



APPLICATION OF STATIC SYNCHRONOUS COMPENSATOR (STATCOM) IN IMPROVING POWER SYSTEM PERFORMANCE: A CASE STUDY OF THE NIGERIA 330 kV ELECTRICITY GRID

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ABSTRACT

Slow response of the conventional traditional methods for improving power system performance creates the need for adoption of advanced control technologies such as Flexible Alternating Current Transmission System (FACTS) with fast response and low cost for stabilizing electricity grid power and voltage. In this work, we examined the effect of application of Static Synchronous Compensator (STATCOM), a FACTS controller on the performance of the Nigeria 330 kV, 28-bus power system. The conventional and modified Newton-Raphson-based power flow equations describing the steady state conditions before and after compensation was made to the system were presented. Solutions to the developed equations were obtained using Matlab software (Version 7.9.0.529 'R2009b'). The results from the analysis showed that before the application of STATCOM, five (5) of the twenty eight (28) buses of the sample system have their voltage magnitudes fell outside the statutory limit of $0.95 \leq V \leq 1.05$ p.u, which were improved to 1.0 p.u. each at inclusion of STATCOM. Similarly, the total system active power loss was reduced by 5.88% from 98.21 to 92.44MW. Evidence from this finding is that STATCOM application on the Nigeria electricity grid will stabilise the system's voltage and reduce the overall transmission active power loss thereby releasing spare capacities for more consumers.

Keywords: Power system performance, FACTS, STATCOM, Nigeria electricity grid, System's voltage and Transmission active power loss.

1. INTRODUCTION

In recent times, the advancement towards the improvement of power system performance globally has been in the direction of the use of advanced control technologies such as Flexible Alternating Current Transmission System (FACTS). Electric power systems generally are very large capital intensive investments consisting of complex interconnected components such as generators, overhead conductors, underground cables, transformers etc. for the transmission and distribution of electric power over long distances from the power generating stations to the consumers. Establishing new power stations and transmission lines for provision of stable, secure and high quality electricity supply in most developing countries of the world including Nigeria may be very slow due to the economic crisis being faced by these countries. Hence,

there is the need to employ the use of appropriate technologies which offer more efficient means of utilizing the existing power facilities with fast response times and low maintenance costs to produce high quality electricity supply. In this respect, FACTS plays a leading role [1, 2, 3, 4].

The electricity supply system in Nigeria is faced with series of operational problems fundamentally poor quality power supply, voltage instability and high transmission loss among others. Traditional methods such as the use of synchronous generator, series compensation capacitor, generator excitation regulation, magnetically controlled reactor, reconfiguration of system structure and switch in or out of shunt and series capacitor have been considered capable of improving voltage and power profiles of power systems [5]. However, these methods suffer

from slow response and wear and tear in the mechanical components which render their application for power transmission improvement and control undesirable [5]. The only economically viable alternative to these methods is the use of power electronics based technology called FACTS which is fast acting and cost effective.

FACTS technology is a new approach taking into advantage the advances in power electronics controllers for enhancing the existing power system infrastructures [2, 3, 6, 7]. FACTS allows improved transmission system operation and control with reduced infrastructure investment, environmental impact, and implementation time, increase system security and reliability, increase power transfer capabilities, and enhance improvement in the quality of the electrical energy delivered to end users [8]. Several kinds of FACTS controllers exist and the most popular types are Inter phase Power Controller (IPC), Generalized Unified Power Flow Controller (GUPFC), Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC), Thyristor Controlled Breaking Reactor (TCR), Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC), Interline Power Flow Controller (IPFC), Thyristor Switched Series Reactor (TSSR), Unified Power Flow Controller (UPFC) [8]. Each of these technologies has their peculiarity which can be employed for different applications and on this basis several studies have been conducted to investigate the potential applications and benefits arising from their installations [9, 10, 11, 12, 13, 14, 15].

In this work, our goal is to study the effect of application of STATCOM for improving power system performance using the Nigeria 330 kV, 28-bus power network as a case study. STATCOM is basically a Voltage Source Inverter (VSI) which utilises Gate Turn off (GTO) thyristors and Direct Current (DC) capacitor to generate a three-phase synchronous voltage at fundamental frequency [6]. It has ability to inject or absorb reactive power for regulating the voltage and power profiles of the power system bus to which it is connected [2, 6].

2. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM is a static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the Alternating Current (AC) system voltage [14]. It is a regulating device which can act as a source or sink of reactive power to an electricity

network and can also serve as source of active power if connected to a source of power [15]. A simplified model of STATCOM consisting of a coupling transformer, a VSI and a DC capacitor is shown in Figure 1.

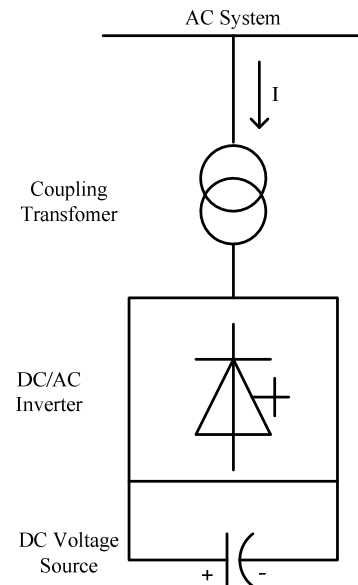


Figure 1: A simple STATCOM model [6]

The control of the reactive power exchange between the STATCOM and the AC system can be achieved either by regulating the amplitude of the STATCOM output voltage or by controlling the inverter output voltage with respect to the AC system voltage [6]. Regulation of the amplitude STATCOM output voltage may result in one of the following conditions: injection of reactive power into the AC system, absorption of reactive power from the AC system and non injection or absorption of reactive power from the AC system while control of the inverter output voltage on the other hand, may cause active power to be supplied or withdrawn from the AC system [6]. For instance, if the output voltage of the STATCOM is higher than the AC system voltage at the point of connection, the STATCOM produces reactive current whereas when the amplitude of the STATCOM voltage is lower than the AC system voltage, it absorbs reactive power [16]. The active power can be increased by connecting a suitable energy storage device across the DC capacitor [16]. Damping of power system oscillations, improvement of transient stability margin and steady-state power transfer capacity, reduction of temporary overvoltage and effective voltages regulation and control are few of the important applications of the STATCOM [17].

3. THE POWER FLOW MODELLING

A power system may be a collection of buses interconnected through transmission lines. For

optimized performance of such an interconnected system, information such as bus voltage levels, reactive power compensation requirements etc. are highly essential and these can be obtained from power flow analysis [18]. Figure 2 is a simplified i^{th} bus model of a power system.

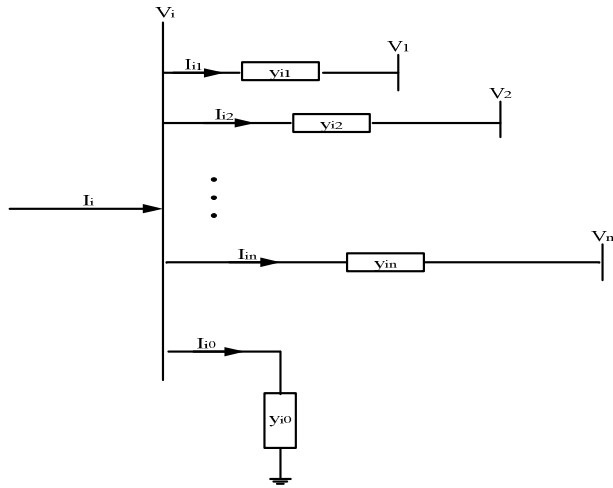


Figure 2: A simplified i^{th} bus model of a power system

Applying the Kirchhoff's Current Law (KCL) to bus i , we obtain an expression for the net current injected at the bus as:

$$I_i = I_{i0} + I_{i1} + I_{i2} + \dots + I_{in} \quad (1)$$

Where I_i is the current injected into bus i , I_{i0} is the current flowing from bus i to ground, I_{i1} is the current flowing from bus i to bus 1, I_{i2} is the current flowing from bus i to bus 2 and I_{in} is the current flowing from bus i to bus n

Application of Ohm's law to each of bus 1 to n with bus i as a reference, equation (1) is modified into equation (2):

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \dots + y_{in}(V_i - V_n) \quad (2)$$

Where V_i is the voltage at bus i , V_1 is the voltage at bus 1, V_2 voltage at bus 2, V_n is the voltage at bus n

By rearranging equation (2), we obtain a simplified expression given by equation (3):

$$I_i = (y_{i0} + y_{i1} + y_{i2} + \dots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \dots - y_{in}V_n \quad (3)$$

Where y_{i0} is the admittance of transmission line between bus i and ground, y_{i1} is the admittance of transmission line between bus i and bus 1, y_{i2} is the admittance of transmission line between bus i and bus 2, and y_{in} is the admittance of transmission line between bus i and bus n

Also, by defining:

$$\begin{cases} Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \dots + y_{in} \\ Y_{i1} = -y_{i1} \\ Y_{i2} = -y_{i2} \\ \vdots \\ Y_{in} = -y_{in} \end{cases} \quad (4)$$

and substituting in equation (3), we obtain equation (5):

$$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \dots + Y_{in}V_n \quad (5)$$

Equation (5) is equivalently expressed as equation (6):

$$I_i = Y_{ii}V_i + \sum_{\substack{k=1 \\ k \neq i}}^n Y_{ik}V_k \quad (6)$$

Recalling from the expression for complex power injected at bus i [18, 19, 20], we obtain equation (7):

$$S_i = P_i - jQ_i = V_i^* I_i \quad (7)$$

Where S_i is the apparent power injected at bus i , P_i is the real power injected at bus i , Q_i is the reactive power injected at bus i and V_i^* is the complex conjugate of bus i voltage.

The use of equation (6) in (7) yields equation (8) given as:

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k \neq i}}^n Y_{ik}V_k \quad (8)$$

Making V_i the subject in equation (8), we obtain equation (9):

$$V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^n Y_{ik}V_k \right] \quad (9)$$

Also, decoupling equation (8) into real and imaginary parts and expressing the components parts in polar form, we obtain equations (10) and (11):

$$P_i = |V_i|^2 G_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^n |Y_{ik}V_k V_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (10)$$

$$Q_i = |V_i|^2 B_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^n |Y_{ik}V_k V_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (11)$$

Where G_{ii} is the self-conductance of bus i and B_{ii} is the self-susceptance of bus i

Considering that the voltage at the buses must be within certain specified statutory limit, the voltage constraint at bus i is then defined by equation (12):

$$V_{i(min)} \leq V_i \leq V_{i(max)} \quad (12)$$

Where $V_{i(min)}$ and $V_{i(max)}$ are minimum and maximum values of voltage at bus i .

Since P_i and Q_i give a measure of the net real and reactive power at the bus i , they can be equivalently expressed by equations (13) and (14):

$$P_i = P_{gi} - P_{li} \quad (13)$$

$$Q_i = Q_{gi} - Q_{li} \quad (14)$$

Where P_{gi} is the real power supply at bus i , P_{li} is the real power demand at bus i , Q_{gi} is the reactive power

supply at bus i and Q_{li} is the reactive power demand at bus i

The reactive power supply constraint at bus is specified by equation (15):

$$Q_{gi(min)} \leq Q_{gi} \leq Q_{gi(max)} \quad (15)$$

Where $Q_{gi(min)}$ and $Q_{gi(max)}$ are minimum and maximum values of reactive power supply at bus i.

It should however be noted that if the constraint given by equation (15) is not satisfied that is Q_{gi} does not lie within the limit, it must be set to appropriate limit. Q_{gi} is set to $Q_{gi(max)}$ if Q_{gi} is greater than $Q_{gi(max)}$ and it is set to $Q_{gi(min)}$ if Q_{gi} is less than $Q_{gi(max)}$ and the constraint that voltage at bus i is fixed must be released [21].

If we consider further a situation when STATCOM is shunt-connected at bus i in Figure 2 and it is treated as var source, equations (13) and (14) can be modified as equations (16) and (17) respectively:

$$P_i = P_{gi} + P_{STCi} - P_{li} \quad (16)$$

$$Q_i = Q_{gi} - Q_{STCi} - Q_{li} \quad (17)$$

Where P_{STCi} is the STATCOM real power at bus i and Q_{STCi} is the STATCOM reactive power at bus i

Equations (16) and (17) are representations of a case where STATCOM injects var into the system at bus i and for var absorption, the signs of P_{STCi} and Q_{STCi} become reversed.

Equations (10) and (11) are non-linear sets of power flow equations and their solution is usually based on iterative technique. The method of solution adopted in this work to power flow equations (10) and (11) with a shunt-connected STATCOM at bus i is Newton-Raphson iterative method and this was adopted because of its faster rate of convergence and accuracy when compared with other methods of solution such as Gauss-Siedel method for non-linear power flow equations [18, 20].

In this work, the modelling and analysis of STATCOM with adopted Newton-Raphson method using rectangular coordinates system was a modified form of the version presented in [22]. The Thevenin's equivalent circuit of the fundamental frequency operation of the switched mode VSI (STATCOM) and its transformer with the bus k replaced by bus i is shown in Figure 3.

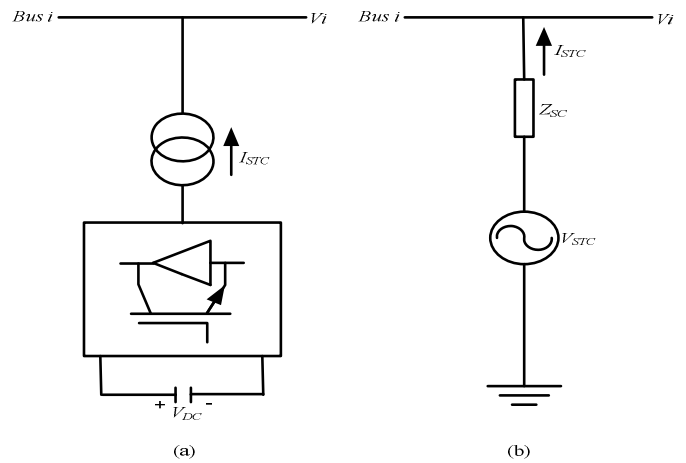


Figure 3: Thevenin's equivalent circuit diagram of STATCOM: (a) STATCOM schematic diagram; (b) STATCOM equivalent circuit [22].

According to Figure 3 above, we obtain equation (18):

$$V_{STC} = V_i + Z_{SC} I_{STC} \quad (18)$$

Where V_{STC} is the STATCOM voltage, I_{STC} is the STATCOM current and Z_{SC} is the transformer's impedance

Equation (18) is expressed in its Norton's equivalent form as:

$$I_{STC} = I_N - Y_{SC} V_i \quad (19)$$

$$\text{With } I_N = Y_{SC} V_{STC} \quad (20)$$

Where I_N is the Norton's current and Y_{SC} is the short-circuit admittance

The STATCOM voltage injection bound constraint is given by equation (21) [22]:

$$V_{STC min} \leq V_{STC} \leq V_{STC max} \quad (21)$$

Where V_{STCmin} and V_{STCmax} are the STATCOM's minimum and maximum voltages.

Equation (19) is transformed into a power expression for STATCOM and power injected into bus i by equations (22) and (23) respectively.

$$S_{STC} = V_{STC} I_{STC}^* = V_{STC} V_{STC}^* Y_{SC}^* - V_{STC} Y_{SC}^* V_i^* \quad (22)$$

$$S_i = V_i I_{STC}^* = V_i V_i^* Y_{SC}^* - V_i V_{STC}^* Y_{SC}^* \quad (23)$$

Where S_{STC} is the STATCOM injected apparent power, I_{STC}^* is the complex conjugate of STATCOM current, V_{STC}^* is the complex conjugate of STATCOM voltage and Y_{SC}^* is the complex conjugate of short-circuit admittance

The bus i and STATCOM voltages in rectangular coordinates system are expressed as equations (24) and (25) respectively:

$$V_i = e_i + j f_i \quad (24)$$

$$V_{STC} = e_{STC} + j f_{STC} \quad (25)$$

Where e_i is the real component of bus i voltage, f_i is the imaginary component of bus i voltage, e_{STC} is the real

component of STATCOM voltage and f_{STC} is the imaginary component of STATCOM voltage

The STATCOM's voltage magnitude and angle are expressed as equations (26) and (27) respectively:

$$|V_{STC}| = (e_{STC}^2 + f_{STC}^2)^{\frac{1}{2}} \tag{26}$$

$$\delta_{STC} = \tan^{-1}\left(\frac{f_{STC}}{e_{STC}}\right) \tag{27}$$

Where $|V_{STC}|$ is the STATCOM voltage magnitude and δ_{STC} is the STATCOM voltage angle

The active and reactive power components for the STATCOM and bus i on the basis of equations (22) to (25) are respectively expressed by equations (28) to (31):

$$P_{STC} = G_{SC}\{(e_{STC}^2 + f_{STC}^2) - (e_{STC}e_i + f_{STC}f_i)\} + B_{SC}(e_{STC}f_i - f_{STC}e_i) \tag{28}$$

$$Q_{STC} = G_{SC}(e_{STC}f_i - e_if_{STC}) + B_{SC}\{e_{STC}e_i + f_{STC}f_i - (e_{STC}^2 + f_{STC}^2)\} \tag{29}$$

$$P_i = G_{SC}\{e_i^2 + f_i^2 - (e_ie_{STC} + f_if_{STC})\} + B_{SC}(e_if_{STC} - f_ie_{STC}) \tag{30}$$

$$Q_i = G_{SC}(e_if_{STC} - f_ie_{STC}) + B_{SC}\{e_ie_{STC} + f_if_{STC} - (e_i^2 + f_i^2)\} \tag{31}$$

Where P_{STC} is the STATCOM real power, Q_{STC} is the STATCOM reactive power, G_{SC} is the short-circuit conductance and B_{SC} is the short-circuit susceptance
The Newton-Raphson set of linearized equations for power flow equations (10), (11), (16) and (17) obtained taken into consideration the modelling of shunt-connected STATCOM at bus i is given by equation (32):

$$\begin{bmatrix} \Delta P_i \\ \Delta |V_i| \\ \Delta P_{STC} \\ \Delta Q_{STC} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial e_i} & \frac{\partial P_i}{\partial f_i} & \frac{\partial P_i}{\partial e_{STC}} & \frac{\partial P_i}{\partial f_{STC}} \\ \frac{\partial |V_i|}{\partial e_i} & \frac{\partial |V_i|}{\partial f_i} & 0 & 0 \\ \frac{\partial P_{STC}}{\partial e_i} & \frac{\partial P_{STC}}{\partial f_i} & \frac{\partial P_{STC}}{\partial e_{STC}} & \frac{\partial P_{STC}}{\partial f_{STC}} \\ \frac{\partial Q_{STC}}{\partial e_i} & \frac{\partial Q_{STC}}{\partial f_i} & \frac{\partial Q_{STC}}{\partial e_{STC}} & \frac{\partial Q_{STC}}{\partial f_{STC}} \end{bmatrix} \begin{bmatrix} \Delta e_i \\ \Delta f_i \\ \Delta e_{STC} \\ \Delta f_{STC} \end{bmatrix} \tag{32}$$

Where the partial derivatives of the Jacobian matrix are defined on the basis of equations (24) and (28) to (31) by the expressions given in equation (33).

3.1 Application of Matlab Software

The solutions to developed power flow equations were obtained using Matlab software, version 7.9.0.529 (R2009b). Matlab is a high performance and user-friendly language. It was adopted for this study purposely because it provides a simple, easy-to-use programming platform for manipulation of mathematical equations.

$$\left\{ \begin{array}{l} \frac{\partial P_i}{\partial e_i} = G_{SC}(2e_i - e_{STC}) + B_{SC}f_{STC} \\ \frac{\partial P_i}{\partial f_i} = G_{SC}(2f_i - f_{STC}) - B_{SC}e_{STC} \\ \frac{\partial P_i}{\partial e_{STC}} = -G_{SC}e_i - B_{SC}f_i \\ \frac{\partial P_i}{\partial f_{STC}} = -G_{SC}f_i + B_{SC}e_i \\ \frac{\partial |V_i|}{\partial e_i} = \frac{e_i}{\sqrt{e_i^2 + f_i^2}} \\ \frac{\partial |V_i|}{\partial f_i} = \frac{e_i}{\sqrt{e_i^2 + f_i^2}} \\ \frac{\partial P_{STC}}{\partial e_i} = -G_{SC}e_{STC} - B_{SC}f_{STC} \\ \frac{\partial P_{STC}}{\partial f_i} = -G_{SC}f_{STC} + B_{SC}e_{STC} \\ \frac{\partial P_{STC}}{\partial e_{STC}} = G_{SC}(2e_{STC} - e_i) + B_{SC}f_i \\ \frac{\partial P_{STC}}{\partial f_{STC}} = G_{SC}(2f_{STC} - f_i) - B_{SC}e_i \\ \frac{\partial Q_{STC}}{\partial e_i} = -G_{SC}f_{STC} + B_{SC}e_{STC} \\ \frac{\partial Q_{STC}}{\partial f_i} = G_{SC}e_{STC} + B_{SC}f_{STC} \\ \frac{\partial Q_{STC}}{\partial e_{STC}} = G_{SC}f_i + B_{SC}(e_i - 2e_{STC}) \\ \frac{\partial Q_{STC}}{\partial f_{STC}} = -G_{SC}e_i + B_{SC}(f_i - 2f_{STC}) \end{array} \right. \tag{33}$$

4. RESULTS AND DISCUSSION

The bus and transmission line data of the Nigeria 330 kV, 28-bus power network used as a case study were collected from the Transmission Company of Nigeria [23]. The 28-bus network shown in Figure 4 consists of twenty-eight (28) buses, nine (9) generation stations, and fifty-two (52) transmission lines. The bus data is shown in Tables 1 and 2 while the transmission line data is shown in Table 3.

The developed power flow equations were coded and simulated using Matlab programming language. The simulation results revealed that before the application of STATCOM, five (5) of the 28 buses namely buses 9, 13, 14, 16 and 22 had their voltage magnitudes fell outside the statutory limit defined by $0.95 \leq V_i \leq 1.05$ p.u. As a result, STATCOM was applied on them. Figure 5 shows the voltage magnitudes of the 28-bus network with and without application of STATCOM.

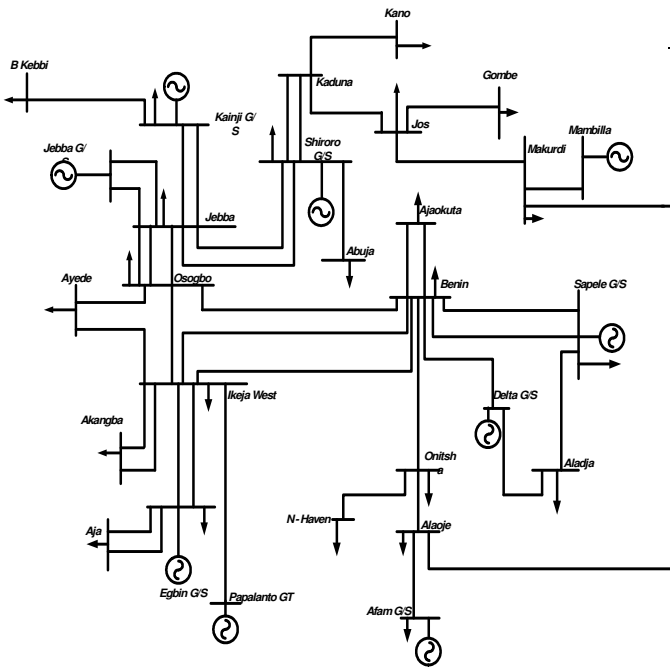


Figure 4: The Nigeria 28-bus network [23]

Bus Number	Bus Name	Load	
		MW	MVar
3	Aja	274.40	205.80
4	Akangba	244.70	258.50
5	Ikeja-West	633.20	474.90
6	Ajaokuta	13.80	10.30
7	Aladja	96.50	72.40
8	Benin	383.30	287.50
9	Ayede	275.80	206.8
10	Osogbo	201.20	150.90
11	Afam	52.50	39.40
12	Alaoji	427.00	320.20
13	New-Heaven	177.90	133.40
14	Onitsha	184.60	138.40
15	B/Kebbi	114.50	85.90
16	Gombe	130.60	97.90
17	Jebba	11.00	8.20
18	Jebba G	0.00	0.00
19	Jos	70.30	52.70
20	Kaduna	193.00	144.70
21	Kanji	7.00	5.20
22	Kano	220.60	142.90
23	Shiroro	70.30	36.10
24	Sapele	20.60	15.40
25	Abuja	110.00	89.00
26	Makurdi	290.10	145.00
27	Mambilla	0.00	0.00
28	Papalanto	0.00	0.00

Table 1: Load data of the Nigeria 28-bus power network [23]

Bus Number	Bus Name	Load	
		MW	MVar
1	Egbin	68.90	51.70
2	Delta	0.00	0.00

Table 2: Load flow data of the Nigeria 28-bus power network showing load and generation at the buses [23]

Bus Number	Bus Code	Voltage Magnitude	Angle Degree	Load		Generator				Static MVar +Qc/-Ql
				MW	MVar	MW	MVar	Qmin	Qmax	
1	1	1.05	0	68.90	51.70	0.00	0.00	-1006	1006	0.00
2	2	1.05	0	0.00	0.00	670.00	0.00	-1030	1000	0.00
3	0	1.00	0	274.40	205.80	0.00	0.00	0.00	0.00	0.00
4	0	1.00	0	244.70	258.50	0.00	0.00	0.00	0.00	0.00
5	0	1.00	0	633.20	474.90	0.00	0.00	0.00	0.00	0.00
6	0	1.00	0	13.80	10.30	0.00	0.00	0.00	0.00	0.00
7	0	1.00	0	96.50	72.40	0.00	0.00	0.00	0.00	0.00
8	0	1.00	0	383.30	287.50	0.00	0.00	0.00	0.00	0.00
9	0	1.00	0	275.80	206.8	0.00	0.00	0.00	0.00	0.00
10	0	1.00	0	201.20	150.90	0.00	0.00	0.00	0.00	0.00
11	2	1.05	0	52.50	39.40	431.00	0.00	-1000	1000	0.00
12	0	1.00	0	427.00	320.20	0.00	0.00	0.00	0.00	0.00
13	0	1.00	0	177.90	133.40	0.00	0.00	0.00	0.00	0.00
14	0	1.00	0	184.60	138.40	0.00	0.00	0.00	0.00	0.00
15	0	1.00	0	114.50	85.90	0.00	0.00	0.00	0.00	0.00
16	0	1.00	0	130.60	97.90	0.00	0.00	0.00	0.00	0.00
17	0	1.00	0	11.00	8.20	0.00	0.00	0.00	0.00	0.00
18	2	1.05	0	0.00	0.00	495.00	0.00	-1050	1050	0.00
19	0	1.00	0	70.30	52.70	0.00	0.00	0.00	0.00	0.00
20	0	1.00	0	193.00	144.70	0.00	0.00	0.00	0.00	0.00
21	2	1.05	0	7.00	5.20	624.70	0.00	-1010	1010	0.00
22	0	1.00	0	220.60	142.90	0.00	0.00	0.00	0.00	0.00

Bus Number	Bus Code	Voltage Magnitude	Angle Degree	Load		Generator			Static MVar + Qc/-Ql	
				MW	MVar	MW	MVar	Qmin		Qmax
23	2	1.05	0	70.30	36.10	388.90	0.00	-1010	1010	0.00
24	2	1.05	0	20.60	15.40	190.30	0.00	-1010	1010	0.00
25	0	1.00	0	110.00	89.00	0.00	0.00	0.00	0.00	0.00
26	0	1.00	0	290.10	145.00	0.00	0.00	0.00	0.00	0.00
27	2	1.05	0	0.00	0.00	750.00	0.00	-1010	1010	0.00
28	2	1.05	0	0.00	0.00	750.00	0.00	-1010	1010	0.00

Table 3: Transmission line data of the Nigeria 28-bus power network [23]

Bus From	Bus To	Resistance (p.u.)	Reactance (p.u.)
3	1	0.0006	0.0044
3	1	0.0006	0.0044
3	1	0.0006	0.0044
4	5	0.0007	0.0050
4	5	0.0007	0.0050
1	5	0.0023	0.0176
1	5	0.0023	0.0176
5	8	0.0110	0.0828
5	8	0.0110	0.0828
5	9	0.0054	0.0405
5	10	0.0099	0.0745
6	8	0.0077	0.0576
6	8	0.0077	0.0576
2	8	0.0043	0.0317
2	7	0.0012	0.0089
7	24	0.0025	0.0186
8	14	0.0054	0.0405
8	10	0.0098	0.0742
8	24	0.0020	0.0148
8	24	0.0020	0.0148
9	10	0.0045	0.0340
15	21	0.0122	0.0916
15	21	0.0122	0.0916
10	17	0.0061	0.0461
10	17	0.0061	0.0461
10	17	0.0061	0.0461
11	12	0.0010	0.0074
11	12	0.0010	0.0074
12	14	0.0060	0.0455
13	14	0.0036	0.0272
13	14	0.0036	0.0272
16	19	0.0118	0.0887
17	18	0.0002	0.0020
17	18	0.0002	0.0020
17	23	0.0096	0.0721
17	23	0.0096	0.0721
17	21	0.0032	0.0239
17	21	0.0032	0.0239
19	20	0.0081	0.0609
20	22	0.0090	0.0680
20	22	0.0090	0.0680
20	23	0.0038	0.0284
20	23	0.0038	0.0284
23	25	0.0038	0.0284
23	25	0.0038	0.0284

Bus From	Bus To	Resistance (p.u.)	Reactance (p.u.)
12	26	0.0071	0.0532
12	26	0.0071	0.0532
19	26	0.0059	0.0443
19	26	0.0059	0.0443
26	27	0.0079	0.0591
26	27	0.0079	0.0591
5	28	0.0016	0.0118
5	28	0.0016	0.0118

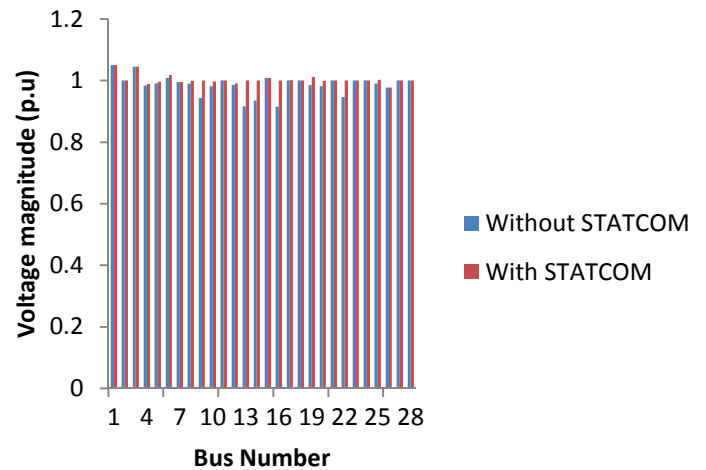


Figure 5: Bar chart showing voltage magnitude of Nigeria 28-bus power network with and without STATCOM.

From the above Figure 5, it was observed that the voltage magnitudes in per unit of buses 9, 13, 14, 16 and 22 improved to 1.0 p.u. each within the statutory limit with the application of STATCOM.

Also, the results revealed that there was an improvement on the transmission of active power at the inclusion of STATCOM on buses 9, 13, 14, 16 and 22. Figure 6 shows the system's total active power loss with and without the application of STATCOM.

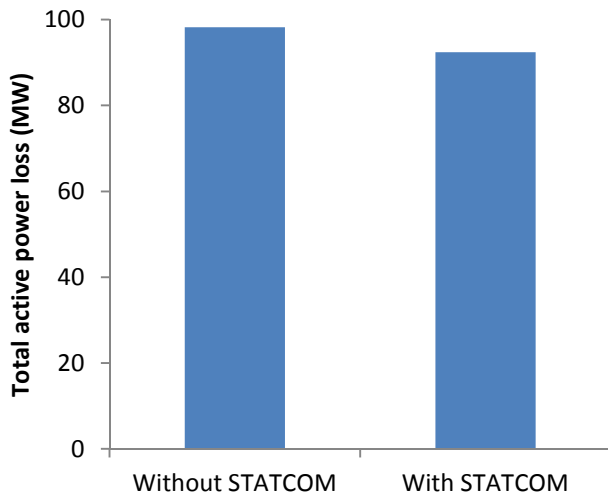


Figure 6: System's total active power loss with and without STATCOM

From the above Figure 6, there was a reduction of 5.88% in total active power loss from 98.21 MW to 92.44 MW, thereby improving the active power transmission capacity of the transmission lines. These results show that STATCOM has the capability to improve the voltage at buses and reduce active power loss on the power system.

5. CONCLUSION

The advancement towards the improvement of power system performance has been a global concern. In this work, the effect of STATCOM as a FACT controller for improving power system performance had been studied using the Nigeria 330 kV, 28-bus power system as a case study. Since the quality of power supply for any given system depends on voltage at the buses and transmission power, it is imperative to keep the bus voltage within the specified statutory limit and reduce the transmission active power loss to minimum. Application of STATCOM on five (5) buses of the Nigeria 28-bus power network whose voltage value fell outside the statutory limit defined by $0.95 \leq V_i \leq 1.05$ p.u. showed improvement on voltage magnitudes of the buses to 1.0 p.u and also reduced the transmission total active power loss from 98.21 MW to 92.44 MW, giving a 5.88% reduction in the total active power loss for the system. The results of this work show that STATCOM if deployed has the capacity to improve the voltage and power profiles of the Nigeria power system network and hence, could efficiently enhance electric power transmission.

6. REFERENCES

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