

Improving the Efficacy of the Nigerian Electric Power Transmission Network Using Static Synchronous Compensator (STATCOM)

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Abstract
This paper deals with the voltage profile enhancement on the Nigerian 330kV transmission power network using static synchronous compensator (STATCOM). Due to increase in power demand, modern power system networks are being operated under highly stressed conditions. This has resulted to difficulty in meeting reactive power requirement especially under planned or sudden changes in voltages, and hence maintaining the bus voltage within acceptable limits has been a major challenge in the power system network, hence the need for this paper which led to the introduction of Static Synchronous Series Compensator into the Nigeria National Grid (NNG) network for the improvement in electric power transmission**.** The 330kV 58 bus NNG was modeled in PSAT and implemented in Matlab/Simulink for the compensation of the identified voltage violated buses. Transmission network data obtained from Transmission Company of Nigerian (TCN) Osogbo and was used to model the test network. Result of simulations of the network models reveal that STATCOM reasonably improved the voltage stability of the violated buses in the Nigeria network. The insertion of the STATCOM gave 100% improvement in voltage stability relative to a network without any device.
Keywords: Voltage stability, STATCOM, HVDC, Voltage profile, FACT, MATLAB/SIMULINK, PSAT
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1. INTRODUCTION

Due to increase in electricity power demand, modern power system networks are being operated under highly stressed conditions. This has resulted to difficulty in meeting reactive power requirement especially under planned or sudden changes in voltages, and hence maintaining the bus voltage within acceptable limits has been a major hurdle in the power system. Above all, there is an infinite challenges in the voltage regulations along the transmission lines even as the conventional means like : Excitation control and voltage regulators at the generating stations, use of tap changing transformers at sending end and receiving end of the transmission lines, switching in shunt reactors during low loads or while energizing long Extra High Voltage lines(EHV), switching in shunt capacitors during high loads or low power factor loads, use of series capacitors in long EHV transmission lines and distribution lines in case of load fluctuations, use of tap changing transformers in industries, substations, distribution substations for reactive power compensations etc. are used in voltage regulations, there is still voltage rise and voltage drops at power stations. In this paper Static Synchronous Compensator (STATCOM) was introduced into the Nigeria grid network for the enhancement in electric power transmission.

Nigeria power industry is shifting from its feat as the greatest Engineering achievement of the 20th century to a weak stressed and vulnerable network. On the other hand, the Nigeria's electricity demand is rapidly increasing, leading to the power system facilities being operated near their capacity limits, it is assumed that the generating units may need to triple by 2020 to keep up with growing demand, requiring about 10,000 MW of new generating capacity. By projection Nigeria electricity demand in 2020 may grow at 1.8% per annum requiring over 40,000 MW of new generating capacity. Going by our estimate this capital project would require roughly about 10 new generating stations plus associated transmission and distribution facilities amounting to an investment of over $20 billion (Ogbuefi,2015).

Technically, the limitation on power transfer capacity on a transmission line can always be removed by addition of new transmission capacity, but the economic, political and environmental considerations in building of new transmission facilities have made this option not always desirable. Therefore, there is every need to employ power electronic devices to be installed on the existing 330kv Nigerian power system for efficient power delivery.

Several methods which could be used to improve the performances of transmission lines according to Oleka, *et al*., (2016) include: Installation of New Transmission Line, Reconductoring, Transmission Line/Terminal Equipment Replacements, Voltage Upgrade, Conversion from single circuit to double circuit, Phase Shifting and Reactive Power Compensation.

Installation of transmission lines are usually the first option that comes to mind whenever a transmission line is limited in the amount of power it can transmit, so as to alleviate overloading by providing additional paths for power flow. It is beneficial by increasing the reliability of the transmission system. However, it has to pass through economic, political and environmental hurdles.

The term Flexible Alternating Current Transmission System (FACTS) devices describes a wide range of high voltage, large power electronic converters that can increase the flexibility of power systems to enhance AC system controllability, stability and increase power transfer capability (Sharma and Jagtap,2016).

FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips. Other benefits attributed to FACTS devices are additional energy sales due to increased transmission capability, reduced wheeling charges due to increased transmission capability and due to delay in investment of high voltage transmission lines or even new power generation facilities. These devices stabilize transmission systems with increased transfer capability and reduced risk of line trips (Kumar and Dubey, 2015). The major problem in power system is upholding steady acceptable system parameters like bus voltage, reactive power and active power under normal operating and anomalous conditions. This is usually system regulation problem and regaining synchronism after a major fault is critical for this phenomenon as Faults can cause loss of synchronism. As effects of instability, faults occur due to insulation breakdown or compromise as result of lightning ionizing air, power cables blowing together in the wind, animals or plants coming in contact with the wires, salt spray, pollution on insulators, system overloading, long transmission lines with uncontrolled buses at the receiving end, shortage of local reactive power, intrinsic factors, natural causes like harsh weather and small generation reserve margins. Such system disturbances have led to the introduction of FACTS devices such as Static Var Compensators (SVC), Static Synchronous Series Compensator (SSSC) Static Synchronous Compensator (STATCOM), Unified Power Controller (UPFC) and Interline Power flow Controller (IPFC), (Karthik and Arul, 2013) and (Makkar and Dewan**,** 2015). In stable power systems, when synchronous machines are disturbed, synchronism will either go back to their original state if there is no net change of power or will reach a new state without loss of synchronism and when there is net change in power; synchronism is lost (Satheesh and Manigandan, 2015**)**. Due to FACTS devices, the power can be transmitted through the chosen routes with consideration to mitigate the loss thereby averting losses due to system tripping or outages. STATCOM, UPFC and SSSC, for instance, are very versatile FACTS controllers. The conventional approach often requires a precise mathematical model of the controlled systems. In power system practice and taking Nigeria as an example, there exist parameter uncertainty problems in the plant modeling and, also, since it is large, complex, geographically widely distributed, and can be affected by unexpected events, the conventional controllers often perform satisfactorily over a rather limited range of operation. These reasons also make global control very difficult.

2. Materials and Method

2.0 Modeling of Power Systems with STATCOM

It is acceptable to expect that for the aim of positive sequence power flow analysis the STATCOM will be represented by a synchronous voltage source with maximum and minimum voltage magnitude limits (Acha et al, 2004). The synchronous voltage source stands for the fundamental Fourier series component of the switched voltage waveform at the AC converter terminal of the STATCOM. The bus at which the STATCOM is connected is represented as a PV bus, which may change to a PQ bus in the case of limits being violated. In this case, the generated or absorbed reactive power would reach to the maximum limit. The STATCOM equivalent circuit shown in Figure 3.1 is used to obtain the mathematical model of the controller for incorporation in power flow algorithms (Adepoju and Komolafe, 2011).

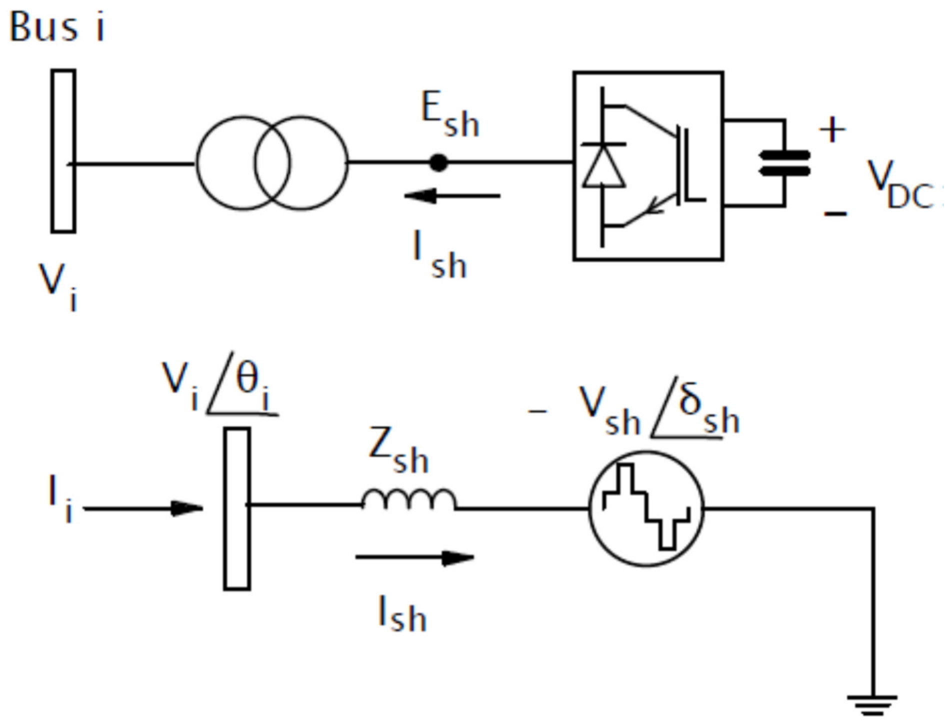

Figure 1: Thevenin's equivalent circuit diagram of STATCOM: (a) STATCOM schematic diagram; (b) STATCOM equivalent circuit

The power flow equations for the STATCOM are derived below:
From first principles and assuming the voltage source representation: (Aborisade et al, 2014):

$V_{sh} = v_{sh}\angle\delta_{sh}$, also $V_i = v_i\angle\theta_i$, (1)

$E_{sh} = V_{sh}(\cos\delta_{sh} + j\sin\delta_{sh})$ (2)

From the STATCOM equivalent circuit of figure 1;

$S_{sh} = V_{sh} I_{sh}^* = V_{sh}\, Y_{sh}^*(V_{sh}^* - V_i^*)$ (3)

After performing some complex operations, the following active and reactive power equations are obtained for the converter and bus i, respectively:

$P_{sh} = V_{sh}^2 G_{sh} + V_{sh} V_i[G_{sh}\cos(\delta_{sh} - \theta_i) + B_{sh}\sin(\delta_{sh} - \theta_i)]$ (4)

$Q_{sh} = V_{sh}^2 B_{sh} + V_{sh} V_i[G_{sh}\sin(\delta_{sh} - \theta_i) - B_{sh}\cos(\delta_{sh} - \theta_i)]$ (5)

$P_i = V_i^2 G_{sh} + V_i V_{sh}[G_{sh}\cos(\theta_i - \delta_{sh}) + B_{sh}\sin(\theta_i - \delta_{sh})]$ (6)

$Q_i = V_i^2 B_{sh} + V_i V_{sh}[G_{sh}\sin(\theta_i - \delta_{sh}) - B_{sh}\cos(\theta_i - \delta_{sh})]$ (7)

Using these power equations, the linearized STATCOM model is as given in equation (8), where the voltage magnitude V_{sh} and phase angle δ_{sh} are taken to be the state variables (Acha et al, 2000)

$$\begin{bmatrix}\Delta P_i\\ \Delta Q_i\\ \Delta P_{sh}\\ \Delta Q_{sh}\end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial\theta_i} & \frac{\partial P_i}{\partial V_i}V_i & \frac{\partial P_i}{\partial\delta_{sh}} & \frac{\partial P_i}{\partial V_{sh}}V_{sh}\\ \frac{\partial Q_i}{\partial\theta_i} & \frac{\partial Q_i}{\partial V_i}V_i & \frac{\partial Q_i}{\partial\delta_{sh}} & \frac{\partial Q_i}{\partial V_{sh}}V_{sh}\\ \frac{\partial P_{sh}}{\partial\theta_i} & \frac{\partial P_{sh}}{\partial V_i}V_i & \frac{\partial P_{sh}}{\partial\delta_{sh}} & \frac{\partial P_{sh}}{\partial V_{sh}}V_{sh}\\ \frac{\partial Q_{sh}}{\partial\theta_i} & \frac{\partial Q_{sh}}{\partial V_i}V_i & \frac{\partial Q_{sh}}{\partial\delta_{sh}} & \frac{\partial Q_{sh}}{\partial V_{sh}}V_{sh} \end{bmatrix} \begin{bmatrix}\Delta\theta_i\\ \frac{\Delta V_i}{V_i}\\ \Delta\delta_{sh}\\ \frac{\Delta V_{sh}}{V_{sh}}\end{bmatrix} \quad (8)$$

2.1 Development of Simulation Model and The Simulation Of 58 Bus Nigeria 330kV Transmission Network with STATCOM Device Connected

The power flow model for STATCOM was derived and written in equation 8 and with this equation, the 58 bus Nigeria 330 kV transmission line network was modeled in PSAT 2.1.8 and simulated in Matlab 2015b environment. The developed PSAT model is as shown in fig 2. The power flow solution of the Nigeria 330kV was implemented in the simulation using Newton – Raphson method of load flow solution. Egbin substation was chosen as the slack bus.

The voltage violated buses was sorted out from the result of the load flow analysis using the permissive voltage bus limit criteria of 0.95 to 1.05 pu or $\pm$5% of the rated bus voltage.

The search for the best position placement of STATCOM was done having known the positions of the violated buses. The method is just to insert the STATCOM device in any of these violated buses since STATCOM is a shunt device. The best position is based on the degree of performance enhancement spread.

2.2 Simulation of Nigeria 330kV Transmission Line

All simulations are done in MATLAB 2015b environment using specially design power system analysis tool PSAT 2.1.8. In this simulation tool, power flow of power system could be simulated and various results like bus voltage and phase angle, line flows and lines losses will be obtained. The simulation was done when no device is connected and when STATCOM device is connected to the 330kV network.

2.3 Test case 1 (NO device connected in the test network)

In this case no device was connected in the 58 bus Nigeria 330 kV transmission line as shown in figure 2.

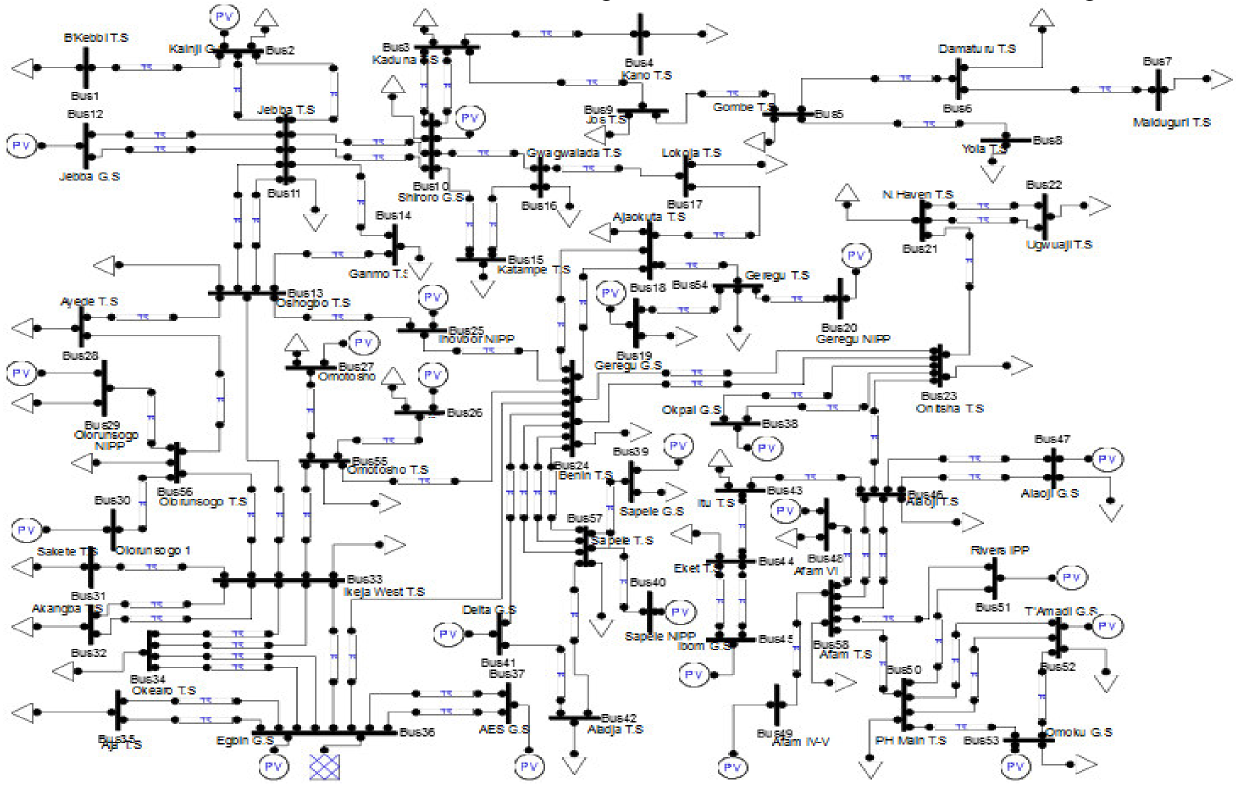

Figure 2: PSAT Model for 58 Bus Nigeria 330 kV Network without FACT Device

2.4 Test Case 2 (STATCOM Device Connected to The Test Network)

In this test case, buses with voltage violations are connected with STATCOM one at a time and simulated to study the performance of the STATCOM in enhancing the voltage profile. PSAT model showing STATCOM connected to bus 7 is shown in Figure 3.

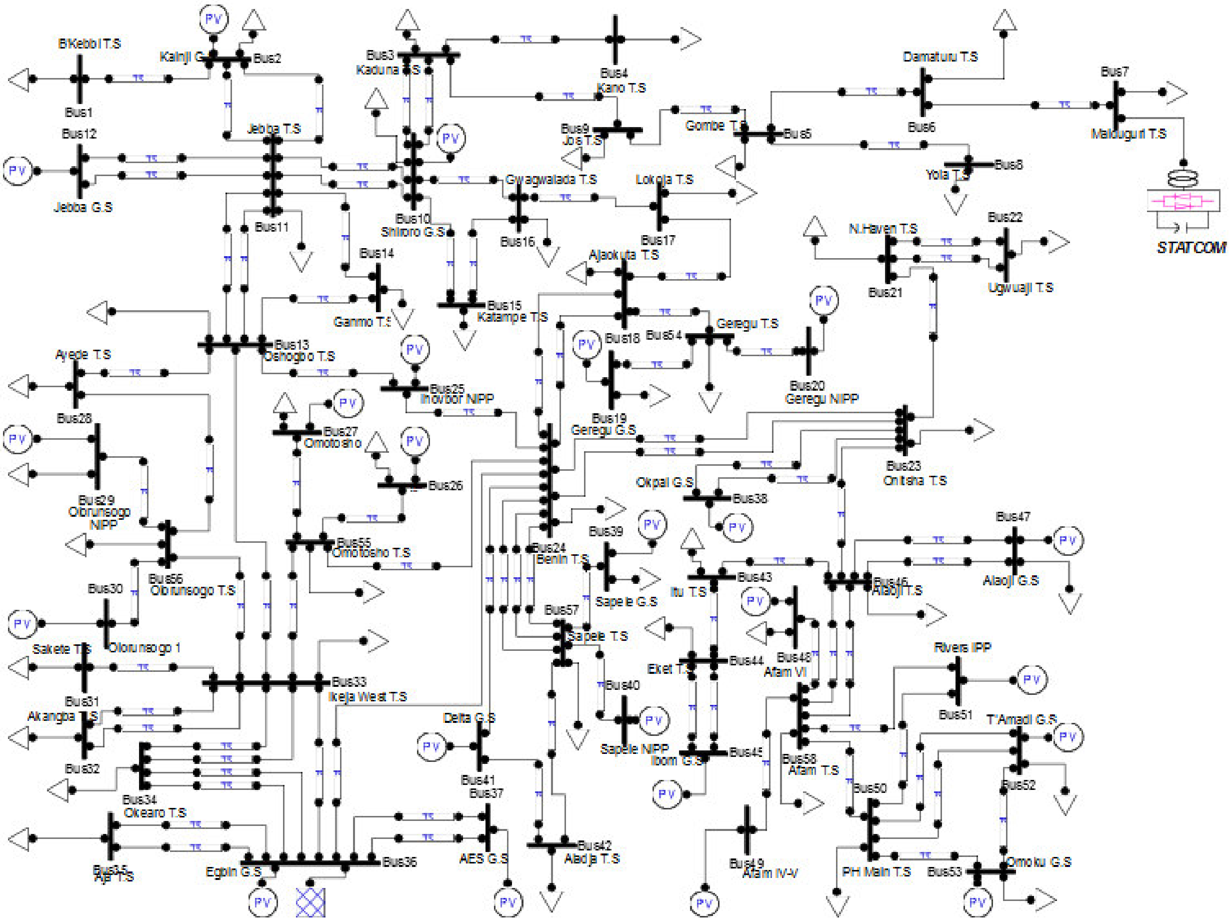

Figure 3: PSAT Model for 58 Bus Nigeria 330 kV Network connected with STATCOM device

2.5 Simulation conditions for STATCOM insertion

STATCOM device was connected at bus 7 and simulations were done at various compensation conditions as stated below:

(i) conditions: power = 100MW and shunt current $I_q = 0.7$ pu

(ii) conditions: power = 100MW and shunt current $I_q = 0.76$ pu

Table 1: Network Statistics

	NETWORK STATISTICS	
Network condition	STATCOM	No FACTS
Buses	58	58
Lines	87	87
Generators	23	23
Loads	46	46

Table 2: Solution Statistics

	SOLUTION STATISTICS	
Power Flow Solution Type	Newton - Raphson	
Simulation Condition	STATCOM	No FACT
Number of Iterations:	5	5
Maximum P mismatch [p.u.]	41.22503	9.28E-12
Maximum Q mismatch [p.u.]	10.03604	0.197854
Power rate [MVA]	100	100

3.Simulation Results and Discussion

Table 3: Bus Voltages without FACTS Insertion

Bus Number	Bus Name	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus 1	BIRNIN KEBBI	0.979671	-0.67098	8.88E-16	-6.7E-16	1.62	1.22
Bus 2	KAINJI	0.97	-0.50455	2.92	-4.49602	0.89	0.67
Bus 3	KADUNA	0.989272	-0.86088	-2E-12	1.78E-13	1.43	0.98
Bus 4	**KANO**	**0.936896**	-1.00471	2.75E-13	8.24E-14	1.94	1.46
Bus 5	**GOMBE**	**0.908595**	-1.14256	-2.5E-12	4.15E-12	0.68	0.51
Bus 6	**DAMATURU**	**0.906397**	-1.17949	2.8E-12	1.17E-12	0.24	0.18
Bus 7	**MAIDUGURI**	**0.897593**	-1.20893	7.61E-12	5.93E-13	0.31	0.2
Bus 8	**YOLA**	**0.9012**	-1.16512	4.58E-12	4.62E-13	0.26	0.2
Bus 9	**JOS**	**0.938719**	-1.00219	-9.3E-12	2.22E-12	0.72	0.54
Bus 10	SHIRORO	1	-0.77658	3	-2.26389	1.7	0.98
Bus 11	JEBBA T/S	1.0016	-0.51444	-1.4E-13	-1.2E-13	2.6	1.95
Bus 12	JEBBA G/S	1	-0.50967	4.03	-2.04678	0	0
Bus 13	OSHOGBO	1.021973	-0.4437	7.55E-15	2.23E-14	1.27	0.95
Bus 14	GANMO	1.013572	-0.48713	2.18E-14	9.44E-15	1	0.75
Bus 15	KATAMPE	0.968761	-0.8546	7.99E-15	-8E-15	3.03	2.27
Bus 16	GWAGWALADA	0.981015	-0.81865	0	8.66E-15	2.2	1.65
Bus 17	LOKOJA	0.983658	-0.66839	-2.2E-16	7.88E-15	1.2	0.9
Bus 18	AJAOKUTA	0.985653	-0.61087	-3.6E-13	1.34E-13	1.2	0.9
Bus 19	GEREGU G/S	0.985	-0.60912	3.85	1.455111	2	1.5
Bus 20	GEREGU (NIPP)	0.985	-0.60933	1.46	-0.00394	0	0
Bus 21	NEW HAVEN	0.971998	-0.93997	-4.9E-15	-3.3E-14	1.96	1.47
Bus 22	UGWAJI	0.971496	-0.94174	8.08E-14	2.33E-14	1.75	1.31
Bus 23	ONITSHA	0.973807	-0.82315	3.5E-14	1.24E-13	1	0.75
Bus 24	BENIN	0.995828	-0.49639	2.98E-14	-5.4E-14	1.44	1.08
Bus 25	IHOVBOR (NIPP)	1	-0.4835	1.166	-1.38708	0	0
Bus 26	OMOTOSHO (NIPP)	1.006	-0.33761	1.147	0.512867	0.9	0.44
Bus 27	OMOTOSHO I	1	-0.33783	0.508	-0.02731	0.3	0.14
Bus 28	AYEDE	0.980821	-0.30971	-4.4E-15	-2.9E-15	1.74	1.31
Bus 29	OLORUNSOGO (NIPP)	0.973	-0.19955	0.93	-0.14974	0.71	0.58
Bus 30	OLORUNSOGO I	0.97	-0.18351	1.027	-0.97025	0	0
Bus 31	SAKETE	0.97798	-0.12887	-4.4E-16	9.77E-15	2.05	1.1
Bus 32	AKANGBA	0.99619	-0.09054	9.33E-15	1.16E-13	2.03	1.52
Bus 33	IKEJA WEST	0.999964	-0.08613	2.13E-14	-7.8E-14	8.47	6.35
Bus 34	OKEARO	1.01469	-0.04388	-6.7E-15	3.72E-14	1.2	0.9
Bus 35	AJA	1.031295	-0.00213	-7.1E-15	-5E-14	1.15	0.86
Bus 36	EGBIN	1.033	0	41.23471	10.03976	0	0
Bus 37	AES	1	0.076642	2.452	-3.49485	0	0
Bus 38	OKPAI	1	-0.78611	4.66	1.692064	0	0
Bus 39	SAPELE G/S	0.985	-0.48992	0.67	-0.95668	0.4	0.18
Bus 40	SAPELE (NIPP)	1	-0.48001	1.111	-0.18175	0	0
Bus 41	DELTA	1.003	-0.4791	3.41	0.905989	0	0
Bus 42	ALADJA	0.992198	-0.49737	7.99E-15	-1E-14	2.1	1.58
Bus 43	ITU	0.97848	-1.53205	3.55E-15	-8.1E-15	1.99	0.91
Bus 44	EKET	0.988548	-1.56369	-1.1E-14	-9.8E-15	2	1.47
Bus 45	IBOM	1	-1.56214	0.305	1.496835	0	0
Bus 46	ALAOJI T/S	0.981995	-1.48959	1.33E-15	6.13E-14	2.4	1
Bus 47	ALAOJI G/S	1	-1.49044	2.5	9.415142	2.27	1.7
Bus 48	AFAM VI	1	-1.51254	6.46	8.916558	5.34	4.01
Bus 49	AFAM IV-V	0.956	-1.51175	0.54	-4.4108	0	0
Bus 50	PH MAIN	0.998574	-1.53855	-8.9E-14	5.84E-14	2.8	1.4
Bus 51	RIVERS (IPP)	1	-1.53337	0.8	1.498423	0	0

Bus Number	Bus Name	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus 52	TRANS AMADI	1	-1.53852	1	1.70441	0.8	0.24
Bus 53	OMOKU	1	-1.53867	0.448	0.208557	0.5	0.1
Bus 54	GEREGU T/S	0.984922	-0.6101	8.33E-13	1.02E-13	2	1.5
Bus 55	OMOTOSHO T/S	0.992783	-0.34213	-1.8E-15	2.61E-14	0.8	0.5
Bus 56	OLORUNSOGO T/S	0.980349	-0.2047	-8.9E-15	-2.7E-14	0.71	0.58
Bus 57	SAPELE T/S	0.996462	-0.4953	-5.9E-14	-2.7E-14	1	0.77
Bus 58	AFAM T/S	0.976824	-1.51604	-6.2E-15	1.47E-13	7.2	4.12

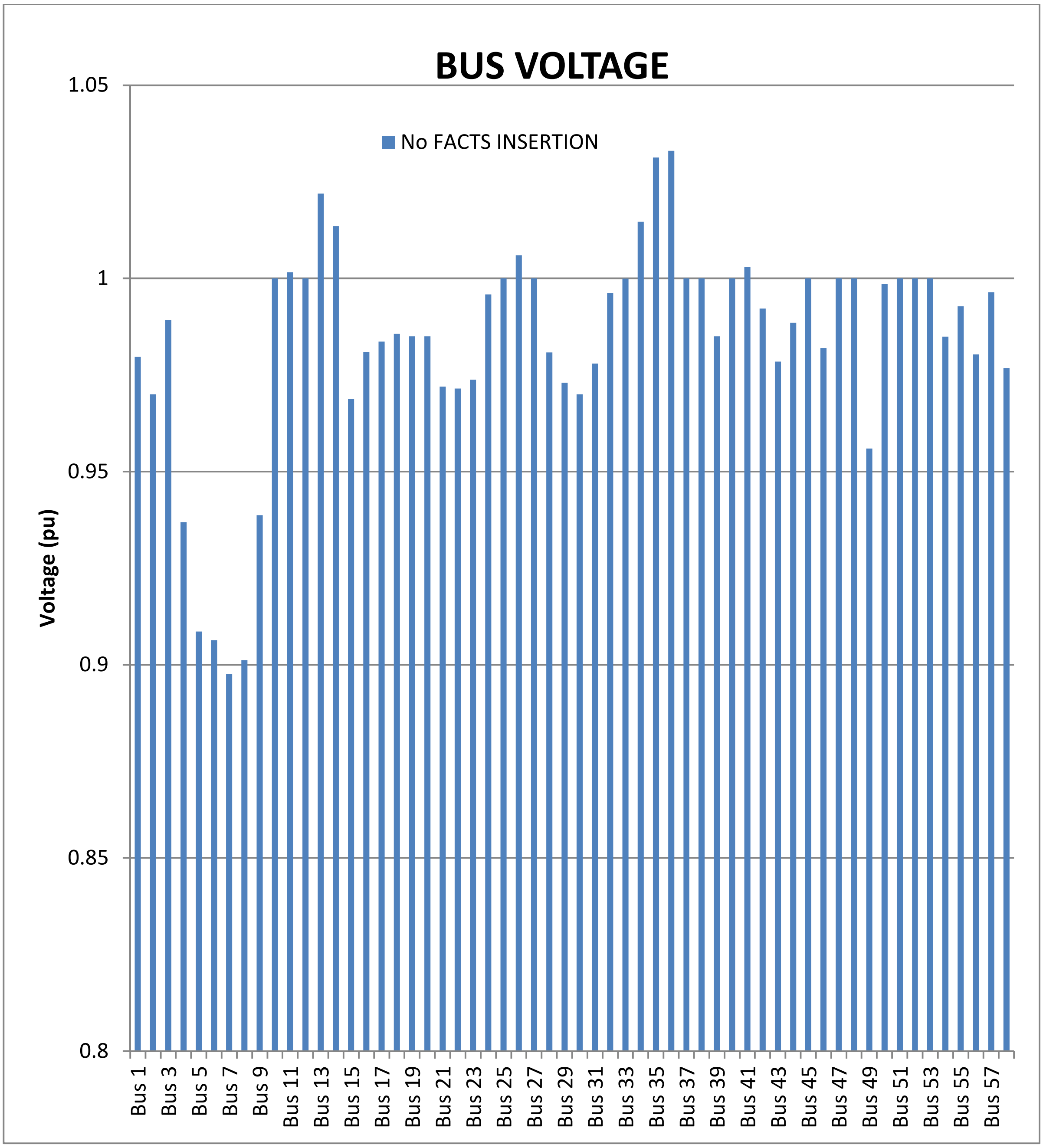

Figure 4: Bus voltages without FACTS insertion

Table 4: Simulation Result of Violated Buses during Insertion of STATCOM at Various Buses

		Bus 9	Bus 5	Bus 6	Bus 7	Bus 8
Bus Number	Bus Name	Voltage V[p.u.]	Voltage V[p.u.]	Voltage V[p.u.]	Voltage V[p.u.]	Voltage V[p.u.]
4	Kano	0.966401	0.957131	0.954405	0.952312	0.954758
5	Gombe	1.043227	1.042307	1.024108	1.010146	1.026444
6	Damaturu	1.049309	1.048337	1.04782	1.030606	1.031568
7	Maiduguri	1.045633	1.04463	1.044097	1.048693	1.027308
8	Yola	1.040173	1.039227	1.020483	1.006095	1.048368
9	Jos	1.040302	1.008153	0.99874	0.991517	0.999953

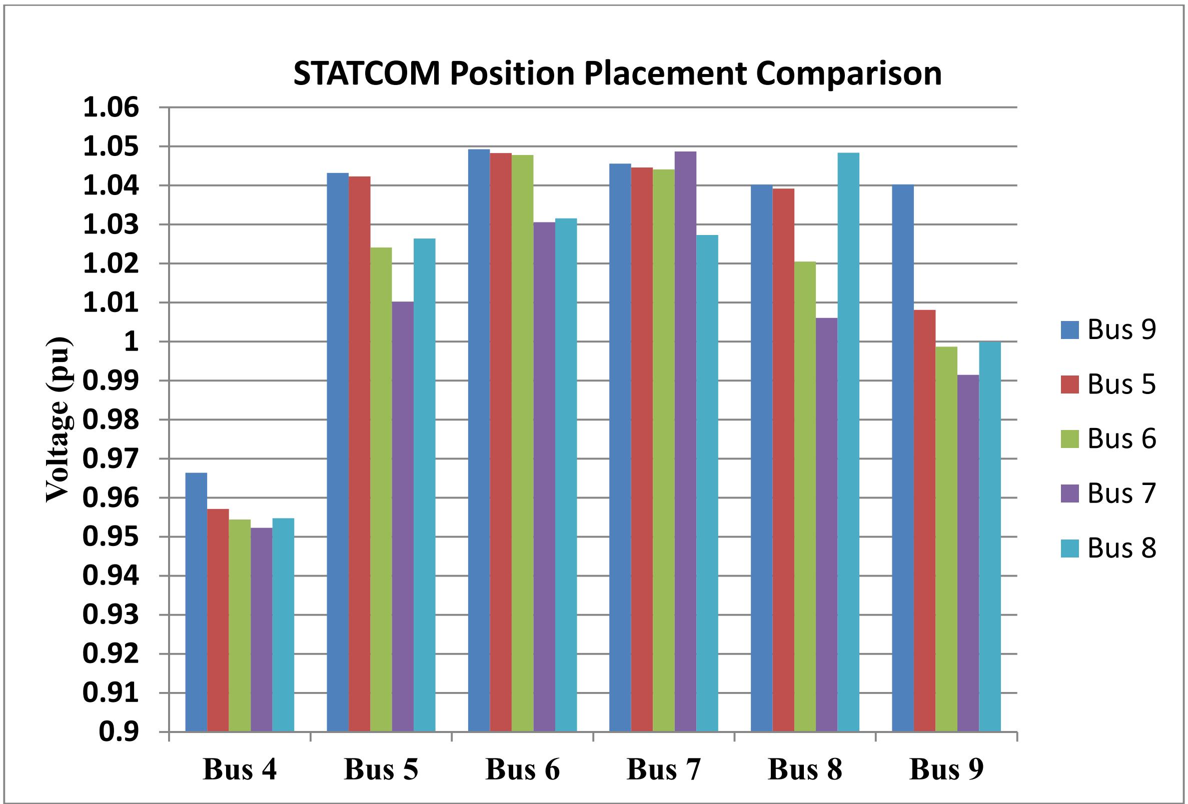

Figure 5 : STATCOM Position Placement Comparaisons (Bus Voltage improvement Perceptive)

Table 5: Violated Bus Voltage upon the Shunt Current Variation of the Inserted STATCOM

		Ish=0.7pu	**Ish=0.76pu**
Bus Number	Bus Name	Voltage V[p.u.]	Voltage V[p.u.]
4	Kano	0.964267	0.966401
5	Gombe	1.033639	1.043227
6	Damaturu	1.039175	1.049309
7	Maiduguri	1.035168	1.045633
8	Yola	1.0303	1.040173
9	Jos	1.032875	1.040302

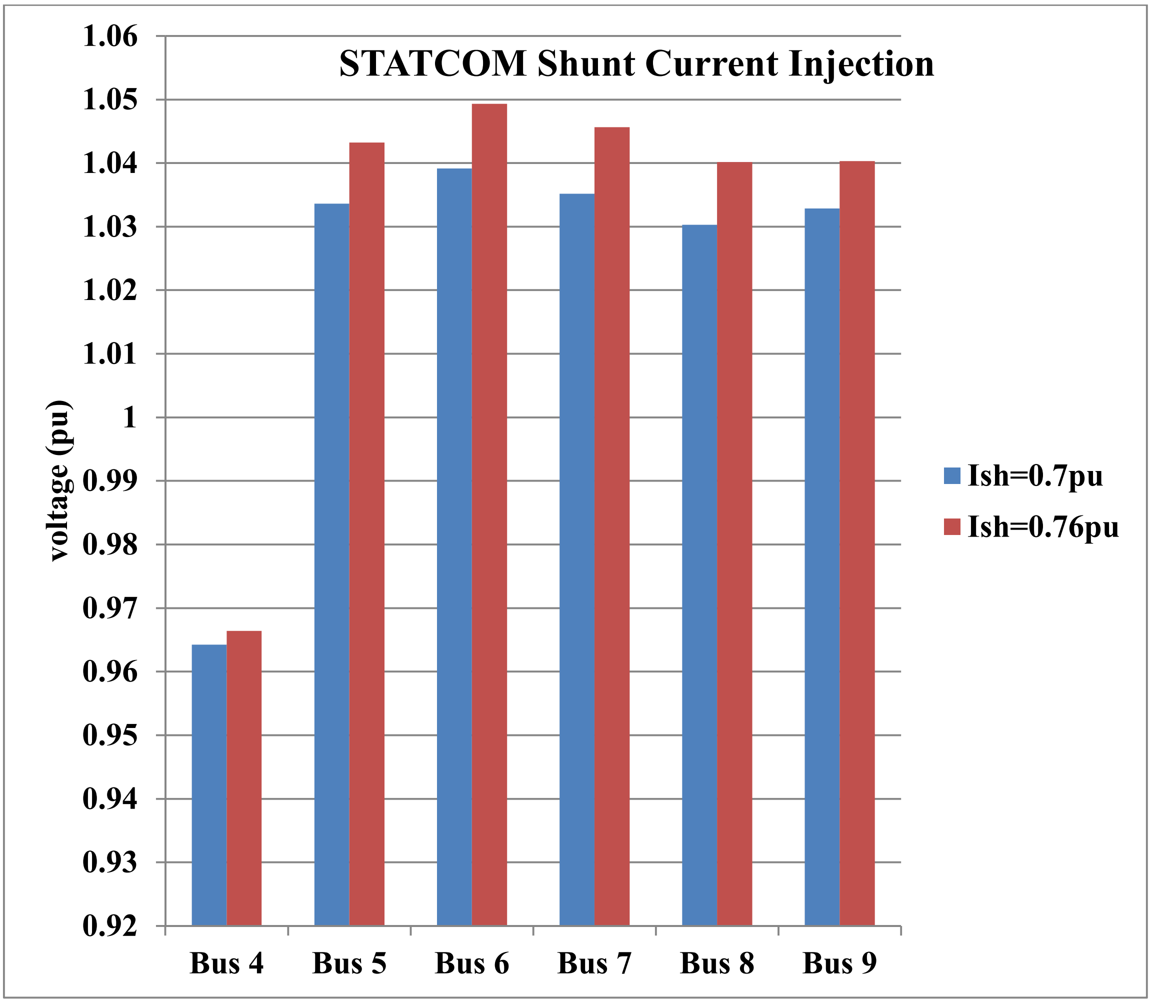

Figure 6: Violated Bus Voltage response upon the Shunt Current Variation of the Inserted STATCOM

The simulation of 58 buses, 330kV Nigerian transmission line network without compensation has shown that six (6) buses had voltage violation see table 5 and figure 4 and these buses are bus 4 (Kano), bus 5 (Gombe), bus 6 (Damaturu) bus 7 (Maiduguri), bus 8 (Yola) and bus 9 (Jos). These voltages violation had occurred majorly on the radial line serving Kaduna to Maiduguri with a single transmission line feeding all the violated busses from Kaduna substation. Violation in Kano was a case of high active and reactive power demand 1.94 pu and 1.46 pu respectively. The major cause of this voltage violation in Kano substation was of course reactive power demand. The cause of violations on buses along Kaduna – Maiduguri line was mostly due to drops along the long line. The total power demand along this line from Kaduna – Maiduguri and the connected line from Gombe to Yola was 2.21pu and 1.63pu, active and reactive power respectively. Maiduguri substation experienced the highest voltage violation because it had longest measured distance from Kaduna 795 km and power demand of 1.95 + j1.43 pu. Compare with Kaduna to Yola, and which had second highest voltage violation of 0.9012 but had distance of 615 km from Kaduna and total power demand of 1.64 + j1.23 pu

Discussion and Result analysis of STATCOM insertion.

The result of simulation of 58 buses, 330kV Nigerian transmission line network when inserted with STATCOM was recorded in table 4 and table 5 and shown graphically in figure 5 and figure 6. The conditions for these simulations were enlisted in section 3.5. Positional placement assessment of STATCOM was recorded in table 4 and shown graphically in figure 5.

The simulation result of STATCOM showed that the position for the insertion of STATCOM for best performance enhancement was at bus 9 (Jos) see table 4 and figure 5. Table 4 showed that STATCOM when placed in bus 9 (Jos) had a better spread of performance enhancement than other positions. The condition of placement was given section 3.5 condition. The simulation conditions showed that at bus 7 (Maiduguri) the STATCOM required least shunt current to correct the voltage violated buses through with least performance enhancement spread. Observation of the result showed that the position where STATCOM had the highest bus voltage improvement was at that bus where STATCOM had the best of performance spread. Compare the performance spread at bus 9 (Jos) with that of bus 5 (Gombe), bus 6 (Damaturu), bus 7 (Maiduguri) and bus 8 (Yola) see table 4.

Increment in the shunt current of the STATCOM brought about increment in the shunt current of the performance enhancement see table 5 and fig 6. Simulation showed that when STATCOM was inserted at its best position bus 9 (Jos), that the value of bus voltage at bus 7 (Maiduguri) moved from 0.897593 pu to 1.035168 pu and 1.045613 pu for shunt current variation of 0.7pu and 0.76 pu respectively.

4.Conclusion

The 58 buses, 330kV Nigerian transmission line network as shown by this paper has 7 voltage violated buses. These buses are Kano (0.9180 pu), Gombe (0.7890 pu), Damaturu (0.7634 pu), Maiduguri (0.7613 pu), Yola (0.7769 pu) and Jos (0.8756 pu). When these voltages violated buses where enhanced by the connection of STATCOM in Jos substation bus, the bus enhancement was 100% better than uncompensated Nigeria 330kV transmission network.

References

Ogbuefi U. C. and Madueme T. C. “A Power Flow Analysis of the Nigerian 330 KV Electric Power System” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. I (Jan – Feb. 2015), PP 46-57 www.iosrjournals.org DOI: 10.9790/1676-10114657

E.U. Oleka, S. N. Ndubisi & G. K. Ijemaru “Electric Power Transmission Enhancement: A Case of Nigerian Electric Power Grid” American Journal of Electrical and Electronic Engineering, 2016, Vol. 4, No. 1, 33-39 DOI:10.12691/ajeee-4-1-5

Kumar and S. B. Dubey (2015), “Enhancement of Transient Stability in Transmission Line Using SVC Facts Controller”, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-2

M.Karthik and P.Arul, ―Optimal Power Flow Control Using FACTS Devices,’’ International Journal of Emerging Science and Engineering (IJESE) ISSN: 2319–6378, Volume-1, Issue-12, October 2013

Makkar C.R and Dewan L. “Transient Stability Improvement of SMIB System using Line Impedance Compensation Mode of UPFC” Transactions on Engineering and Science Volume 3 Issue 1 2015

Satheesh, A. Maintaining Power System Stability with Facts Controller using Bees Algorithm and NN / A. Satheesh, T. Manigandan // Journal of Theoretical and Applied Information Technology. - 10th March 2015. - Vol. 49 Issue 1. - P. 38-47

Enrique Acha, Claudio R. FuerteEsquivel, Hugo Ambriz-Pérez and César AngelesCamacho Publisher: J.Wiley & Sons. ISBN: 0-470-85271-2 Year of publication: 2004

E. Acha ,C. R. Fuerte-Esquivel, and H. Ambriz-Perez, "A comprehensive Newton-Raphson UPFC model for the quadratic power flow solution of practical power networks," in IEEE Transactions on Power Systems, vol. 15, no. 1, pp. 102-109, Feb. 2000, doi: 10.1109/59.852107.

Adepoju O.A., Komolafe G. A., Analysis and Modelling of Static Synchronous Compensator (STATCOM): A comparison of Power Injection and Current Injection Models in Power Flow Study International Journal of Advanced Science and Technology Vol. 36, November, 2011

Aborisade, D.O., Adebayo, I.G., and Oyesina, K.A. “A comparison of the Voltage Enhancement and Loss Reduction Capabilities of STATCOM and SSSC FACTS Controllers” American Journal of Engineering Research (AJER) e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-03, Issue-01, pp-96-105 2014

Suraj Kumar and Priyajit Dash “A Study on TSCS, SSSC, SVC Facts Device” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 5, Issue 6, June 2016

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