Voltage Profile Enhancement in The Nigeria 330kv Line Using Statcom

OFOMA CHINEDU SAMSON[1], ATUCHUKWU A.J.[2]
[1] Department of Electrical and Electronic Engineering Federal Polytechnic, Oko, Nigeria
[2] Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria

Abstract- This research examines bus voltages in the Nigeria 330kV interconnected power system. The work devised a dependable solution model and strategy for improving violated bus in the Nigerian 330kV line. Unfortunately, electricity is not always used in large demand in a location it is been generated due to the nature of the transmission line, there is possibility of experiencing low bus voltages, lines overload, frequency fluctuations and poor system damping in the power network, thereby making the stability of the network to be weak when subjected to fault conditions. Load flow analysis was carried out on the system with the view of estimating and analyzing the real and reactive power flow and bus voltages. The input data for the power flow analysis was obtain from TRANSCON (TCN), the data was fed into PSAT 2.1.8 in MATLAB 2018b environment and analyze using Newton-Raphson iterative algorithm. The simulation results of the 58buses shows that (6) six buses did not satisfy the statutory voltage limit of 0.95Pu to 1. 05Pu.The buses that were out of the tolerance includes: Kano(0.9352Pu), Gombe (0.8979Pu), Damaturu (0.8942Pu), Maduguri (0.8845Pu), Yola (0.8898Pu) and Jos 0.9331Pu). The bus voltage profile shows that most of the violated buses are in the northern part of Nigeria. This due to lack of generators in the Northern Nigerian. The problem of low voltage was solved by the use of FACTS device using continuation power flow method, the violated buses were cleared by optimal placement of STATCOM at Maduguri substation.

Indexed Terms- Transmission, STATCOM, Power flow study, Compensation

I. INTRODUCTION

In Nigeria the power demand is far more than the generated available power, this has led to overloading of existing fifty-eight bus twenty three generating station in Nigeria grid and most of buses and lines operated beyond the tolerable base voltage and thermal limits respectively [1][2].Considering the fact that most of the existing Nigeria generating stations were located far from the load centers with partial longitudinal network, there is possibility of experiencing low bus voltages, lines overload, frequency fluctuations and poor system damping in the power network, thereby making the stability of the network to be weak when subjected to fault conditions. In other to ascertain the impact of the integrated power projects on the existing network, a power or load flow program must be carried out [3].

A power-flow study usually uses simplified notations such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyzes the power systems in normal steady-state operation [4].

This is important as the magnitudes of the bus voltages were required to be held within a specified limit. The following parameters can be determined in load flow study: Power flows in all branches in a network, power contributed by each generator, power loss in each component in the network and nodal voltage magnitudes and angles throughout the network [5]. In case of violations, Flexible Alternating Current Transmission System (FACTS) Controllers with fast responses are employed instead electromechanical devices to enhance power system performance [6].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 [7]. However, these methods suffer from slow response and wear and tear in the mechanical components which hinder their application for power transmission improvement and control undesirable.

II. STATIC SYNCHRONOUS COMPENSATOR

The static synchronous compensator (STATCOM) is also known as an advanced static VAR compensator (ASVC), as a static condenser (STATCON), and as a static synchronous generator (SSG). STATCOM is a shunt-type, inverter-based compensating device with the ability to generate and absorb reactive power [8]. STATCOMs operate similar to synchronous condensers, where a synchronous condenser is an ideal synchronous machine connected to a power grid, and working in no load conditions [9].

A STATCOM system is, at the minimum, made up of a transformer, a VSC with feedback control, and DC link capacitors.

III. MATERIALS METHOD

A. Modelling of Power Systems with STATCOM

The STATCOM equivalent circuit shown in Fig. 1 is used to obtain the mathematical model of the controller for incorporation in power flow algorithms [6].

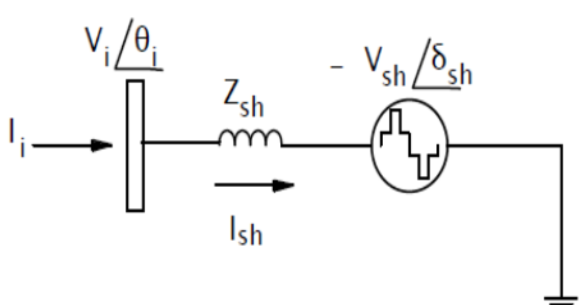

Fig. 1: Thevenin's equivalent circuit diagram of STATCOM

IV. UNITS

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

$$P_{sh} = V_{sh}^2 G_{sh} + V_{sh}V_i[G_{sh}\cos(\delta_{sh}-\theta_i) + B_{sh}\sin(\delta_{sh}-\theta_i)] \quad (1)$$

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

$$P_i = V_i^2 G_{sh} + V_iV_{sh}[G_{sh}\cos(\theta_i-\delta_{sh}) + B_{sh}\sin(\theta_i-\delta_{sh})] \quad (3)$$

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

Using these power equations, the linearized STATCOM model is given in equation (5), where the voltage magnitude V_{sh} and phase angle δ_{sh} are taken to be the state variables [10].

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \\ \Delta P_{sh} \\ \Delta Q_{sh} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial \theta_i} & \frac{\partial P_i}{\partial V_i}V_i & \frac{\partial P_i}{\partial \delta_{sh}} & \frac{\partial P_i}{\partial V_{sh}}V_{sh} \\ \frac{\partial Q_i}{\partial \theta_i} & \frac{\partial Q_i}{\partial V_i}V_i & \frac{\partial Q_i}{\partial \delta_{sh}} & \frac{\partial Q_i}{\partial V_{sh}}V_{sh} \\ \frac{\partial P_{sh}}{\partial \theta_i} & \frac{\partial P_{sh}}{\partial V_i}V_i & \frac{\partial P_{sh}}{\partial \delta_{sh}} & \frac{\partial P_{sh}}{\partial V_{sh}}V_{sh} \\ \frac{\partial Q_{sh}}{\partial \theta_i} & \frac{\partial Q_{sh}}{\partial V_i}V_i & \frac{\partial Q_{sh}}{\partial \delta_{sh}} & \frac{\partial Q_{sh}}{\partial V_{sh}}V_{sh} \end{bmatrix} \begin{bmatrix} \Delta\theta_i \\ \frac{\Delta V_i}{V_i} \\ \Delta\delta_{sh} \\ \frac{\Delta V_{sh}}{V_{sh}} \end{bmatrix} \quad (5)$$

B. Modelling of Power in Transmission Line

Consider an electrical transmission system with n – buses as shown in Fig. 2. The current flowing in bus i-th term is given by:

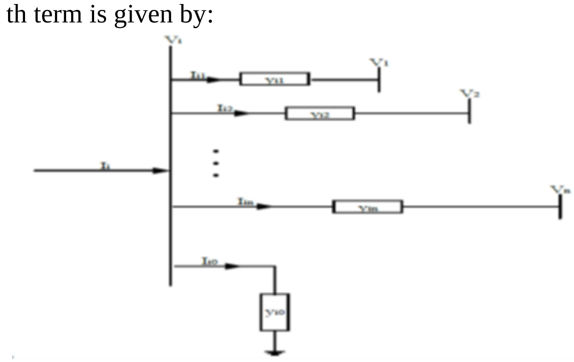

Fig. 2: A simplified I – th bus model of a power system

$$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 \cdots Y_{in}V_n \quad (6)$$

Equation (6) can be expressed as

$$I_i = Y_{ii}V_i + \sum_{j=1}^{n} Y_{ij}V_j$$

The expression for the complex power is given in (Gupta, 2011) as

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

From equation (6) and (7) we

$$\frac{P_i - jQ_i}{V_i} = Y_{ii}V_i + \sum_{j=1}^{n} Y_{ij}V_j, \qquad j \neq i \qquad (8)$$

Solving for V_i in equation above

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i} + \sum_{j=1}^{n} Y_{ij}V_j\right], \quad j \neq i \qquad (9)$$

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

$$P_i = |V_i|^2 G_{ii} + \sum_{j=1}^{n} |Y_{ij}V_jV_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i), \; j \neq i \qquad (10)$$

$$Q_i = |V_i|^2 B_{ii} + \sum_{j=1}^{n} |Y_{ij}V_jV_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i), \; j \neq i \qquad (11)$$

C. Newton-Raphson Power Flow

The Newton Raphson method formulates and solves iteratively the following load flow equation:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}\begin{bmatrix}J_1 J_2\\ J_3 J_4\end{bmatrix} = \begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix} \qquad (12)$$

where ΔP and ΔQ are bus real power and reactive pwer mismatch vectors between specified value and calculated value, respectively: ΔV and $\Delta\delta$ represents bus voltage angle and magnitude vectors in an uncremental form: and J_1 through J_4 are called jacobian matrices.

D. Overview of Nigeria Transmission System

The Nigerian national grid is an interconnection of 9,454.8KM length of 330KV and 8,985.28km length of 132KV transmission lines with Twenty-three power stations. The grid interconnects these stations with fifty-eight buses and eighty-seven transmission lines of either dual or single circuit lines and four control centers (one national control center at Oshogbo and three supplementary control centers at Benin, Shiroro and Egbin).

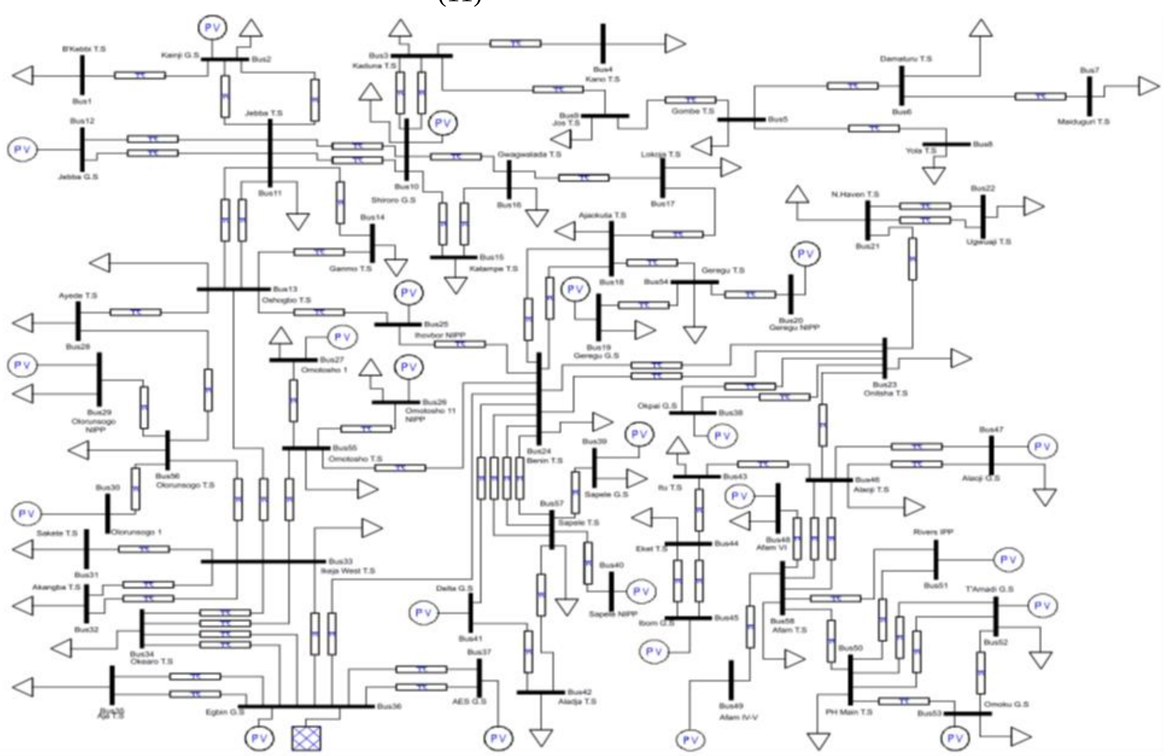

Fig. 3: Single Line Diagram of 58 Buses, 330kv Nigeria Transmission Network for Case 1 Study System

V. SIMULATIONS AND RESULTS

This section presents the result of the simulation conducted in this paper. Table 1 shows the line flow simulations result of 58 buses 330kV transmission line network.

Table 1: Line Flow Simulation Result of 58 Buses, 330 kV Transmission Line Network

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.]
1	Birnin Kebbi	0.9797	0.6710	-	-	1.6200	1.2200
2	Kainji	0.9700	-0.5045	2.9200	-4.4960	0.8900	0.6700
3	Kaduna	0.9880	-0.8609	-	-	1.4300	0.9800
4	Kano	**0.9352**	-1.0051	-	-	1.9400	1.4600
5	Gombe	**0.8979**	-1.1451	-	-	0.6800	0.5100
6	Damaturu	**0.8942**	-1.1828	-	-	0.2400	0.1800
7	Maiduguri	**0.8845**	-1.2130	-	-	0.3100	0.2000
8	Yola	**0.8898**	-1.1682	-	-	0.2600	0.2000
9	Jos	**0.9331**	-1.0028	-	-	0.7200	0.5400
10	Shiroro	1.0000	-0.7766	3.0000	-2.1790	1.7000	0.9800
11	Jebba T/S	1.0016	-0.5144	-	-	2.6000	1.9500
12	Jebba G/S	1.0000	-0.5097	4.0300	-2.0467	-	-
13	Oshogbo	1.0220	-0.4437	-	-	1.2700	0.9500
14	Ganmo	1.0136	-0.4871	-	-	1.0000	0.7500
15	Katampe	0.9688	-0.8546	-	-	3.0300	2.2700
16	Gwagwalada	0.9810	-0.8186	-	-	2.2000	1.6500
17	Lokoja	0.9837	-0.6683	-	-	1.2000	0.9000
18	Ajaokuta	0.9857	-0.6108	-	-	1.2000	0.9000
19	Geregu G/S	0.9850	-0.6090	3.8500	1.4546	2.0000	1.5000
20	Geregu (NIPP)	0.9850	-0.6092	1.4600	-0.0045	-	-
21	New Haven	0.9724	-0.9395	-	-	1.9600	1.4700
22	Ugwaji	0.9719	-0.9413	-	-	1.7500	1.3100
23	Onitsha	0.9741	-0.8228	-	-	1.0000	0.7500
24	Benin	0.9959	-0.4963	-	-	1.4400	1.0800
25	Ihovbor (NIPP)	1.0000	-0.4834	1.1660	-1.3929	-	-
26	Omotosho (NIPP)	1.0060	-0.3375	1.1470	0.5119	0.9000	0.4400
27	Omotosho I	1.0000	-0.3377	0.5080	-0.0283	0.3000	0.1400
28	Ayede	0.9808	-0.3097	-	-	1.7400	1.3100
29	Olorunsogo (NIPP)	0.9730	-0.1995	0.9300	-0.1499	0.7100	0.5800
30	Olorunsogo I	0.9700	-0.1835	1.0270	-0.9704	-	-
31	Sakete	0.9780	-0.1289	-	-	2.0500	1.1000
32	Akangba	0.9962	-0.0905	-	-	2.0300	1.5200

33	Ikeja West	1.0000	-0.0861	-	-	8.4700	6.3500
34	Okearo	1.0147	-0.0439	-	-	1.2000	0.9000
35	Aja	1.0313	-0.0021	-	-	1.1500	0.8600
36	Egbin	1.0330	0.0000	41.2292	10.0363	-	-
37	Aes	1.0000	0.0766	2.4520	-3.4949	-	-
38	Okpai	1.0000	-0.7857	4.6600	1.6564	-	-
39	Sapele G/S	0.9850	-0.4898	0.6700	-0.9584	0.4000	0.1800
40	Sapele (NIPP)	1.0000	-0.4799	1.1110	-0.1835	-	-
41	Delta	1.0030	-0.4790	3.4100	0.9016	-	-
42	Aladja	0.9922	-0.4972	-	-	2.1000	1.5800
43	Itu	0.9830	-1.5300	-	-	1.9900	0.9100
44	Eket	0.9879	-1.5464	-	-	2.0000	1.4700
45	Ibom	1.0000	-1.5449	0.3050	1.6019	-	-
46	Alaoji T/S	0.9834	-1.4878	-	-	2.4000	1.0000
47	Alaoji G/S	1.0000	-1.4885	2.5000	8.8133	2.2700	1.7000
48	Afam Vi	1.0000	-1.5107	6.4600	8.2675	5.3400	4.0100
49	Afam IV-V	0.9560	-1.5100	0.5400	-5.0313	-	-
50	Ph Main	0.9973	-1.5274	-	-	2.8000	1.4000
51	Rivers (IPP)	1.0000	-1.5227	0.8000	2.7534	-	-
52	Trans Amadi	1.0000	-1.5274	1.0000	2.0070	0.8000	0.2400
53	Omoku	1.0000	-1.5276	0.4480	0.3897	0.5000	0.1000
54	Geregu T/S	0.9849	-0.6100	-	-	2.0000	1.5000
55	Omotosho T/S	0.9928	-0.3420	-	-	0.8000	0.5000
56	Olorunsogo T/S	0.9804	-0.2047	-	-	0.7100	0.5800
57	Sapele T/S	0.9965	-0.4952	-	-	1.0000	0.7700
58	Afam T/S	0.9798	-1.5145	-	-	7.2000	4.1200

The simulation result showing the bus voltages of the Nigeria 58 bus network is shown in Fig. 4. Six (6) buses fall off the statutory voltage limit of 0.95 pu to 1.05 pu. These buses are (Kano 0.9352 pu, Gombe 0.8979 pu, Damaturu 0.8942 pu, Maiduguri 0.8845 pu, Yola 0.8898pu and Jos 0.9331 pu). The voltage sensitivity index using continuation power flow is presented in Table 2.

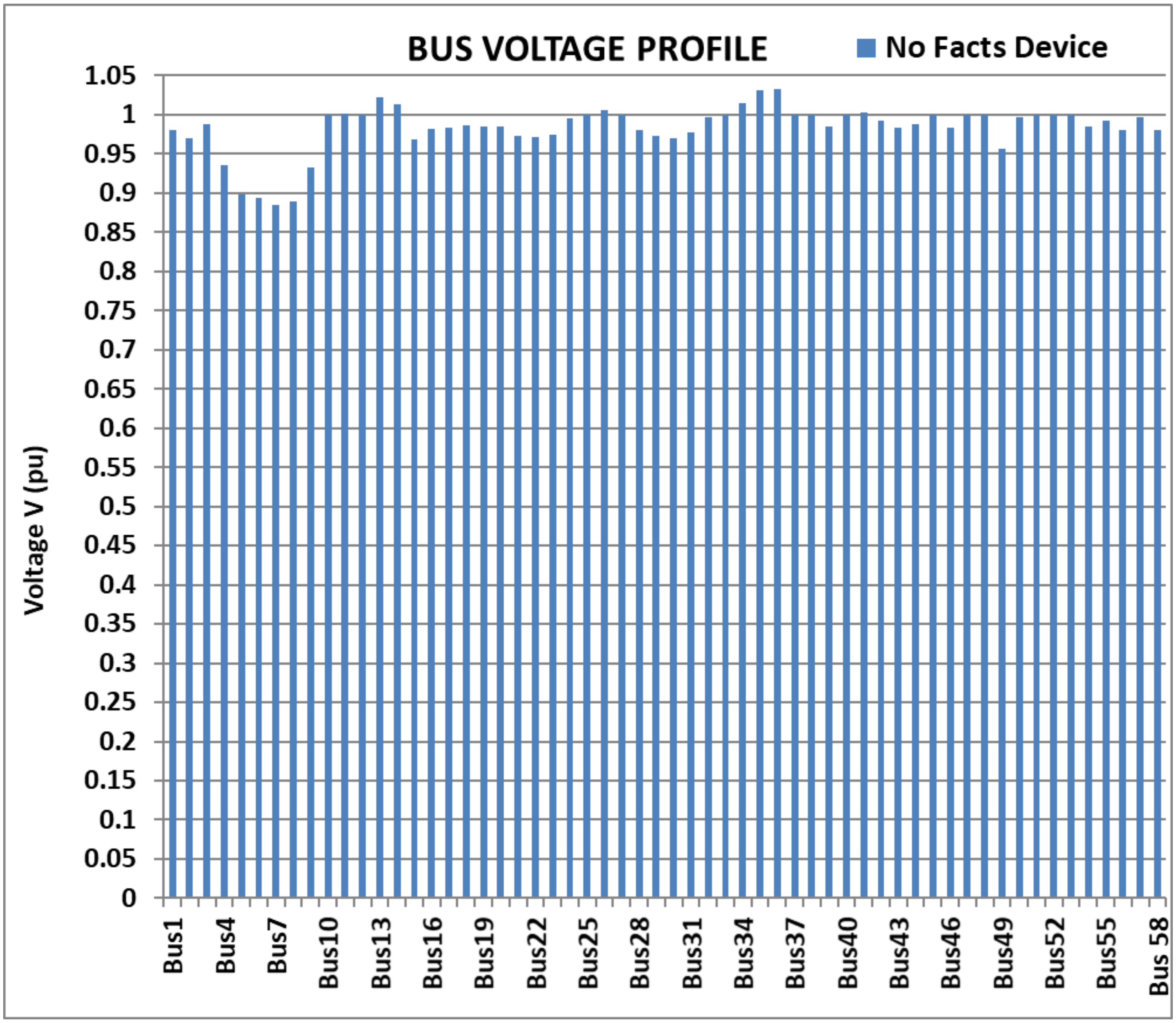

Fig. 4 Bar Representation of the Simulated Bus Voltages of the System

Table 2: Voltage Sensitivity Index Using Continuation Power Flow

Item	Bus Number	Bus Name	V [p.u.]
1	7	Maiduguri	0.657327
2	6	Damaturu	0.680242
3	8	Yola	0.685194
4	5	Gombe	0.703747
5	9	Jos	0.819654
6	4	Kano	0.876375
7	22	Ugwaji	0.939308
8	21	New Haven	0.940023

The result of continuation power flow on the 58 buses, 330 kV transmission network for the ranking of the vulnerable buses to voltage collapse, the most vulnerable bus to voltage collapse is Maiduguri bus and is considered as the optimal placement for STATCOM and the voltage profile is shown in Table 3.

Table 3: The Bus Voltage Profile When STATCOM is inserted in Maiduguri Bus

BUS NUMBER	BUS NAME	BUS VOLTAGE	BUS NUMBER	BUS NAME	BUS VOLTAGE
1	BIRNIN KEBBI	0.979671	30	OLORUNSOGO I	0.97
2	KAINJI	0.97	31	SAKETE	0.977995
3	KADUNA	0.999913	32	AKANGBA	0.996205
4	KANO	0.951046	33	IKEJA WEST	0.999978
5	GOMBE	1.001766	34	OKEARO	1.014698
6	DAMATURU	1.024453	35	AJA	1.031295
7	MAIDUGURI	1.050127	36	EGBIN	1.033
8	YOLA	0.995588	37	AES	1
9	JOS	0.987168	38	OKPAI	1
10	SHIRORO	1	39	SAPELE G/S	0.985
11	JEBBA T/S	1.001603	40	SAPELE (NIPP)	1
12	JEBBA G/S	1	41	DELTA	1.003
13	OSHOGBO	1.021997	42	ALADJA	0.992207
14	GANMO	1.013584	43	ITU	0.982957
15	KATAMPE	0.968767	44	EKET	0.987872
16	GWAGWALADA	0.981024	45	IBOM	1
17	LOKOJA	0.983665	46	ALAOJI T/S	0.983379
18	AJAOKUTA	0.985655	47	ALAOJI G/S	1
19	GEREGU G/S	0.985	48	AFAM VI	1
20	GEREGU (NIPP)	0.985	49	AFAM IVV	0.956
21	NEW HAVEN	0.972384	50	PH MAIN	0.997301
22	UGWAJI	0.971883	51	RIVERS (IPP)	1
23	ONITSHA	0.974108	52	TRANS AMADI	1
24	BENIN	0.995877	53	OMOKU	1
25	IHOVBOR (NIPP)	1	54	GEREGU T/S	0.984923
26	OMOTOSHO (NIPP)	1.006	55	OMOTOSHO T/S	0.992817
27	OMOTOSHO I	1	56	OLORUNSOGO T/S	0.980362
28	AYEDE	0.980847	57	SAPELE T/S	0.996489
29	OLORUNSOGO (NIPP)	0.973	58	AFAM T/S	0.979811

Comparison of Violated Bus Voltages before and after Insertion of Facts Devices (STATCOM) as witness in the result for the optimal placement for the bus voltage profile enhancement in the 58 buses, 330 kV Nigeria transmission network is given in Table 4.

Table 4: Violated Buses of 58 Bus 330kv Transmission Line System When Facts Devices Are Inserted

		STATCOM	NO FACT
Bus Number	Bus Name	Voltage V[p.u.]	Voltage V[p.u.]
4	Kano	0.9510	0.9352
5	Gombe	1.0018	0.8979
6	Damaturu	1.0245	0.8942
7	Maiduguri	1.0501	0.8845
8	Yola	0.9956	0.8898
9	Jos	0.9872	0.9331

The results obtained have been presented. The result of the simulation of 58 buses shows that six (6) buses fall off the statutory voltage limit of 0.95 pu to 1.05 pu. These buses are (Kano 0.9352 pu, Gombe 0.8979 pu, Damaturu 0.8942 pu, Maiduguri 0.8845 pu, Yola 0.8898pu and Jos 0.9331 pu). The bus voltage profile showed that the voltage violated buses are in the northern part of Nigeria, this is due to the fact that most of this voltage violated buses are linked with long distance single transmission lines that are radial in nature. These problems of bus voltage violations are exacerbated by lack of power generating units close to the area of violation. The result of continuation power flow on the 58 buses, 330 kV transmission network for the ranking of the vulnerable buses to voltage collapse shows that the most vulnerable bus to voltage collapse is Maiduguri bus. This position is considered as the optimal position for the placement of STATCOM for voltage profile enhancement.

CONCLUSION

The result of simulation of optimal insertion of STATCOM at Maiduguri substation of 58 buses, 330 kV Nigeria transmission network for bus voltage profile enhancement shows that all the bus voltages has been improved and all the violated bus voltages cleared. Maiduguri bus which was the weakest bus was improved from 0.8845 pu to 1.05 pu.

REFERENCES

[1] Sadat, H. (2007). “Power system analysis. Mc-Graw-Hill. New Delhi.

[2] Omorogiuwa, E. and Ogujor A. (2012) Determination of Bus Voltages, Power Losses and Flows in The Nigeria 330kv Integrated Power System. International Journal of Advances in Engineering & Technology

[3] Mehta V. K. and Mehta 2004 “Principles of Power System. S. Chand, New Delhi,

[4] Atuchukwu, J. Aghara, J. And Obi, F. U (2020). Series Compensation Of The Integrated Nigeria‘S 330kv Transmission Grid System. International Journal of Applied Science and Engineering Review ISSN: 2582-6271.

[5] Omorogiuwa, 2011 “Ph.D Thesis on Efficiency Improvement Of The Nigeria 330KV Network Using Facts Device’’, University Of Benin, Benin City 2011

[6] Adepoju G. A. Komolafe, O. A. and Aborisade, D. O. (2011). “Power flow Analysis of the Nigerian Transmission system Incorporating Facts controllers”. *International Journal of Applied Science and Technology.* Vol. 1 No. 5.

[7] Adebisi O. I., Adejumobi I. A., Ogunbowale P. E., & Ade-Ikuesan O. O. (2018). Erformance Improvement of Power System Networks Using Flexible Alternating Current Transmission Systems Devices: The Nigerian 330 kV Electricity Grid as AaCase Study. ECH Journal of Engineering and Technology 12(2), 46-55.

[8] P. Rodriguez, G. Medeiros, A. Luna, M. C. Cavalcanti, and R. Teodorescu, “Safe current injection strategies for a STATCOM under asymmetrical grid faults,” in Proc. IEEE ECCE, 2010, pp. 3929–3935.

[9] Çetin,A (2017)"Design and implementation of a voltage source converter based STATCOM for reactive power compensation and harmonic filtering," Middle East Technical University, Ankara, Turkey

[10] Acha, E., Fuerte-Esquivel, C.R and Ambriz-Perez., H (2014), FACTS: Modeling and Simulation in Power Networks, Wiley,London, U.K.