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APPLICATION OF FACTS DEVICES TO THE 330kV NIGERIAN SYSTEM FOR VOLTAGE AND POWER CONTROL

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ABSTRACT
This paper presents the results of investigation of the application of Flexible AC Transmission Systems (FACTS) devices such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and Unified Power Flow Controller to Nigerian 330kV transmission system for voltage regulation and power flow control. Models of FACTS devices which have tested on standard power networks were selected for inclusion in Newton-Raphson algorithm for power flow analysis. The STATCOM and UPFC models in rectangular form were presented as against the polar form available in literature. Power flow analysis was carried out for the Nigerian 330kV transmission system with the inclusion of some FACTS to demonstrate the use of the devices within the system.

KEY WORDS
FACTS, Newton-Raphson, SVC, VSC, STATCOM. and UPFC

1. Introduction

Power flow control has traditionally relied on generator control, voltage regulation by means of tap-changing and phase-shifting transformers, and reactive power plant control [1]. Shunt reactors and capacitors are used to regulate voltage at different locations within the network.

However due to the deregulation of the power supply there has been exploration of new ways of voltage regulation and maximising the power transfers in existing transmission facilities while maintaining reliability and stability. Flexible AC transmission system (FACTS) is one of these new technologies that can support system voltage at appropriate locations within the network and control power flow on the transmission networks [2]. In the last decade there has been increase in the use of FACTS devices such as static var compensator (SVC), static synchronous compensator (STATCOM), Unified power flow controller (UPFC). In spite of the increase in use of FACTS devices worldwide there is no reported case of installation of FACTS device in the Nigerian transmission network.

As Nigerian power sector is being gradually deregulated it is important for the investing companies to know the part of system that requires state of the art facilities for immediate fund injection in order to make the system more efficient. This paper is to identify locations for the installations of the FACTS devices within the Nigerian 330kV transmission system and to show the improvements in the system due to inclusion of the following FACTS devices, SVC, STATCOM, and UPFC within the network for power flow analysis.

In order to carry out power flow analysis for the Nigerian 330kV transmission system efficient models are needed. Acha et al [3] provides the models of SVC, STATCOM, and UPFC which have been well tested in standard systems with very good results. This serves as motivation to use the SVC model presented in [3] and the rectangular coordinate models of STATOM and UPFC in this work.

The Nigerian Electric Power Network has been shown to suffer from serious voltage depression at high load demand [4]. The present system is unable to meet the load demand of consumers and hence load shedding and system failures are common place. Two stations are identified for the installation of either SVC or STATCOM. The Nigerian system may be divided into three sections, North, West and East, the use of UPFC to control active power flows from one section of network to the other is also investigated. Four test cases are considered to show the performance of the FACTS devices in network

2. Power Flow Model of SVC STATCOM and UPFC

2.1 Static Var Compensator (SVC)

The SVC consists of a thyristor controlled reactor in parallel with a bank of capacitors. From an operational point of view, the SVC behaves like a shunt connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance [5]. The detail derivation of nonlinear power equations and the linearised equations required by Newton's method can be found in [3] and this model is used in this work.

2.2 Static Compensator (STATCOM)

The schematic diagram of figure 1 is used to model STATCOM within the Newton-Raphson method in rectangular co-ordinates. The STATCOM consists of switched-mode voltage source inverter connected to the and its transformer is

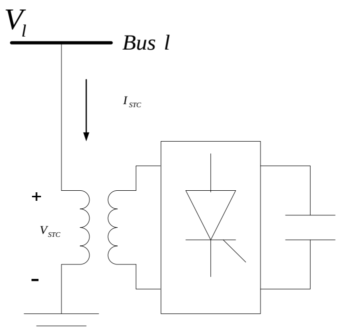

Figure 1. STATCOM

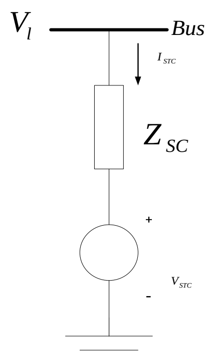

Figure 2. STATCOM equivalent circuit

The Thevenin's equivalent circuit representing the fundamental frequency operation of the switched-mode voltage source inverter and its transformer is expressed as

$$V_{STC} = V_l + Z_{SC} I_{STC} \tag{1}$$

while its Norton equivalent form is

$$I_{STC} = I_N - Y_{SC} V_l \tag{2}$$

where

$$I_N = \frac{V_{STC}}{Z_{SC}} = Y_{SC} V_{STC}$$

In these expressions, V_{STC} is the voltage source representing the voltage source inverter while I_{STC} is its associated current. Also, Z_{SC} is the transformer short-circuit impedance.

The current expression in (2) is transformed into a power injection by the VSC and power injected into bus l as shown in equations 3 and 4 respectively.

$$S_{STC} = V_{STC} I_{STC}^* = V_{STC}^2 Y_{SC}^* - V_{STC} Y_{SC}^* V_l^* \tag{3}$$

$$S_l = V_l I_{STC}^* = V_{STC} Y_{SC}^* V_l^* - V_l^2 Y_{SC}^* \tag{4}$$

Using rectangular coordinate representation, the active and reactive powers for the STATCOM and node l respectively are:

$$P_{STC} = G_{SC}\left(E_l^2 + F_l^2 - E_{STC} E_l - F_{STC} F_l\right) + B_{SC}\left(E_{STC} F_l - F_{STC} E_l\right) \tag{5}$$

$$Q_{STC} = -B_{SC}\left(E_l^2 + F_l^2 - E_{STC} E_l - F_{STC} F_l\right) + G_{SC}\left(E_{STC} F_l - F_{STC} E_l\right) \tag{6}$$

and

$$P_l = -G_{SC}\left[E_l^2 + F_l^2 - \left(E_l E_{STC} + F_l F_{STC}\right)\right] - B_{SC}\left(E_l F_{STC} - F_l E_{STC}\right) \tag{7}$$

$$Q_l = B_{SC}\left(E_l^2 + F_l^2 - E_l F_{STC} - F_l E_{STC}\right) - G_{SC}\left(E_l F_{STC} - F_l E_{STC}\right) \tag{8}$$

The linearised set of equations, assuming that the STATCOM is connected to bus l of the network and that the active power of the VSC is constant, may be given by

$$\begin{bmatrix} \Delta P_l \\ \Delta |V_l| \\ \Delta Q_{STC} \\ 0 \end{bmatrix} = \begin{bmatrix} \frac{\partial P_l}{\partial E_l} & \frac{\partial P_l}{\partial F_l} & \frac{\partial P_l}{\partial E_{STC}} & \frac{\partial P_l}{\partial F_{STC}} \\ \frac{\partial V_l}{\partial E_l} & \frac{\partial V_l}{\partial F_l} & 0 & 0 \\ \frac{\partial Q_{STC}}{\partial E_l} & \frac{\partial Q_{STC}}{\partial F_l} & \frac{\partial Q_{STC}}{\partial E_{STC}} & \frac{\partial Q_{STC}}{\partial F_{STC}} \\ \frac{\partial P_{STC}}{\partial E_l} & \frac{\partial P_{STC}}{\partial F_l} & \frac{\partial P_{STC}}{\partial E_{STC}} & \frac{\partial P_{STC}}{\partial F_{STC}} \end{bmatrix} \begin{bmatrix} \Delta E_l \\ \Delta F_l \\ \Delta E_{STC} \\ \Delta F_{STC} \end{bmatrix} \tag{9}$$

2.3 Unified power flow controller

The basic principles of UPFC operation are well established in the literature [7]. Using the UPFC schematic diagram of figure 3, modelling the UPFC device within the Newton-Raphson method in rectangular co-ordinates may be carried out as follows:

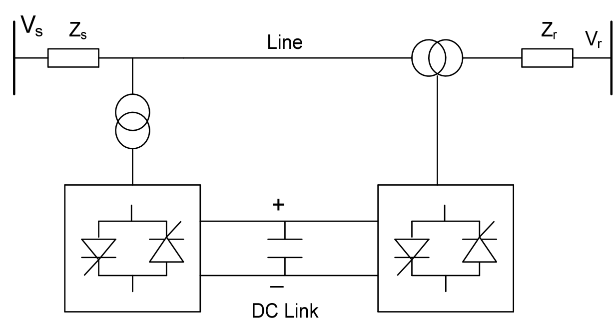

Figure 3. Schematic diagram of UPFC

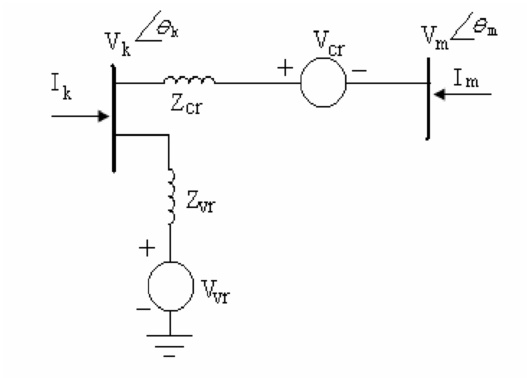

Figure 4. Equivalent circuit of UPFC

The output voltage of the series converter is added to the AC terminal voltage V_0 via the series connected coupling transformer. The injected voltage V_{CR} acts as an AC series voltage source, changing the effective sending-end voltage as seen from node *m*. The product of the transmission line current I_m and the series voltage source V_{CR}, determines the active and reactive power exchanged between the series converter and the AC system.

The real power demanded by the series converter is supplied from the AC power system by the shunt converter via the common DC link. The shunt converter is able to generate or absorb controllable reactive power in both operating modes (i.e. rectifier and inverter). The independently controlled shunt reactive compensation can be used to maintain the shunt converter terminal AC voltage magnitude at a specified value.

2.3.1 UPFC equivalent circuit

The UPFC equivalent circuit shown in figure 4 is used to derive the steady-state model.

The equivalent circuit consists of two ideal voltage sources representing the fundamental Fourier series component of the switched voltage waveforms at the AC converter terminals. The ideal voltages sources are:

$$V_{VR} = V_{VR}\left(\cos\delta_{VR} + j\sin\delta_{VR}\right) = e_{VR} + jf_{VR} \quad (10)$$

$$V_{CR} = V_{CR}\left(\cos\delta_{CR} + j\sin\delta_{CR}\right) = e_{CR} + jf_{CR} \quad (11)$$

where V_{VR} and δ_{VR} are the controllable magnitude $\left(V_{VR\min} \le V_{VR} \le V_{VR\max}\right)$ and angle $\left(0 \le \delta_{VR} \le 2\pi\right)$ of the voltage source representing the shunt converter. The magnitude V_{CR} and angle δ_{CR} of the voltage source of the series converter are controlled between limits $\left(V_{CR\min} \le V_{CR} \le V_{CR\max}\right)$ and $\left(0 \le \delta_{CR} \le 2\pi\right)$, respectively.

2.3.2 UPFC power equations

Based on the equivalent circuit shown in Figure 3(b), the power equations for the UPFC are as follow;

At the sending and receiving ends nodes

$$S_k = P_k + jQ_k = \left(V_k^2 - V_k V_{CR}^* - V_k V_m^*\right)Y_{CR}^* + (V_k^2 - V_k V_{VR}^*)Y_{VR}^* \quad (12)$$

$$S_m = P_m + jQ_m = V_m\left(V_m^* + V_{CR}^* - V_k^*\right)Y_{CR}^* \quad (13)$$

Series converter power

$$S_{CR} = V_{CR} I_{CR}^* = P_{CR} + jQ_{CR} = V_{CR}\left(V_m^* + V_{CR}^* - V_k^*\right)Y_{CR}^* \quad (14)$$

Shunt converter power

$$S_{VR} = V_{VR} I_{VR}^* = \left(P_{VR} + jQ_{VR}\right) = V_{VR}\left(V_k^* - V_{VR}^*\right)Y_{VR}^* \quad (15)$$

Power flow from bus k to bus m is

$$S_{km} = P_{km} + jQ_{km} = \left(V_k^2 - V_k V_{CR}^* - V_k V_m^*\right)Y_{CR}^* \quad (16)$$

Assuming a loss free converter operation, the UPFC neither absorbs nor injects active power with respect to the AC system.

$$\mathrm{Re}\left(-S_{VR} + S_{CR}\right) = \mathrm{Re}\left(-V_{VR} I_{VR}^* + V_{CR} I_m^*\right) = 0 \quad (17)$$

The DC link voltage, V_{dc} remains constant. The active power associated with the series converter becomes the DC power $V_{dc} I_2$. The shunt converter must supply an equivalent amount of DC power to maintain V_{dc} constant. Hence, the active power supplied to the shunt converter, P_{VR} must satisfy the active power demanded by the series converter, P_{CR}, i.e.

$$P_{VR} + P_{CR} = 0 \quad (18)$$

2.3.3 UPFC Jacobian equations

The UPFC equations are combined with the network nodal voltage in rectangular form in a single frame-of-reference for a unified solution through a Newton-Raphson method. The UPFC linearised power equations are combined with the linearised system of equations corresponding to the rest of the network,

$$\left[f(x)\right] = \left[J\right]\left[\Delta X\right] \quad (19)$$

where

$$\left[f(x)\right]=$$
$$\left[\Delta P_k\ \Delta P_m\ \Delta Q_k\ \Delta Q_m\ \Delta P_{mk}\ \Delta Q_{mk}\ \Delta P_{bb}\ \Delta\left|V_k\right|\right]^T \quad (20)$$

where

$$\Delta\left|V_k\right| = \left|V_{k(specified)}\right| - \left|V_{k(calculated)}\right| \quad (21)$$

ΔP_{bb} is the power mismatch given by equation 20 and the superscript T indicates transposition. $\left[X\right]$ is the solution vector and $\left[J\right]$ is the Jacobian matrix. For the case when the UPFC controls voltage magnitude at the AC shunt converter terminal (node k), active power flowing from node m to node k and reactive power injected at node m , and assuming that node m is PQ-type, the Jacobian and the solution vector matrix are,

$$\left[\Delta X\right] = \left[\Delta e_k\ \Delta e_m\ \Delta f_k\ \Delta f_m\ \Delta e_{VR}\ \Delta f_{VR}\ \Delta e_{CR}\ \Delta f_{CR}\right]^T \quad (22)$$

$$[J]=\begin{bmatrix}
\frac{\partial P_k}{\partial e_k} & \frac{\partial P_k}{\partial e_m} & \frac{\partial P_k}{\partial f_k} & \frac{\partial P_k}{\partial f_m} & \frac{\partial P_k}{\partial e_{VR}} & \frac{\partial P_k}{\partial f_{VR}} & \frac{\partial P_k}{\partial e_{CR}} & \frac{\partial P_k}{\partial f_{CR}} \\
\frac{\partial P_m}{\partial e_k} & \frac{\partial P_m}{\partial e_m} & \frac{\partial P_m}{\partial f_k} & \frac{\partial P_m}{\partial f_m} & 0 & 0 & \frac{\partial P_m}{\partial e_{CR}} & \frac{\partial P_m}{\partial f_{CR}} \\
\frac{\partial Q_k}{\partial e_k} & \frac{\partial Q_k}{\partial e_m} & \frac{\partial Q_k}{\partial f_k} & \frac{\partial Q_k}{\partial f_m} & \frac{\partial Q_k}{\partial e_{VR}} & \frac{\partial Q_k}{\partial f_{VR}} & \frac{\partial Q_k}{\partial e_{CR}} & \frac{\partial Q_k}{\partial f_{CR}} \\
\frac{\partial Q_m}{\partial e_k} & \frac{\partial Q_m}{\partial e_m} & \frac{\partial Q_m}{\partial f_k} & \frac{\partial Q_m}{\partial f_m} & 0 & 0 & \frac{\partial Q_m}{\partial e_{CR}} & \frac{\partial Q_m}{\partial f_{CR}} \\
\frac{\partial P_{mk}}{\partial e_k} & \frac{\partial P_{mk}}{\partial e_m} & \frac{\partial P_{mk}}{\partial f_k} & \frac{\partial P_{mk}}{\partial f_m} & 0 & 0 & \frac{\partial P_{mk}}{\partial e_{CR}} & \frac{\partial P_{mk}}{\partial f_{CR}} \\
\frac{\partial Q_{mk}}{\partial e_k} & \frac{\partial Q_{mk}}{\partial e_m} & \frac{\partial Q_{mk}}{\partial f_k} & \frac{\partial Q_{mk}}{\partial f_m} & 0 & 0 & \frac{\partial Q_{mk}}{\partial e_{CR}} & \frac{\partial Q_{mk}}{\partial f_{CR}} \\
\frac{\partial P_{bb}}{\partial e_k} & \frac{\partial P_{bb}}{\partial e_m} & \frac{\partial P_{bb}}{\partial f_k} & \frac{\partial P_{bb}}{\partial f_m} & \frac{\partial P_{bb}}{\partial e_{VR}} & \frac{\partial P_{bb}}{\partial f_{VR}} & \frac{\partial P_{bb}}{\partial e_{CR}} & \frac{\partial P_{bb}}{\partial f_{CR}} \\
\frac{\partial V_k}{\partial e_k} & 0 & \frac{\partial V_k}{\partial f_k} & 0 & 0 & 0 & 0 & 0
\end{bmatrix} \quad (23)$$

3. Test Cases

The models are tested on the Nigerian 330kV transmission system to show the improvement in voltage profile of the system due to installation of static Var compensator (SVC) and the static compensator (STATCOM). The improvements in the network when the two FACTS devices are installed are compared. The control of real power with Unified power controller from station, (Osogbo) to the Ikeja-west, Lagos, and the commercial nerve centre of Nigeria is also considered.

Figure 5 shows the single line diagram of the Nigerian 330kV network. It consists seven generating stations, twenty-four load stations and thirty-nine transmission lines The system may be divided into three major sections:- North, South-East and the South-West sections. The system is radial with long transmission lines in the Northern section. The North is connected to the South through one triple circuit lines between Jebba and Osogbo while the West is linked to the East through one transmission line from Osogbo to Benin and one double circuit line from Ikeja to Benin.

Steady state evaluation of the power network had revealed that the system is prone to voltage instability at loads above 4200MW [4]. The stations that are most affected are Gombe, Jos and Kano in the North and New-Haven in the South-East.

3.1 Base case

The voltage profile of the system is shown in Table I. It can be seen that the voltage at buses 16 (Gombe) and 22 (Kano) are lower than the acceptable limit of 10% for the Nigerian 330kV transmission system [8]. These buses are candidates for installation of SVC or STATCOM.

Table 1
Load flow results of 24 bus system without and with SVC and STATCOM

Bus No	Bus Name	Base case Voltage		Case-1 Voltage		Case-2 Voltage	
		Mag. pu	Ang. deg	Mag. pu	Ang. deg	Mag. pu	Ang. deg
1	Egbings	1.050	0.00	1.050	0.00	1.050	0.00
2	Deltags	1.050	-1.19	1.050	-1.17	1.050	-1.17
3	Aja	1.045	-0.28	1.045	-0.28	1.045	-0.28
4	Akangba	0.987	-5.66	0.987	-5.65	0.987	-5.65
5	Ikejawest	0.995	-5.21	0.995	-5.20	0.995	-5.20
6	Ajaokuta	1.054	-7.04	1.054	-7.02	1.054	-7.02
7	Aladja	1.046	-2.76	1.046	-2.74	1.046	-2.74
8	Benin	1.034	-6.68	1.034	-6.65	1.034	-6.65
9	Ayede	0.972	-7.84	0.972	-7.81	0.972	-7.81
10	Oshogbo	1.024	-4.99	1.024	-4.95	1.024	-4.95
11	Afamgs	1.050	-17.32	1.050	-17.30	1.050	-17.30
12	A-Haven	1.033	-17.94	1.033	-17.92	1.033	-17.92
13	N-Kebbi	0.929	-18.94	0.929	-18.92	0.929	-18.92
14	Onitsha	0.971	-16.13	0.971	-16.11	0.971	-16.11
15	B- Kebbi	0.950	-4.12	0.950	-4.07	0.950	-4.07
16	Gombe	0.866	-31.81	0.900	-31.27	0.900	-31.27
17	Jebba	1.046	-1.68	1.046	-1.62	1.046	-6.62
18	Jebbags	1.050	-1.44	1.050	-1.38	1.050	-1.38
19	Jos	0.948	-24.14	0.966	-23.94	0.966	-23.94
20	Kaduna	0.999	-16.80	1.005	-16.71	1.005	-16.71
21	Kainjigs	1.000	1.99	1.000	2.04	1.000	2.04
22	Kano	0.880	-25.01	0.900	-24.77	0.900	-24.77
23	Shirorogs	1.050	-12.35	1.050	-12.26	1.050	-12.26
24	Sapele	1.050	-5.17	1.050	-5.15	1.050	-5.15

Table 2
SVC data for Table I (case 1)

Bus No.	Bus Station	Susceptance pu	Firing angle deg	Injected Reactive Power Mvar
16	Gombe	0.102	130.18	8.27
22	Kano	0.164	131.59	13.29

Table 3
STATCOM data for Table I (Case 2)

Bus No.	Bus Station	STATCOM voltage		STATCOM Power	
		Magnitude pu	Angle Deg	Active MW	Reactive Mvar
16	Gombe	0.9092	-31.27	0.00	-8.27
22	Kano	0.9148	-24.77	-0.00	-13.29

3.1.1 Case 1

SVC compensator is included in the network to control voltages at buses 16 and 22 to 0.9p.u. Table I (Case 1) shows that the voltage profile of the system has improved due to the connected SVC. The adjacent buses Kaduna, and Jos voltages increased to 0.963p.u. and 1.0055p.u. respectively.

Table 2 shows the parameters of the SVC. The susceptance of the SVC for Gombe and Kano are 0.102p.u. and 0.164p.u. respectively which fall within the limits of -0.25 and 0.25 p.u.

The reactive power injected at buses 16 and 22 to maintain the voltages at 0.9p.u. are 8.27Mvar and 13.29Mvar respectively.

3.1.2 Case 2

Static synchronous compensator (STATCOM) is included in the network to control voltage at buses 16 and 22 to 0.9p.u. As expected the voltage profile is the same as when SVC is installed in network.

Table 3 shows the parameters of the STATCOM. The voltage magnitude of the STATCOM at buses 16, and 22 are shown to be 0.9092p.u. and 0.9148pu respectively. These voltages fall within the acceptable limits of 0.9 and 1.1.p.u. The injected reactive powers required to maintain the voltages at these buses are the same as that of the SVC.

3.1.3 Case 3

UPFC is included in the network to control the active power flow from bus 10 (Oshogbo) to bus 5 (Ikeja-West) from base case value of 10.2-MW to 50-MW while the reactive power flow is regulated at 30.44-Mvar.

Table 4 shows the power flow in lines connected to Oshogbo and Ikeja-West without and with UPFC installed between Osogbo and Ikeja-West. From the table it can been seen that the power flow pattern through the lines changed in order to satisfy the power flow control along the Osogbo -Ikeja-West transmission line.

Table 5 shows the UPFC parameters. The UPFC operates within the voltage magnitude limits for both the series and the shunt converters. The sending-end and receiving-end UPFC complex powers are showed in Table 7.

The Newton-Raphson power flow with the inclusion of the UPFC in the Nigerian 330kV transmission network converges quadratically in 6 iterations. Case 4 has shown that although the Nigerian 330kV transmission system is radial, UPFC can still be installed in order to regulate the active power flow in the network.

3.1.4 Case 4

In this case the UPFC is included in the line connecting bus 10 (Oshogbo) to bus 8 (Benin) and used to regulate the active power flow in it from 40.3-MW to 56-MW. The reactive power flow to bus 8 is maintained at 68.00Mvar.

Table 6 shows the transmission line power flows in lines connected to Oshogbo and Benin buses. The power flows are also modified to satisfy the new power flow between Osogbo and Benin. Table 5 shows the UPFC parameters while Table 7 shows the complex powers at the sending-end and receiving-end of the UPFC. The UPFC was able to control the active and reactive power flows at 56MW and 68Mvar without violating the voltage limits constraints. The power flow also converges quadratically in 6 iterations.

Table 4
Transmission line power flows with UPFC installed between Oshogbo and Ikeja-West buses

FROM BUS	TO BUS	Base Case				Case 3:UPFC connected			
		PJI MW	QJI MVAr	PJI MW	QJI MVAr	PJI MW	QJI MVAr	PJI MW	QJI MVAr
Ikeja-West	Benin	25.11	-104.38	-24.77	-6.28	33.14	102.16	-32.77	8.65
Ikeja-West	Ayede	115.18	17.23	-114.35	-62.67	138.93	21.61	-137.73	69.01
Benin	Oshogbo	-39.21	-32.41	39.39	70.63	-23.20	27.26	23.30	75.31
Ayede	Oshogbo	-161.45	-144.13	163.41	113.96	-138.07	137.79	139.63	-104.90

Table 5
UPFC data

Converter	Injected Voltage		Voltage limits	
	Magnitude pu	Angle Deg	V_{HIGH} pu	V_{LOW} Deg
Test case4				
Shunt Converter	1.0185	-5.88	1.1	0.9
Series Converter	0.0641	-104.14	0.2	0.0001
Test case5				
Shunt Converter	1.0069	-5.40	1.1	0.9
Series Converter	0.1056	-167.44	0.2	0.001

Table 6
Transmission line power flows with UPFC installed between Oshogbo and Benin buses

FROM BUS	TO BUS	Case 1				Case 5			
		PJI MW	QJI MVAr	PJI MW	QJI MVAr	PJI MW	QJI MVAr	PJI MW	QJI MVAr
Ikeja-West	Benin	25.11	-104.38	-24.77	-6.28	16.62	106.17	-16.29	4.91
		25.11	-104.38	-24.77	-6.28	16.62	106.17	-16.29	4.91
Ikeja-West	Ayede	115.18	17.23	-114.35	-62.67	123.66	-21.98	-122.69	66.24
Ikeja-West	Oshogbo	-10.14	-85.96	10.28	-13.80	1.78	17.63	-1.67	81.93
Ayede	Oshogbo	-161.45	-144.13	163.41	113.96	153.11	140.56	154.91	-109.54

Table 7
UPFC Complex Power

UPFC Power	Active Power MW	Reactive Power Mvar
Test case4		
Sending-end UPFC Power	50	30.48
Receiving-end UPFC Power	50	30.44
Test case5		
Receiving-end UPFC Power	56	67.75
Receiving-end UPFC Power	56	68.00

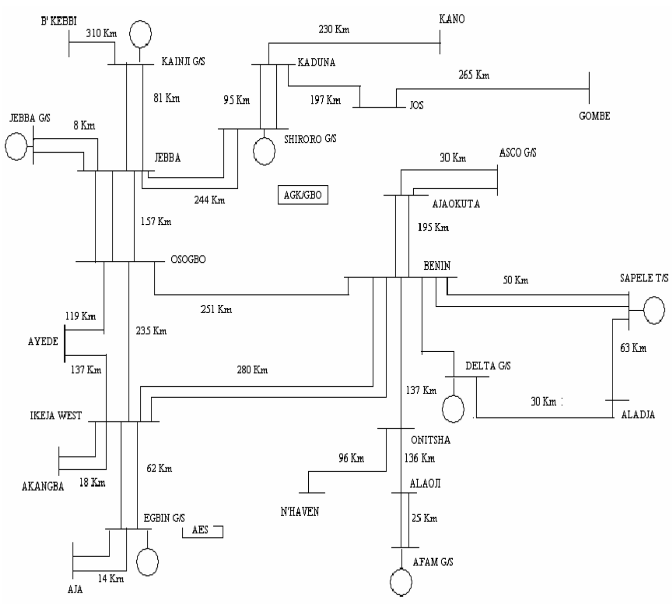

Figure 5. One line diagram of Nigeria 330kV transmission power system.

4. Conclusion

Power flow analysis was carried out for the Nigerian 330kV transmission system to identified possible locations for the installation of FACTS devices, SVC, STATCOM and UPFC. Possible locations were identified and models of SVC, STATCOM and UPFC developed in reference 3 were selected for application to the Nigerian transmission network. The SVC and STATCOM were able to regulate the voltage buses where they were installed to specified values without violating the susceptance and voltage limits of the FACTS devices. Moreover the UPFC was able to control the active power flow through the line connecting the northern part of the country to the commercial nerve centre of the Nigeria where there is high demand for power supply. We have been able to show the feasibility and performance of SVC, STATCOM, and UPFC when installed in the Nigerian 330kV transmission system.

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