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A comparison of the Voltage Enhancement and Loss Reduction Capabilities of STATCOM and SSSC FACTS Controllers

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Abstract: - Power systems deteriorate with time as load grows and generation is added. The transmission system is also usually subjected to a number of steady-state and transient problems. This leads to voltage instability and increased system losses. This work addressed the problems of voltage instability, active and reactive power losses. Presented in this paper is a comparison of the voltage enhancement and loss reduction capabilities of Static Synchronous compensator (STATCOM) and Static Synchronous Series Compensator (SSSC) at low voltage buses in the Nigerian 330kV grid. Power flow equations involve solution to nonlinear algebraic equations using reliable mathematical algorithms. In this work, the Newton Raphson iterative algorithm was adopted due to its ability to converge after a few iterations. Simulation of power flow solutions without any Flexible Alternating Current Transmission System (FACTS) device (STATCOM and SSSC) and with STATCOM and SSSC were done using a MATLAB based program. Where voltage drops were noticed, STATCOM and SSSC were incorporated in turn and the new voltage magnitudes were computed. The voltage enhancement capability of the devices is thus demonstrated. The system losses were also computed for each case. Such low voltage buses are buses 9(Ayede), 13(New-Haven), 14(Onitsha) and 16(Gombe). The results obtained from the incorporation of both devices into the grid system were satisfactory. The voltage magnitudes at these buses were sufficiently improved to maintain it at or above 1.0pu with both STATCOM and SSSC. The active power and reactive power losses also reduced by 0.171% and 1.009% respectively when STATCOM was applied while the incorporation of SSSC into the Nigerian grid system reduced active power and reactive power loss by 1.078% and 10.326% respectively.

Keywords: - *Voltage stability, Power Flow, Line Flow, FACTS devices, STATCOM, SSSC*

I. INTRODUCTION

Electrical energy is the most popular and widely used form of energy because it can be transported easily and relatively efficiently at lower cost. [1] [2]. The transmission system which connects the generation and the consumers are however always subjected to disturbances in one form or the other which consequently affects the power system adversely.

The ability of the transmission system to transmit power becomes impaired by a number of steady-state and dynamic limitations [3]. These steady-state and transient problems usually affect the power system negatively. This can culminate in limited power transfer and system instability and in some critical cases it may result into total system collapse [4],[5]. This implies that the relative advantage of the use of electrical energy is threatened in the form of reduced efficiency and higher cost of transmission. In addition, the Nigerian network topology is such that the generating stations are located far from major load centres, resulting in low bus voltages [6] [7]. Voltage instability is directly associated with reactive power imbalance [8].

As a result of this, there exists a continuous challenge to improve stability of power systems [9]. Control in power systems is thus of tremendous importance. Power flow control has traditionally relied on generator control, voltage regulation (by means of tap-changing and phase-shifting transformers) and reactive power plant compensation switching. Phase-shifting transformers have been used for the purpose of regulating active power in alternating current (AC) transmission networks. In practice, some of them are permanently operated with fixed angles, but in most cases their variable tapping facilities are actually made use of [10] [11] and [12].

However, with the rapid advances in power electronics area, it has become possible to apply power electronics to power system. Flexible Alternating Current Transmission System (FACTS) devices are based on the rapid development of power electronics technology to improve stability of power system. FACTS devices can be categorized in two groups. The first group of FACTS devices uses the Thyristor to control the reactors or capacitors (i.e. the Thyristor-based devices). The second group of FACTS devices uses more advanced power electronics to control power flow of power system. [9] . [13] further divided FACTS devices into three groups based on their switching technology viz, mechanically switched (such as phase shifting transformers), thyristor switched and fast switched, using IGBTs. While some types of FACTS, such as the phase shifting transformer (PST) and the static VAR compensator (SVC) are already well known and used in power systems, new developments in power electronics and control have extended the application range of FACTS. The stability of power system can be much better improved by coordination control of FACTS devices.

Simply put, Flexible AC Transmission System (FACTS) controllers are essentially power electronics based controllers. With the applications of FACTS technology, bus voltage magnitude and power flow along the transmission lines can be more flexibly controlled [14].

Furthermore, intermittent renewable energy sources and increasing international power flows provide new applications for FACTS. The additional flexibility and controllability of FACTS allow to mitigate the problems associated with the unreliable of supply issues of renewable [9]. Meanwhile, [17] had worked on steady state voltage stability enhancement using SSSC considering Nigerian grid power system as a case study. However, [17] did not place emphasis on the loss reduction capability of the SSSC, and above all, STATCOM FACTS controller device was not considered in the paper.

This paper therefore focused on the application of STATCOM (a shunt controller) and SSSC (a series controller) at low voltage buses in the Nigerian 330kV grid to compare the voltage enhancement and loss reduction capabilities of Static Synchronous compensator (STATCOM) and Static Synchronous Series Compensator (SSSC).

II. STRUCTURE OF 28-BUS 330KV NIGERIAN TRANSMISSION SYSTEM

The single line diagram of the Nigerian 330kV network is as shown in figure 3. It consists of nine generating stations and twenty-six load stations. The system may be divided into three major sections: - North, South-East and the South-West sections, as shown in Figure 1. 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.

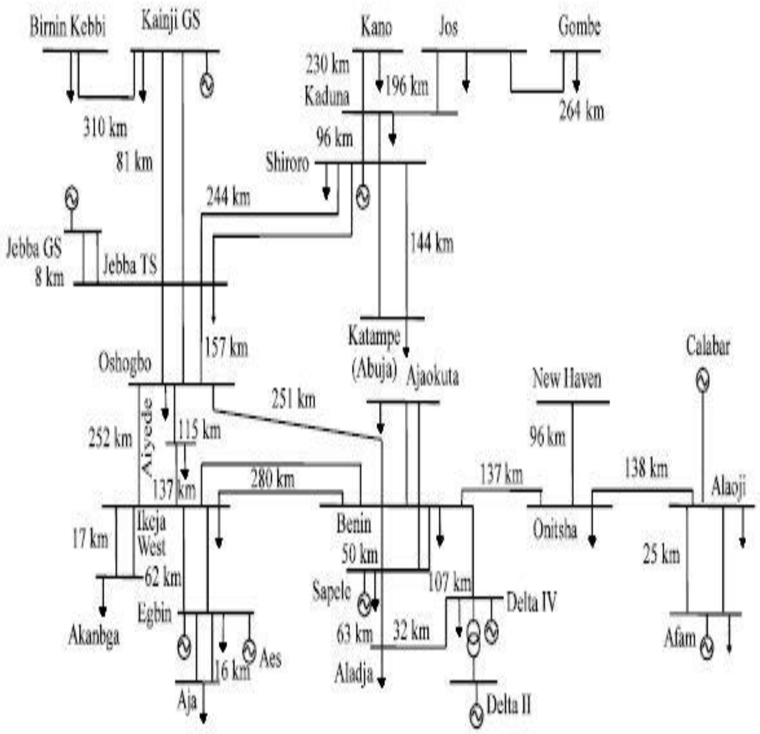

Figure 1: 28-bus 330kV Nigerian transmission system Source: [15]

III. STATIC SYNCHRONOUS SERIES COMPENSATOR

A static synchronous compensator (STATCOM) is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power.

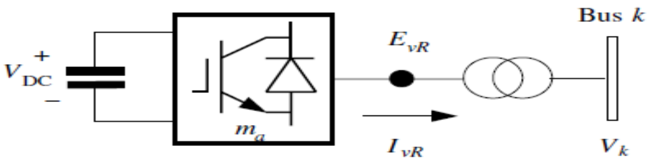

Figure 2: STATCOM schematic diagram Source: [11]

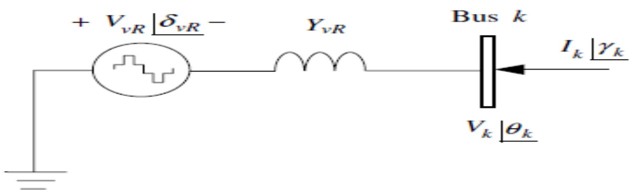

Figure 3: STATCOM equivalent circuit Source: [11]

IV. STATIC SYNCHRONOUS SERIES COMPENSATOR

This device works in a similar manner to the STATCOM. It has a voltage source converter serially connected to a transmission line through a transformer. It injects voltage in quadrature with one of the line end voltages in order to regulate active power flow. It does not draw reactive power from the AC system; it has its own reactive power provisions in the form of a DC capacitor.

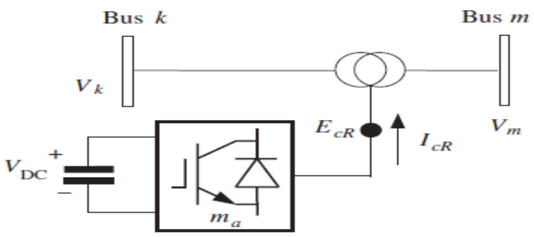

Fig. 4 : Schematic representation of SSSC [11]

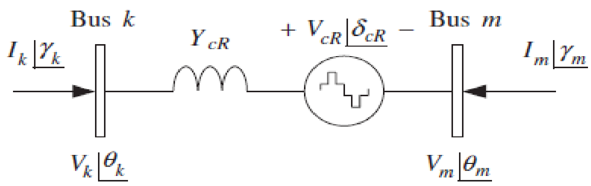

Figure 5 : SSSC equivalent circuit Source: [11]

V. PROBLEM FORMULATION

A Power flow Equations

A typical bus of a power system network is as shown in Figure (6). Transmission lines are represented by their equivalent π model where impedance has been converted to per unit admittances on common MVA base. [1]

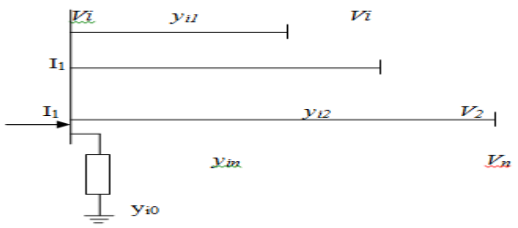

Figure 6: Typical bus

In any system, the active and reactive power are given by equations (1) and (2)

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (1)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (2)$$

Expanding equation (1) and (2) in Taylor's series about the initial estimate and neglecting all higher order results in the following set of linear equations. Details of this equation is presented in [1].

The linearized form of this equation is as shown in equation (3)

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial V_n} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \frac{\partial P_n^{(k)}}{\partial V_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial V_n} \\ \hline \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \frac{\partial Q_2^{(k)}}{\partial V_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial V_n} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n} & \frac{\partial Q_n^{(k)}}{\partial V_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial V_n} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix} \quad (3)$$

VI. STEADY-STATE MODEL OF STATCOM

From first principles and assuming the voltage source representation: [11]:

$$E_{vR} = V_{vR}(cos\delta_{vR} + jsin\delta_{vR}) \quad (4)$$

From the STATCOM equivalent circuit of figure 3;

$$S_{vR} = V_{vR} I_{vR}^* = V_{vR} Y_{vR}^* (V_{vR}^* - V_k^*) \quad (5)$$

Solution for the active and reactive converter powers yields equations (6) and (7) ;

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)] \quad (6)$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)] \quad (7)$$

Active and reactive powers at bus k are given by equations (8) and (9);

$$P_k = V_k^2 G_{vR} + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})] \quad (8)$$

$$Q_k = -V_k^2 B_{vR} + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) - B_{vR} \cos(\theta_k - \delta_{vR})] \quad (9)$$

Using these power equations, the linearized STATCOM model is given in equation (10), where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables [11];

$$\begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k} V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k} V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}} V_{vR} \end{bmatrix} \quad (10)$$

Steady-State Model of SSSC

The SSSC voltage source is given by the equation (11) [16];

$$E_{cR}^{\rho} = V_{cR}^{\rho}(cos\delta_{cR}^{\rho} + jsin\delta_{cR}^{\rho}) \quad (11)$$

The boundary condition for V_{cR} and δ_{cR} are as given by equations (12) and (13);

$$V_{cR.min} \le V_{cR} \le V_{cR.max} \quad (12)$$

$$0 \le \delta_{cR} \le 2\pi \quad (13)$$

Considering the SSSC Thevenin equivalent circuit and equation, the expressions for the active and reactive powers at bus k are as in equations (14) and (15) [16];

$$P_k = V_k^2 Q_{kk} - V_k V_m [G_{km} cos(\theta_k - \theta_m) - B_{km} \sin(\theta_k - \theta_m)] - V_k V_{cR} [G_{km} \cos(\theta_k - \delta_{cR}) - B_{km} \sin(\theta_k - \delta cR \quad (14)$$

$$Q_k = -V_k^2 B_{kk} - V_k V_m [G_{km} sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] - V_k V_{cR} [G_{km} sin(\theta_k - \delta_{cR}) - B_{km} cos(\theta_k - \theta cR \quad (15)$$

The active and reactive power relations for the converter are given in (16) and (17);

$$P_{cR} = V_{cR}^2 G_{mm} - V_{cR} V_k [G_{km} cos(\delta_{cR} - \theta_k) - B_{km} sin(\delta_{cR} - \theta_k)] - V_{cR} V_m [G_{mm} cos(\delta_{cR} - \theta_m) - B_{mm} sin(\delta_{cR} - \theta_m)] \quad (16)$$

$Q_{cR} = -V_{cR}^2 B_{mm} - V_{cR} V_k [G_{km} sin(\delta_{cR} - \theta_k) - B_{km} cos(\delta_{cR} - \theta_k)] - V_{cR} V_m [G_{mm} sin(\delta_{cR} - \theta_m) -$
$Bmmcos\delta cR{-}\theta m$ (17)

The linearized SSSC model is thus shown in equation (18) [16];

$$\begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial V_k}V_k & \frac{\partial P_k}{\partial V_m}V_m & \frac{\partial P_k}{\partial \delta_{cR}} & \frac{\partial P_k}{\partial V_{cR}}V_{cR} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_k}V_k & \frac{\partial P_m}{\partial V_m}V_m & \frac{\partial P_m}{\partial \delta_{cR}} & \frac{\partial P_m}{\partial V_{cR}}V_{cR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial V_k}V_k & \frac{\partial Q_k}{\partial V_m}V_m & \frac{\partial Q_k}{\partial \delta_{cR}} & \frac{\partial Q_k}{\partial V_{cR}}V_{cR} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial V_k}V_k & \frac{\partial Q_m}{\partial V_m}V_m & \frac{\partial Q_m}{\partial \delta_{cR}} & \frac{\partial Q_m}{\partial V_{cR}}V_{cR} \\ \frac{\partial P_{mk}}{\partial \theta_k} & \frac{\partial P_{mk}}{\partial \theta_m} & \frac{\partial P_{mk}}{\partial V_k}V_k & \frac{\partial P_{mk}}{\partial V_m}V_m & \frac{\partial P_{mk}}{\partial \delta_{cR}} & \frac{\partial P_{mk}}{\partial V_{cR}}V_{cR} \\ \frac{\partial Q_{mk}}{\partial \theta_k} & \frac{\partial Q_{mk}}{\partial \theta_m} & \frac{\partial Q_{mk}}{\partial V_k}V_k & \frac{\partial Q_{mk}}{\partial V_m}V_m & \frac{\partial Q_{mk}}{\partial \delta_{cR}} & \frac{\partial Q_{mk}}{\partial V_{cR}}V_{cR} \end{bmatrix}$$

(18)

VII. IMPLEMENTATION

A MATLAB based program was developed for the power flow analysis of electrical power systems without and with steady-state model of the FACTS controllers, STATCOM and SSSC. The flow chart algorithm is presented in figure 6.

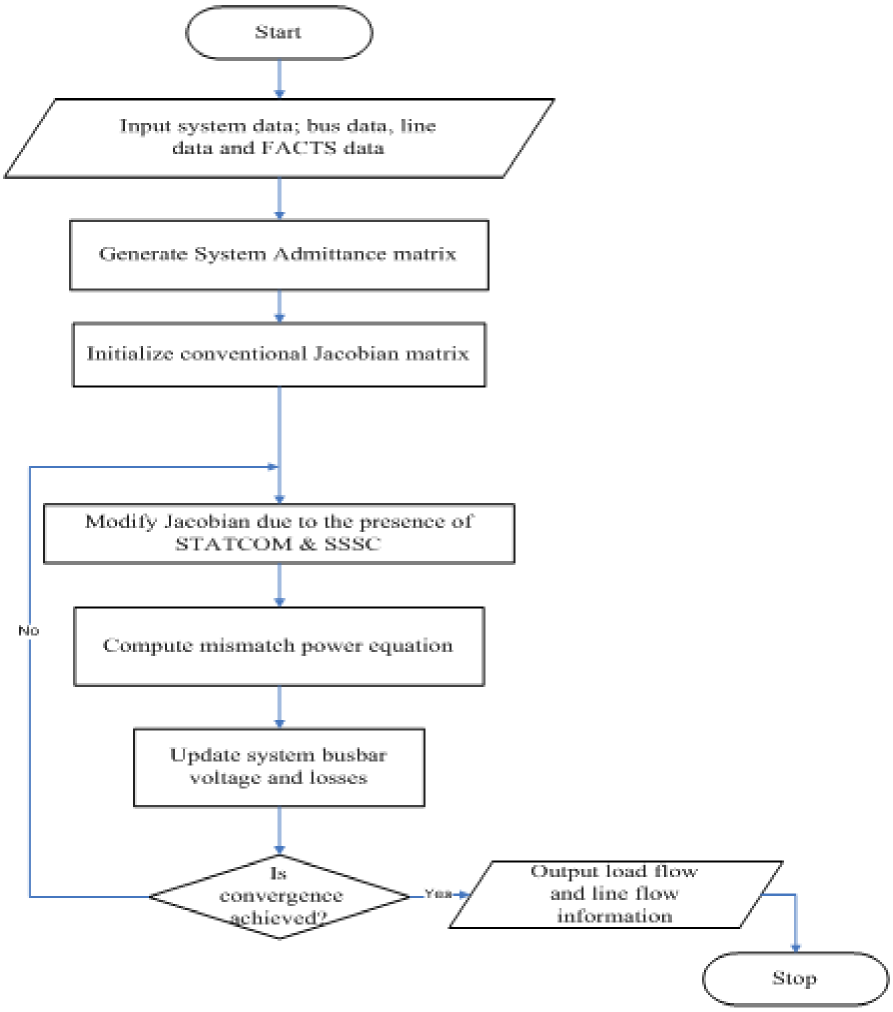

Figure 6: Flow Chart for the implementation

VIII. RESULTS AND DISCUSSIONS

This section presents the results of the power flow analysis for 330kV Nigerian 28-bus system under the various conditions i.e. with and without the application of FACTS devices. Bus 1 is taken as the reference bus which caters for losses on the other buses. Its phase angle is 0.
The Power Flow solutions, Line Flow and Losses were subsequently presented.

A. Power Flow Results

Case A: Power Flow solution without the Incorporation of STATCOM and SSSC

The result of the Power Flow Solutions for the system under consideration is as presented in Table 1. The accuracy is 1.000*e*-012 as specified in the power flow program while the maximum power mismatch has a value of 3.47417*e*-013. Convergence was achieved after 6 iterations.

Table 1: Power Flow Solution without SSSC and STATCOM using Newton-Raphson iterative technique

Bus No	Bus Name	V mag	Angle	Load		Generation	
				MW	MVAR	MW	MVAR
1	Egbin	1.050000	0	68.9	51.7	157.0774	534.3012
2	Delta	1.050000	11.8396	0	0	670	-20.0718
3	Aja	1.045002	-0.284	274.4	205.8	0	0
4	Akangba	1.018570	0.640607	344.7	258.5	0	0
5	Ikeja	1.025957	1.064812	633.2	474.9	0	0
6	Ajaokuta	1.061519	5.964331	13.8	10.3	0	0
7	Aladja	1.045662	10.27407	96.5	72.4	0	0
8	Benin	1.041416	6.322001	383.3	287.5	0	0
9	**Ayede**	**0.989663**	**1.970789**	**275.8**	**206.8**	**0**	**0**
10	Osogbo	1.031274	7.598416	201.2	150.9	0	0
11	Afam	1.050000	10.22838	52.5	39.4	431	317.5332
12	Alaoji	1.038084	9.568155	427	320.2	0	0
13	**New Heaven**	**0.976528**	**2.44244**	**177.9**	**133.4**	**0**	**0**
14	**Onitsha**	**0.993851**	**3.765763**	**184.6**	**138.4**	**0**	**0**
15	Benin-Kebbi	1.064558	13.60785	114.5	85.9	0	0
16	**Gombe**	**0.993725**	**3.685152**	**130.6**	**97.9**	**0**	**0**
17	Jebba	1.050483	13.29239	11	8.2	0	0
18	Jebbag	1.050000	13.55467	0	0	495	-101.197
19	Jos	1.050656	9.796701	70.3	52.7	0	0
20	Kaduna	1.03954	5.939198	193	144.7	0	0
21	Kainji	1.050000	16.46001	7	5.2	624.7	-267.215
22	Kano	1.010139	1.968138	220.6	142.9	0	0
23	Shiroro	1.050000	8.10979	70.3	36.1	388.9	55.22139
24	Sapele	1.050000	7.870247	20.6	15.4	190.3	113.8765
25	Abuja	1.049254	13.63136	110	89	0	0
26	Okpai	1.029469	6.031589	290.1	145	0	0
27	AES	1.050000	25.28002	0	0	750	-106.81
28	Calabar	1.050000	3.274312	0	0	750	319.2044
	Total			**4371.8**	**3173.2**	**4456.977**	**844.8423**

In this case, the voltage profile for the unfortified system shows buses 9(Ayede), 13(New-Haven), 14(Onitsha) and 16(Gombe) to be having voltages below 1.0pu and thus has to be reinforced in order to maintain the bus voltage magnitudes at 1.0pu.

Case B: Power Flow Solution with the incorporation of STATCOM

This section presents the power flow solution when the system has been reinforced by the incorporation of STATCOM. Improvement in voltage magnitude at the four low voltage buses that is , buses 9(Ayede), 13(New-Haven), 14(Onitsha) and 16(Gombe) were presented in Table 2.

Table 2: Power Flow solution with STATCOM

Bus No	Bus Name	V mag	Angle	Load		Generation	
				MW	Mvar	MW	Mvar
1	Egbin	1.050000	0	68.9	51.7	166.2599	521.114
2	Delta	1.050000	11.6819	0	0	670	-23.3005
3	Aja	1.045002	-0.284	274.4	205.8	0	0
4	Akangba	1.019565	0.589399	344.7	258.5	0	0
5	Ikeja	1.026945	1.012784	633.2	474.9	0	0
6	Ajaokuta	1.062528	5.803115	13.8	10.3	0	0
7	Aladja	1.045663	10.11687	96.5	72.4	0	0
8	Benin	1.042400	6.160435	383.3	287.5	0	0
9	**Ayede**	**1.000000**	**1.797337**	**275.8**	**206.8**	**0**	**0**
10	Osogbo	1.034286	7.366748	201.2	150.9	0	0
11	Afam	1.050000	9.967147	52.5	39.4	431	375.3341
12	Alaoji	1.036044	9.320848	427	320.2	0	0
13	**New Heaven**	**1.000000**	**2.085903**	**177.9**	**133.4**	**0**	**0**
14	**Onitsha**	**1.000000**	**3.510967**	**184.6**	**138.4**	**0**	**0**
15	Benin-Kebbi	1.064558	13.32334	114.5	85.9	0	0
16	**Gombe**	**1.000000**	**2.862205**	**130.6**	**97.9**	**0**	**0**
17	Jebba	1.050649	13.00717	11	8.2	0	0
18	Jebbag	1.050000	13.27031	0	0	495	-118.64
19	Jos	1.000000	9.709066	70.3	52.7	0	0
20	Kaduna	1.029477	5.526562	193	144.7	0	0
21	Kainji	1.050000	16.17549	7	5.2	624.7	-268.667
22	Kano	1.000000	1.473855	220.6	142.9	0	0
23	Shiroro	1.050000	7.695393	70.3	36.1	388.9	129.7094
24	Sapele	1.050000	7.714093	20.6	15.4	190.3	99.95579
25	Abuja	1.028255	13.60363	110	89	0	0
26	Okpai	1.029469	5.617192	290.1	145	0	0
27	AES	1.050000	25.33482	0	0	750	-32.6636
28	Calabar	1.050000	3.227603	0	0	750	301.7016
	Total			**4371.8**	**3173.2**	**4466.16**	**984.5439**

Case C: Power Flow Solutions with the incorporation of SSSC

Presented in this case is the power flow solutions when SSSC was incorporated in the system.There is a significant improvement in the voltage magnitude at the four low voltage buses that is , buses 9(Ayede), 13(New-Haven), 14(Onitsha) and 16(Gombe) as shown in Table 3.

Table 3: Power Flow solution with SSSC

Bus No	Bus Name	V mag	Angle	Load		Generation	
				MW	Mvar	MW	Mvar
1	Egbin	1.050000	0	68.9	51.7	-119.909	581.1085
2	Delta	1.050000	15.77806	0	0	670	-20.9867
3	Aja	1.045002	-0.284	274.4	205.8	0	0
4	Akangba	1.018395	1.966547	344.7	258.5	0	0
5	Ikeja	1.025784	2.390896	633.2	474.9	0	0
6	Ajaokuta	1.061805	9.90179	13.8	10.3	0	0
7	Aladja	1.045663	14.21267	96.5	72.4	0	0
8	Benin	1.041695	10.25936	383.3	287.5	0	0
9	**Ayede**	**1.000000**	**5.692264**	**275.8**	**206.8**	**0**	**0**
10	Osogbo	1.032672	11.37605	201.2	150.9	0	0
11	Afam	1.050000	16.78539	52.5	39.4	431	374.8972
12	Alaoji	1.036060	16.13899	427	320.2	0	0
13	**New Heaven**	**1.000000**	**9.17094**	**177.9**	**133.4**	**0**	**0**
14	**Onitsha**	**1.000000**	**10.399**	**184.6**	**138.4**	**0**	**0**
15	Benin-Kebbi	1.064558	17.89175	114.5	85.9	0	0
16	**Gombe**	**1.000000**	**12.9235**	**130.6**	**97.9**	**0**	**0**
17	Jebba	1.050548	17.57602	11	8.2	0	0
18	Jebbag	1.050000	17.83863	0	0	495	-107.994
19	Jos	1.000000	16.45181	70.3	52.7	0	0
20	Kaduna	1.029907	11.8995	193	144.7	0	0
21	Kainji	1.050000	20.7439	7	5.2	624.7	-267.781
22	Kano	1.000000	8.921075	220.6	142.9	0	0
23	Shiroro	1.050000	13.55912	70.3	36.1	388.9	118.9867
24	Sapele	1.050000	11.80914	20.6	15.4	190.3	109.9318
25	Abuja	1.028261	20.38124	110	89	0	0
26	Okpai	1.029469	11.48092	290.1	145	0	0
27	AES	1.050000	32.11241	0	0	750	-32.6868
28	Calabar	1.050000	4.599461	0	0	750	322.2772
		Total		**4371.8**	**3173.2**	**4179.991**	**1077.753**

Table 4 shows a comparison of the voltage magnitude at the low voltage buses with and without FACTS devices

Table 4: Voltage profile with and without FACTS devices

Bus No	Bus Name	Voltage Magnitude		
		NO FACTS	WITH STATCOM	WITH SSSC
9	Ayede	0.989663	1.000	1.000
13	New Heaven	0.976528	1.000	1.000
14	Onitsha	0.993851	1.000	1.000
16	Gombe	0.993725	1.000	1.000

Buses 9(Ayede), 13(New-Haven), 14(Onitsha), 16(Gombe) are the low voltage buses as shown in case A. To enhance the voltage magnitude at each of those buses, it therefore becomes necessary to reinforce the system by incorporating STATCOM and SSSC into it as in cases B and C. The updated voltages are shown in

Table 6. A comparison of the voltage improvement at the reinforced low voltage buses expressed as a percentage is presented by Table 5.

Table 5: Voltage improvement at reinforced buses

Bus No	% increase using STATCOM	% increase using SSSC
9	1.044	1.044
13	2.404	2.404
14	0.619	0.619
16	0.631	0.631

B. **Line flow and Losses**

The total active and reactive power losses is calculated by the power flow programme using Newton-Raphson iterative techque. The total active power loss and reactive power loss obtained for the base case (i.e without the incorporation of STATCOM and SSSC) are 85.177MW and 2328.358MVAR respectively. However, after the incorporation of STATCOM, the total active power loss is reduced to 85.031MW while the total reactive power loss reduced to 2304.868MVAR. Similarly, the total active power loss and reactive power loss obtained after the incorporation of SSSC are 84.259MW and 2087.875MVAR respectively. This is shown in Table 6. The effect of these devices expressed as a percntage decrease in losses is also presented in Table 7.

Table 6: Active and Reactive power Losses

Power Loss	No FACTS Controller	With STATCOM incorporated	With SSSC incorporated
Active Power(MW)	85.177	85.031	84.259
Reactive Power(MVAR)	2328.358	2304.868	2087.875

Table 7: Effect of STATCOM and SSSC on Active and Reactive Power Losses

	% decrease with STATCOM incorporated	% decrease with SSSC incorporated
Active Power Loss (MW)	0.171	1.078
Reactive Power Loss (MVAR)	1.009	10.326

IX. CONCLUSION

In this research work, a power flow analysis was carried out using MATLAB and the buses with low voltages were identified. The effect of the application of SSSC and STATCOM for enhancing voltage stability and loss reduction was demonstrated and compared. Both devices gave satisfactory result, raising the magnitude of the voltage at the buses where they were applied and at other load buses sufficiently to maintain the voltage at 1.0pu, thereby reinforcing the grid. The system losses were also significantly reduced. Active power and reactive power losses reduced by 0.171% and 1.009% respectively when STATCOM was applied. Also the incorporation of SSSC into the Nigerian grid system reduced active power and reactive power losses by 1.078% and 10.326% respectively. STATCOM and SSSC provided approximately the same effect on the voltage. However, SSSC gives a higher reduction in losses compared to STATCOM.

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