kV Transmission Network grid system is, therefore, the main goal of this study.

This research therefore focuses on achieving the following objectives;

- i. To evaluate the performance of Hybrid and Single FACTS with respect to voltage profiles of the Network system buses and transmission losses (Active and Reactive power losses) when connected to Gombe 132kV transmission network.
- ii. To optimally locate the FACTS for voltage stability enhancement in Gombe 132 kV transmission grid system using Ant Colony optimization Technique.

Methodology

The placement of the STATCOM and SVC on the network will be determined by modelling them and applying ant colony optimization techniques. In MATLAB's power system analysis toolbox (PSAT), the hybrid FACTS devices—Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM)—will be used for the simulations. The network's behaviours will be examined when no FACTS device is connected, when only STATCOM is connected, and when hybrid FACTS is connected to the network.

Materials

The materials to be used for the power network analysis include PSAT software in MATLAB/SIMULINK environment, Gombe 132 kV single line diagram and its parameters.

Northeast 132 kV Single Line Diagram

The main focus of this case study is the single-line diagram of the current 330/132 kV, 12-bus network, enhanced with line contingency control variables. From the Gombe 132 kV station to different distribution substations, Figure 1 shows how the power grid network is integrated.

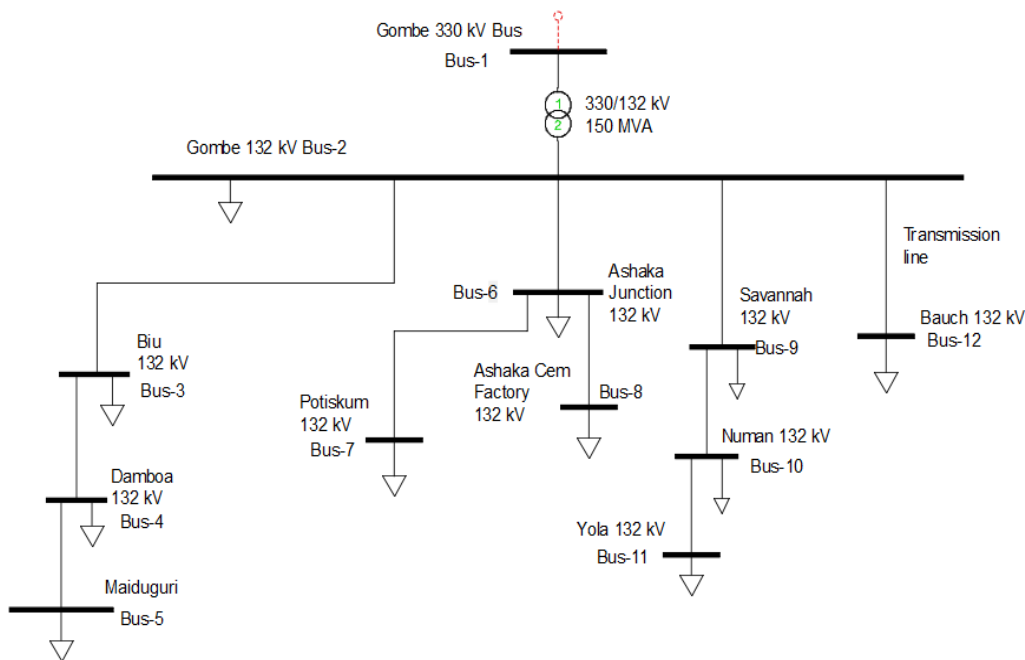


Figure 1: Gombe 132kv Transmission Single Line Diagram

Northeast (Gombe) 132 kV Transmission Line Parameters

Input data for the study and simulation requires a variety of factors, such as the resistance, reactance, and susceptibility of transmission lines, in addition to voltage and transformer/load data for the 330 kV Jos in-feed substations and Northeast 330/132 kV buses. In light of shifting system needs, these inputs seek to identify key centres that are having problems with low voltage profiles. The following tables display operational data analysis obtained from the Transmission Company of Nigeria (TCN) Gombe: Line parameters, including line voltage, length, and impedances such as resistance, reactance, and half-line charging susceptibility, are shown in Table 1 in units (p.u.) on a 100 MVA basis. Power network bus data is shown in Table 2, which also includes bus voltage, average load on each bus, and actual and reactive power loading on the bus.

Table 1: Transmission Line Parameters in P.U on 100MVA Base

S/N	Name of Branch	Type	Length (km)	Rated Voltage (kV)	Current Limit (A)	R (p.u)	X (p.u)	B (p.u)
I	Jos-Gombe	Bison	265	330	1360	0.0095	0.051	1.010
II	Jos-Bauchi	Bison	118	132	400	0.140	0.280	0.057
III	Bauchi-Gombe	Bison	146	132	306	0.172	0.344	0.042
IV	Gombe-Biu	Hyena	126	132	400	0.221	0.311	0.059
V	Biu-Damboa	Wolf	92	132	400	0.162	0.227	0.042
VI	Gombe-Ashaka-Junction	Hyena	84	132	400		0.197	0.041
VII	Ashaka/Junction-Factory	Hyena	10	132	306	0.118	0.024	0.005
VIII	Ashaka-Potiskum	Wolf	94	132	306	0.110	0.221	0.046
IX	Gombe-Savannah	Hyena	95	132	306	0.166	0.233	0.044
X	Savanah-Numan	Hyena	85	132	306	0.149	0.211	0.039
XI	Numan-Yola	Hyena	50	132	306	0.087	0.123	0.023
XII	Damboa-Maiduguri	Wolf	85	132	400	0.149	0.209	0.039

Source: Jos Electricity Distribution Company (JEDCO) Gombe, Nigeria, (2024).

Table 2: Bus Data of Gombe 132 kV Transmission Network

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

Source: Jos Electricity Distribution Company (JEDCO) Gombe, Nigeria, (2024).

Modeling of STATCOM

Operation of STATCOM

STATCOM can be either a current source or a voltage source inverter (VSI). The VSI system is discussed in this work. Figure 2 displays the STATCOM basic block diagram. The VSI creates a set of three-phase AC output voltages from the DC voltage across the storage device. Through resistance and leaky reactance, these voltages are in phase with the A. C. system. Depending on the switching device, STATCOM can be either IGBT for low voltage, low power applications or GTO for high voltage, high power applications. For direct power factor adjustment, it is important to note that the dc capacitor in STATCOM is significantly smaller than the standard ac capacitor.

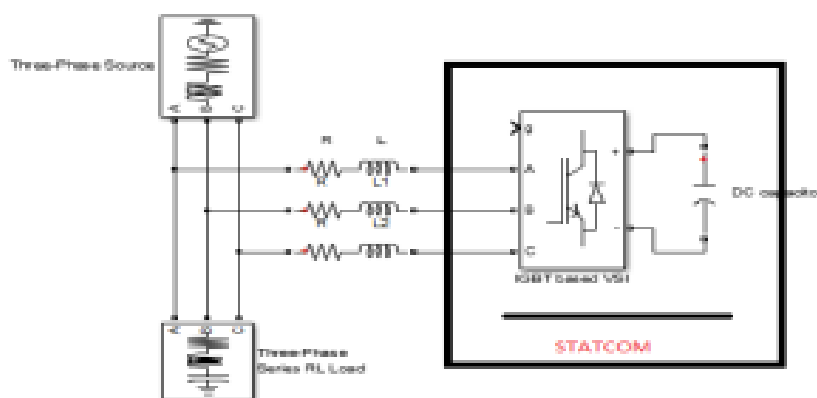


Figure 2: Basic Diagram of STATCOM

Principle of STATCOM Operation

The purpose of STATCOM is to manage reactive power in phase with the system voltage and suppress voltage variation. It has the ability to constantly and linearly correct for both inductive and capacitive current. The inverter voltage $V_{STATCOM}$, the voltage across the leakage reactance V_L , and the resistance in both the inductive and capacitive modes add up to the terminal voltage V_{bus} . It indicates that STATCOM provides reactive power to the system if its output voltage, $V_{STATCOM}$, is in phase with the bus terminal voltage, V_{bus} , and if $V_{STATCOM}$ is higher than V_{bus} . Reactive power from the power system is absorbed by STATCOM if $V_{STATCOM}$ is less than V_{bus} . There will be no power exchange if $V_{STATCOM}$ and V_{bus} are equal; in such case, STATCOM will function in floating mode. The STATCOM operational concept is depicted in Figure 3.

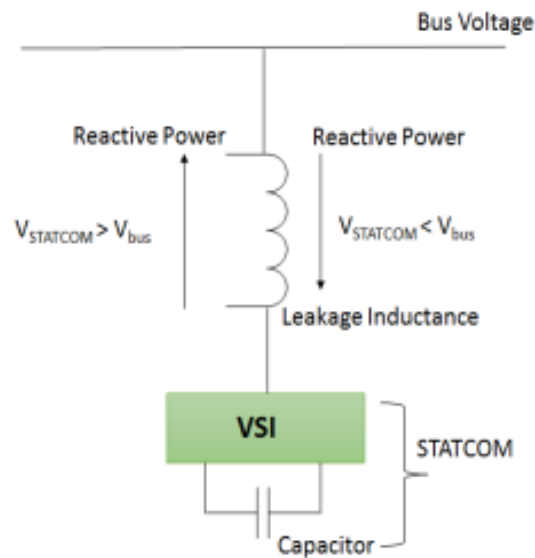


Figure 3: operating Principle of STATCOM

Terminal voltage V_{bus} (AC side) is equal to sum of STATCOM output voltage and voltage drop across line reactor and resistance.

V_{bus} = bus terminal voltage

$V_{STATCOM}$ = output voltage of STATCOM

$R + j\omega L = X_L$ = Inductive Reactance

V_{dc} = DC capacitor voltage

General mathematical equation of STATCOM for active power, reactive power and STATCOM output voltage may be given as:

$$P = (V_{bus} \times V_{STATCOM} \div X_L) \sin \alpha \quad (1)$$

$$Q = V_{bus} \times V_{bus} X_L - (V_{bus} \times V_{STATCOM} \div X_L) \cos \alpha \quad (2)$$

Mathematical Modeling of STATCOM

This study uses a standard A. C. system to demonstrate STATCOM performance. Figure 1 displays the STATCOM basic configuration. Resistance, leakage inductance, and VSI and DC capacitors make up STATCOM. Inductance and resistance serve as the system's magnetic coupling. They offer grid circuit and inverter circuit isolation. A DC capacitor serves as a source and maintains a steady voltage. It uses an IGBT with an anti-parallel diode. While the diode does the rectification action, the IGBT does the converter action. To determine resistance, leakage inductance, and DC side capacitance, utilize equations (1) through (8). The STATCOM's ac-side circuit's first order differential equation is

$$dI_{sa}/dt = 1/L_s (-R_s * I_{sa} + E_{sa} - E_{ta}) \quad (1)$$

$$dI_{sb}/dt = 1/L_s (-R_s * I_{sb} + E_{sb} - E_{tb}) \quad (2)$$

$$dI_{sc}/dt = C (-R_s * I_{sc} + E_{sc} - E_{tc}) \quad (3)$$

These equations are converted on R-l frame of reference (the synchronously rotating frame of reference) as follows

$$\begin{bmatrix} I_{sR} \\ I_{sl} \end{bmatrix} = \begin{bmatrix} \frac{-R_s}{L_s} & \omega \\ -\omega & \frac{-R_s}{L_s} \end{bmatrix} \begin{bmatrix} I_{sR} \\ I_{sl} \end{bmatrix} + \frac{1}{L_s} \begin{bmatrix} E_{sR} & E_{tl} \\ E_{sl} & E_{tl} \end{bmatrix} \quad (4)$$

STATCOM DC side equation is

$$dV_{dc}/dt = 1/C_s (I_{dc} + V_{dc}) \quad (5)$$

Instantaneous powers at the ac and dc terminals of the converter are equal, giving the following power-balance equation:

$$V_{dc} * I_{dc} = 3/2 (E_{sR} * I_{sR} + E_{sl} * I_{sl}) \quad (6)$$

Where the constant 3/2 is reference frame transformation constant. Based on the phasor diagram E_{sR} and E_{sl} is

$$E_{sR} = E_s \cos\theta_s = Kcs * V_{dc} * \cos\theta_s \quad (7)$$

$$E_{sl} = E_s \sin\theta_s = Kcs * V_{dc} * \sin\theta_s \quad (8)$$

Modeling of SVC

An SVC is a shunt connected FACTS device that regulates a given bus voltage by varying its equivalent susceptance. Variable shunt susceptance and firing angle models are two basic models of an SVC that are frequently used for reactive power compensation and voltage control analyses; however, in this work, the firing angle model—which shows that equivalent susceptance is a function of the changing firing angle, α , of the thyristor-controlled reactor (TCR)—was taken into consideration because it eliminates the need for an extra iterative loop to solve for the firing angle. This model is shown in Figure 4.

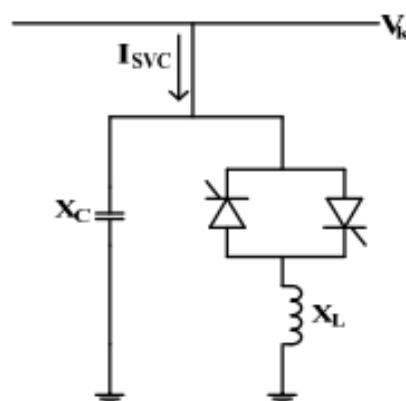


Figure 4: Firing angle model of an SVC

A parallel combination of TCR equivalent reactance (X_L -TCR) and SVC capacitive reactance (X_C) yields the equivalent susceptance of the SVC, B_{SVC} , which is the inverse of the SVC

reactance, X_{SVC} , in Figure 4. X_{SVC} is characterized by equations (11) and (12), whereas X_L -TCR is described by equations (9) to (12).

$$X_{L-TCR} = \frac{\pi X_L}{\alpha_{eq}} \quad (9)$$

where α_{eq} = TCR inductive reactance = ωL

α_{eq} = Equivalent TCR firing angle

$$= 2(\pi - \alpha_{SVC}) + \sin(2\alpha_{SVC}) \quad (10)$$

with $\pi/2 \leq \alpha_{SVC} \leq \pi$

$$X_{SVC} = \frac{X_C X_L}{X_C \alpha_{eq} / \pi - X_L} \quad (11)$$

Where $X_C = \frac{1}{\omega C}$

Therefore, B_{SVC} is obtained from equation (36)

$$B_{SVC} = \frac{1}{X_{SVC}} = \frac{\frac{X_C(2(\pi - \alpha_{SVC}) + \sin(2\alpha_{SVC})) - X_L}{\pi}}{X_C X_L} \quad (12)$$

When the voltage magnitude at SVC connection point ($V_{SVC} = V_K$) is specified, SVC reactive power (Q_{SVC}) can be calculated by equation (13) (Mbae & Nwulu, 2022) [ref13]

$$Q_{SVC} = Q_K = -V_K^2 B_{SVC} = \frac{V_K^2}{X_C X_L} \left\{ X_L - \frac{X_C}{\pi} (2(\pi - \alpha_{SVC}) + \sin(2\alpha_{SVC})) \right\} \quad (13)$$

An observation on equation (13) reveals that Q_{SVC} is maximum when $\alpha_{SVC} = \frac{\pi}{2}$ and minimum when $\alpha_{SVC} = \pi$. These respectively give equations (14) and (15):

$$Q_{SVC}^{MAX} = \frac{V_K^2}{X_C X_L} \{X_L - X_C\} \quad (14)$$

$$Q_{SVC}^{MIN} = \frac{V_K^2}{X_C X_L} \quad (15)$$

The linearized Newton-Raphson load flow equations for this SVC model are expressed by equations (16) and (17) [ref14] (Olabisi & Ayeni, 2023)

$$\begin{bmatrix} \Delta P_K \\ \Delta Q_K \end{bmatrix}^{(r)} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2V_K^2 [\cos(2\alpha_{SVC}) - 1]}{\pi X_L} \end{bmatrix}^{(r)} \begin{bmatrix} \Delta \delta_K \\ \Delta \alpha_{SVC} \end{bmatrix}^{(r)} \quad (16)$$

$$\alpha_{SVC}^{(r)} = \alpha_{SVC}^{(r-1)} + \alpha_{SVC}^{(r)} \quad (17)$$

The whole set of linearized load flow equations characterizing the system, including the SVC, is obtained by combining the linearized power load equations and the Newton-Raphson load flow equations (16) and (17) of the SVC model. As a result, the Jacobian matrix will become larger. All partial derivatives of the SVC's real power with regard to the state variables (δ, V) are zero since it doesn't use any real power.

Ant Colony Optimization (ACO)

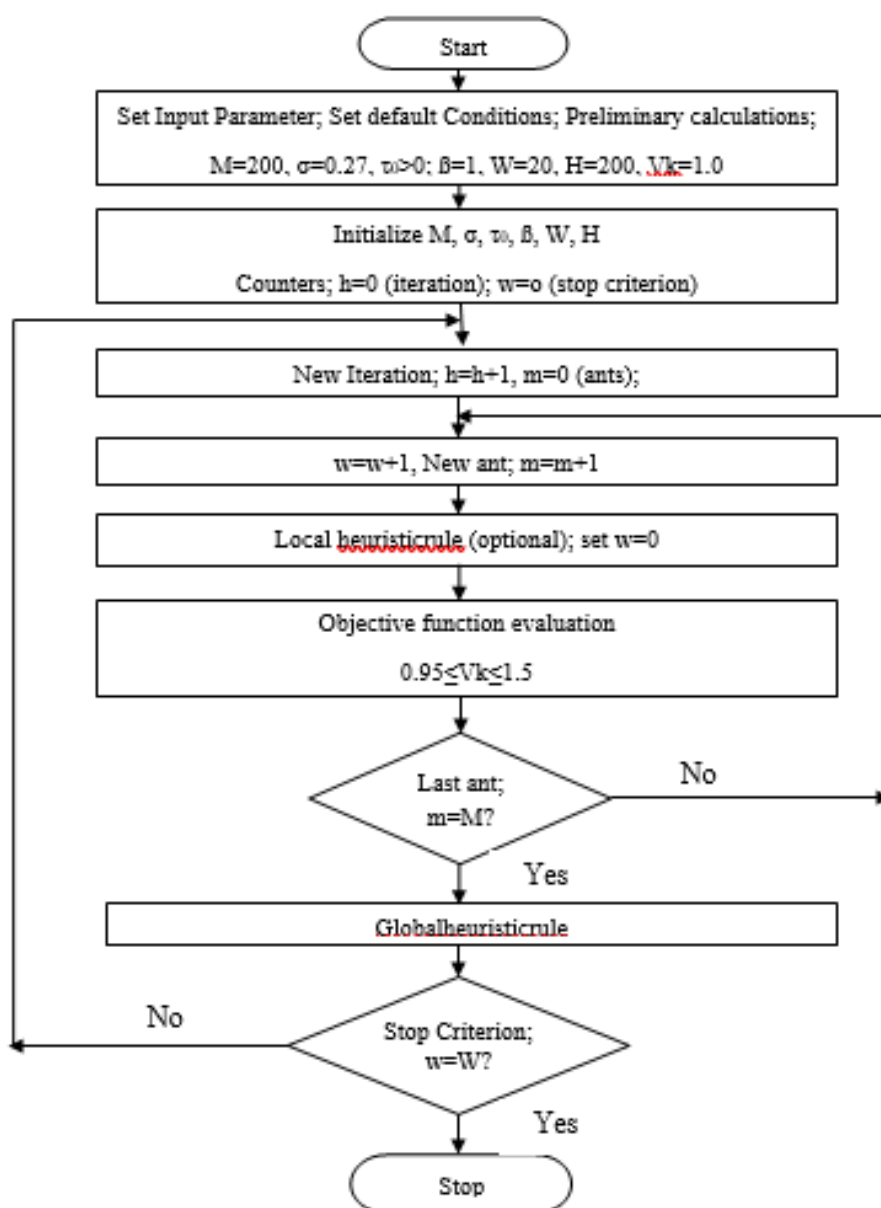


Figure 5: ACO Flow Chart for FACTS placement

Optimization

The Matrix Laboratory (MATLAB) application software environment was used to simulate the Ant Colony Optimization (ACO) pseudo codes that were produced from the Algorithm flow chart in Figure 5. ACO helps solve many real-world problems: It works great for finding the shortest routes, like in delivery planning over other optimization method. Bus 2 was determined to be the best bus by using the same methods on the IEEE 14-Bus network. This authenticates the validity of the ACO algorithm's result for the best location of FACTS (STATCOM & SVC) in the Gombe 132 kV network. The method converged at the 50th iteration with the optimal bus at Bus 2, having been run with a number of buses (Nbus=12).

Simulation

The Nigerian North East Gombe 132 kV Power Network shown in Figure 6 were simulated using the parameters of Table 1 and Table 2.

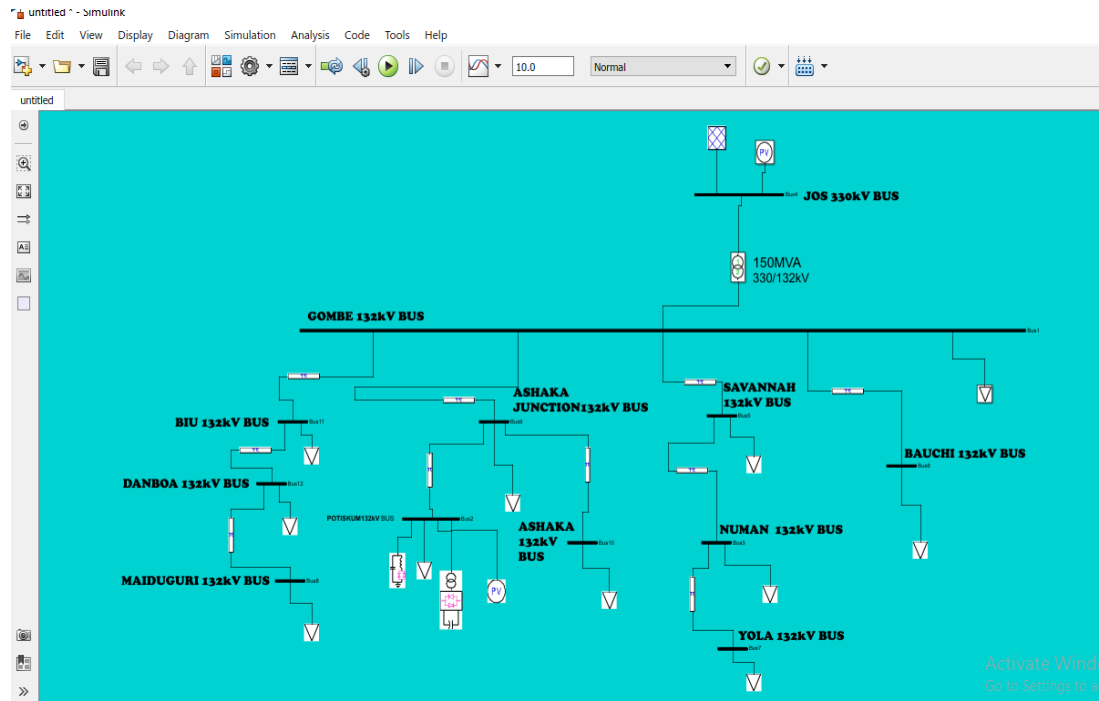


Figure 6: Network Model in PSAT with STATCOM and SVC at bus 2 in MATLAB Environment

Results and Discussion

Voltage Profile

Results without FACTS (Base case)

Table 3 displays the power flow findings for the system without STATCOM, including the voltage profile and the amount of actual and reactive power produced. Figure 7 shows a bar graph of the voltage magnitudes vs the power network's bus number.

Table 3: Voltage Magnitude Without FACTS (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

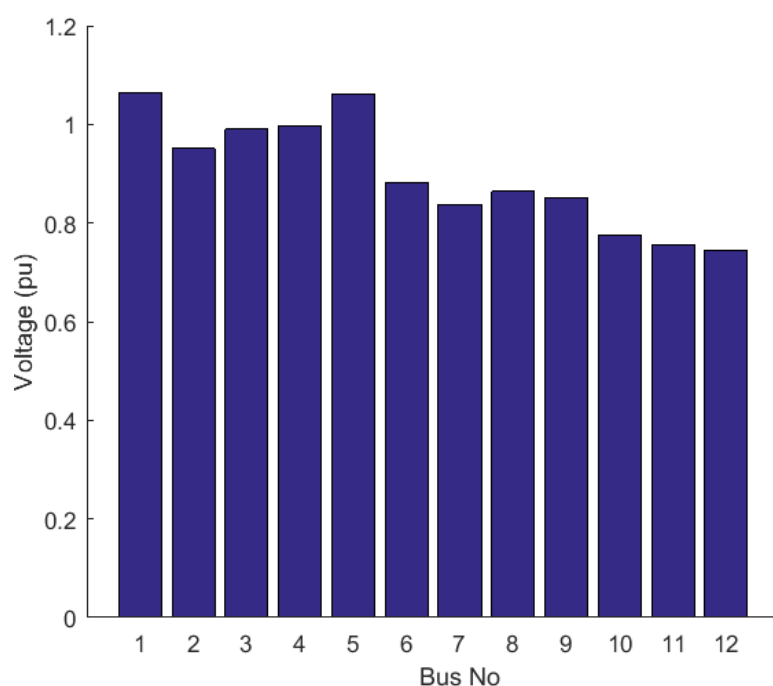


Figure 7: Voltage Magnitude Without FACTS (Base Case)

Bus Voltage Magnitude with STATCOM

Results for placement of only STATCOM at bus-2 is as shown in Table 4 and a bar graph plot of the voltage magnitude versus the bus number is as shown in Figure 8.

Table 4: Bus Voltage Magnitude with STATCOM

Bus no	Voltage magnitude with STATCOM at each bus									
	2	3	4	6	7	8	9	10	11	12
1	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064
2	1.000	0.954	0.951	0.993	0.984	0.982	0.986	0.979	0.977	1.020
3	1.023	1.000	0.992	1.018	1.012	1.011	1.013	1.010	1.007	1.031
4	1.007	1.004	1.000	1.006	1.004	1.004	1.005	1.003	1.003	1.010
5	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060
6	0.939	0.887	0.884	1.000	0.976	0.970	0.923	0.916	0.913	0.953
7	0.901	0.842	0.838	0.962	1.000	0.930	0.881	0.872	0.870	0.942
8	0.922	0.868	0.865	0.985	0.960	1.000	0.906	0.900	0.895	0.945
9	0.900	0.854	0.851	0.892	0.882	0.880	1.000	0.971	0.961	0.940
10	0.823	0.778	0.776	0.814	0.805	0.802	0.937	1.000	0.983	0.956
11	0.802	0.759	0.756	0.794	0.784	0.782	0.920	0.984	1.000	0.960
12	0.783	0.747	0.745	0.777	0.771	0.769	0.772	0.767	0.765	1.000

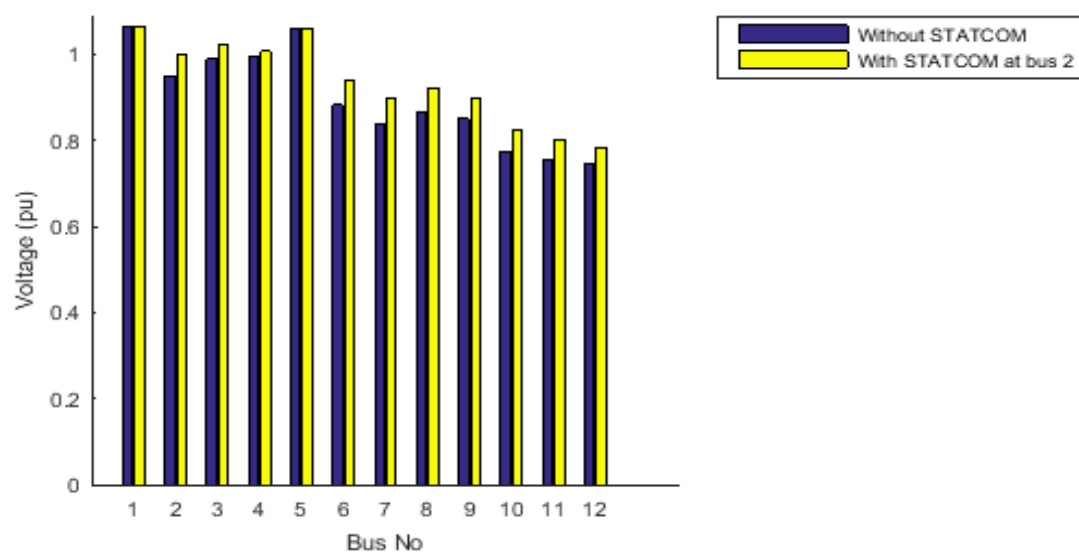
**Figure 8:** Voltage Magnitude with STATCOM at Bus-2**Bus Voltage Magnitude with STATCOM and SVC**

Table 5 displays the results of the STATCOM and SVC placement at bus-2, and Figure 9 displays a bar graph plot of the voltage magnitude against the bus number.

Table 5: Bus Voltage Magnitude with STATCOM and SVC

Bus No	Vm (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	0.69383	0.28687	0.00000	0.00000
2	1.02720	-4.75470	0.00000	0.00000	0.20000	0.16000
3	1.04070	4.13650	0.00000	0.00000	0.01500	0.01200
4	1.01300	15.81280	0.00000	0.00000	0.01200	0.00980
5	1.01300	21.72500	0.80000	0.18103	0.32500	0.26000
6	0.97010	-8.14900	0.00000	0.00000	0.08900	0.05000
7	0.95051	-10.08350	0.00000	0.00000	0.15500	0.08900
8	0.95389	-9.07260	0.00000	0.00000	0.08900	0.05000
9	0.99528	-8.88150	0.00000	0.00000	0.02800	0.02200
10	0.99289	-12.40850	0.00000	0.00000	0.03200	0.09000
11	1.00000	-14.11920	0.00000	0.12053	0.09000	0.03600
12	1.00000	-14.61250	0.00000	0.00000	0.30000	0.24000

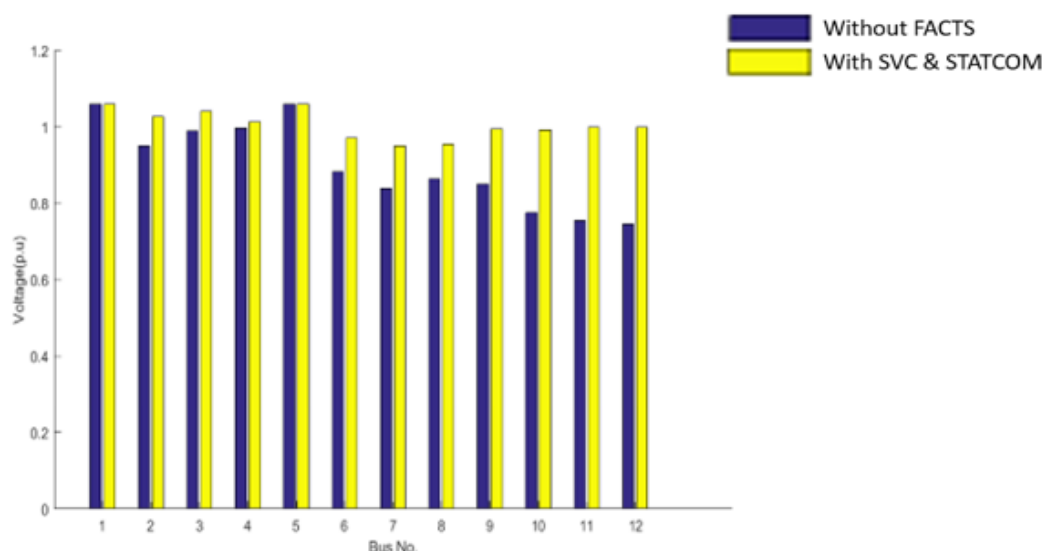


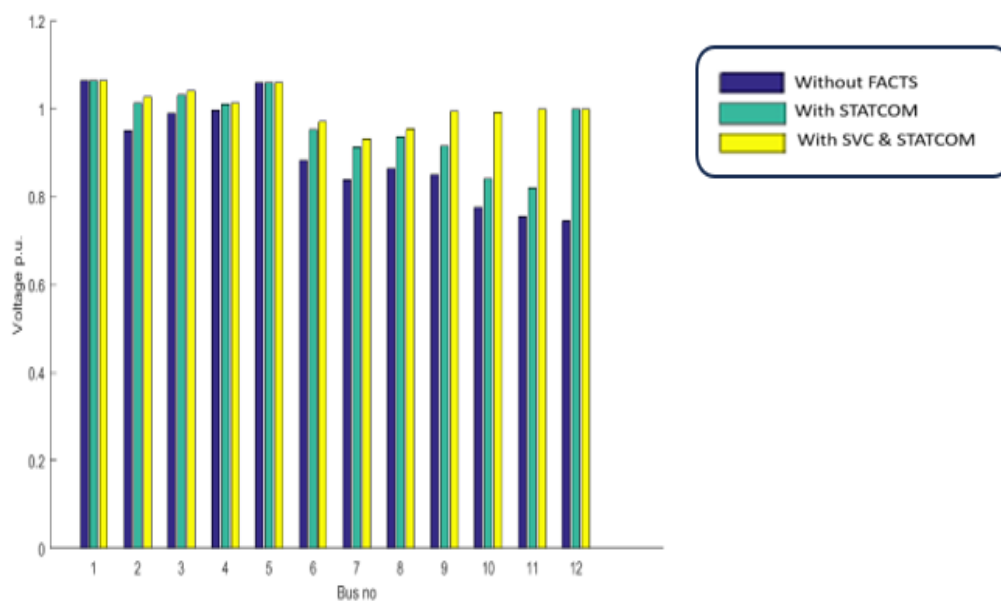
Figure 9: Voltage Magnitude with STATCOM and SVC at Bus-2

Voltage Profile Comparison

Comparison of voltage improvement in the power network is made without FACTS, with STATCOM and HYBRID as shown in Table 6 and its plot is depicted in Figure 10.

Table 6: Voltage Profile of the Network with and Without FACTS

Bus no	Voltages without FACTS (p.u)	Voltages with STATCOM (p.u)	Voltages with STATCOM & SVC (p.u)
1	1.0600	1.06400	1.06400
2	0.95096	1.01200	1.02720
3	0.99012	1.03060	1.04070
4	0.99730	1.00990	1.01300
5	1.06000	1.06000	1.06000
6	0.88295	0.95284	0.97010
7	0.83760	0.94220	0.94651
8	0.86422	0.93616	0.95389
9	0.85091	0.91462	0.99528
10	0.77530	0.94010	0.99289
11	0.75582	0.88010	1.00000
12	0.74462	1.00000	1.00000

**Figure 10:** voltage Magnitude without FACTS, with STATCOM and Hybrid FACTS (SVC & STATCOM)**Comparison of Real Power Loss**

Real power loss with STATCOM, SVC & STATCOM, and without FACTS into the power network is compared in Table 8. In Figure 11, a plot of actual power loss is displayed.

Table 8: Real Power Loss on the Transmission Line

Transmission line/no of buses	Real power losses without FACTS (pu)	Real power losses with STATCOM (pu)	Real power losses with SVC & STATCOM (pu)
2-3/1	0.03650	0.03667	0.0369
3-4/2	0.02056	0.02089	0.02107
4-5/3	0.02998	0.03043	0.0307
6-7/4	0.00522	0.00433	0.00433
10-11/5	0.00155	0.00164	0.00227
6-8/6	0.00124	0.00104	0.00099
2-12/7	0.05448	0.04229	0.03679
9-10/8	0.00396	0.00397	0.00178
2-9/9	0.01291	0.01247	0.00749
2-6/10	0.01683	0.01396	0.01336
1-2/11	0.00739	0.00393	0.00332

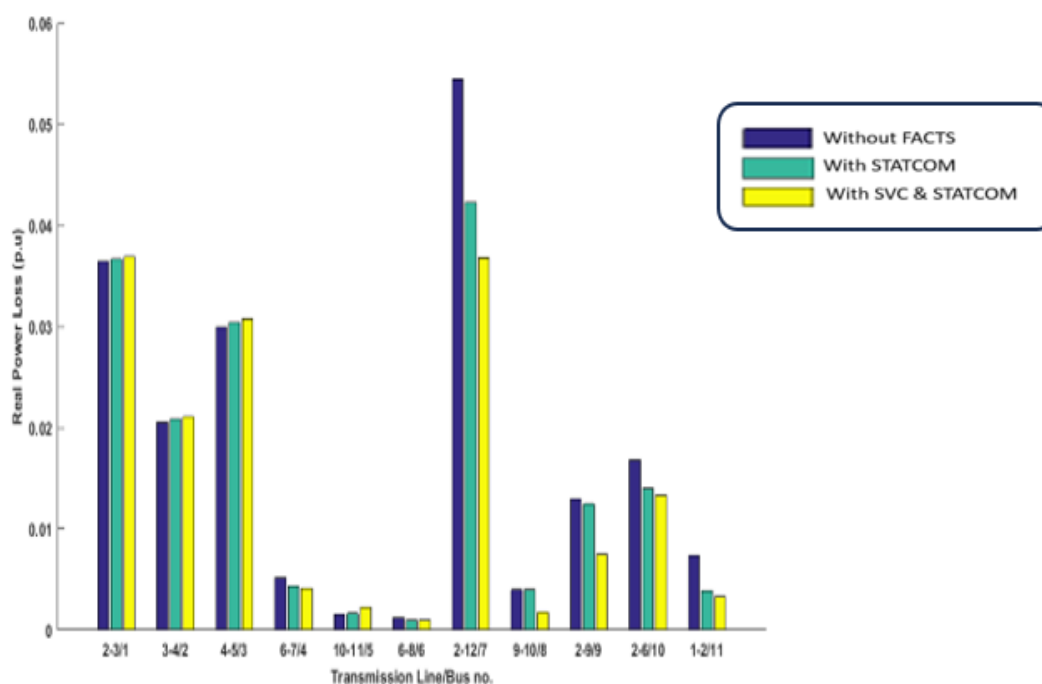


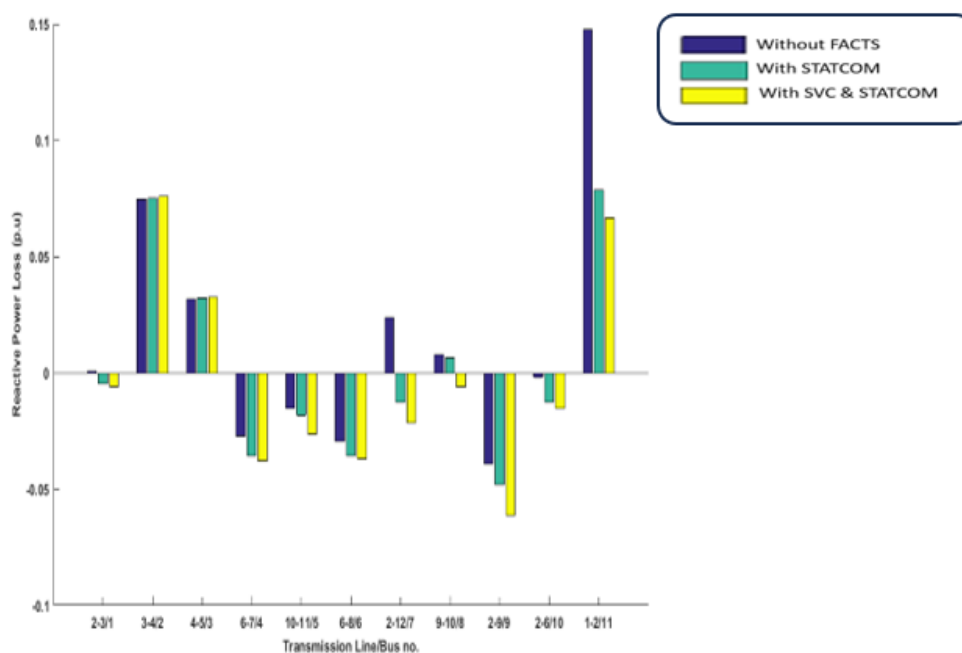
Figure 11: Comparison of Real Power Loss

Reactive power loss with and without FACTS

Table 9 indicates the reactive power flow with and without locating FACTS into the power network and its corresponding plot as shown in Figure 12.

Table 9: Reactive Power Loss on the Transmission Lines

Transmission line/ no of buses	Reactive power losses without FACTS (pu)	Reactive power losses with STATCOM (pu)	Reactive power losses with SVC & STATCOM (pu)
2-3/1	0.00078	-0.0048	-0.00596
3-4/2	0.07454	0.07519	0.07581
4-5/3	0.03154	0.03205	0.03238
6-7/4	-0.02737	-0.03574	-0.03781
10-11/5	-0.01525	-0.0182	-0.02637
6-8/6	-0.02958	-0.0354	-0.03689
2-12/7	0.02368	-0.01282	-0.02145
9-10/8	0.00773	0.00625	-0.00619
2-9/9	-0.03928	-0.04801	-0.06133
2-6/10	-0.00187	-0.01279	-0.01533
1-2/11	0.14772	0.07851	0.06639

**Figure 12:** Reactive Power Loss with and without FACTS

Analysis

Voltage Profile

Bus-12 in Figure 8 has the lowest voltage magnitude in the power flow, and other surrounding buses also have low voltage. This is evident even without the inclusion of FACTS. The majority of bus voltages fall below the 0.95p.u. to 1.05p.u. acceptable voltage range. However, the results in Table 4 showed that the voltages at the majority of buses

have grown to a range between 0.942 p.u. and 1.05 p.u. since the inclusion of FACTS devices (STATCOM) to the network. As seen in Figure 9, some of the bus voltages are within the permissible voltage range, while others are getting close to it.

As seen in Figure 10, a better voltage profile was seen when SVC and STATCOM were combined as opposed to when STATCOM was used alone. When only STATCOM is added to the network, the voltage improves by 9%. However, when SVC and STATCOM are combined, the network's voltage improves by 12%.

Real power loss control with and without FACTS

The findings in Table 8 show that, on average, real power losses were decreased in the majority of transmission line branches when using STATCOM. As seen in Figure 11, the real power loss is 16% lower in the majority of STATCOM-equipped lines than in the system without STATCOM, and it drops to 10% when combined SVC and STATCOM. It suggests that adding a hybrid FACTS system enhances the system's performance even further.

Reactive power loss control with and without FACTS

Inductive loads, such as motors and transformers, to name a few, create positive reactive power loss, while capacitive loads, like computer equipment, variable speed drives for motors, and lighting ballasts, cause negative reactive power loss, as shown in the data of Table 9. The reduction of reactive power was also noted and contrasted. The results show that the network with STATCOM has a lower reactive power loss than the network without FACTS. The combination of SVC with STATCOM results in a greater reduction in reactive power loss, as seen in Figure 12.

Conclusion

The study investigated the impact of hybrid FACTS on system stability of Nigeria 132kV North-East transmission network as compared to single FACTS system. It was discovered that the hybrid usage of FACTS devices yielded an improved performance in power system stability in terms of the voltage profiles and power losses. In this study, combination of SVC and STATCOM were used as hybrid and its performance was compared with single FACTS devices in this case STATCOM. Ant colony optimization techniques were used to deploy the FACTS devices on the network after they were modelled. The network behaviours were examined when no FACTS devices were connected, when only Single FACTS was connected, and when hybrid FACTS was connected to the network. The simulations were conducted using hybrid FACTS devices—static var compensator (SVC) and static synchronous compensator (STATCOM)—in MATLAB's Power System Analysis Toolbox (PSAT). The results show that adding STATCOM alone to the network improves voltage profile by 9%, while the combination of SVC and STATCOM improves voltage profile by 12%. When STATCOM and hybrid (SVC & STATCOM) are linked to the network, the actual power loss was decreased from 16% to 10%, respectively. For further research the optimal

placement and impact of three different FACTS devices, SVC, TCSC and UPFC on power stability of power transmission network can be investigated.

Competing Interests

Authors have declared that no competing interests exist.

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