Voltage Profile Improvement of Nigeria 330kv Power System Using STATCOM Device

ENGR M.O EDEH[1], DR O. A EZECHUKWU[2], F. O ENEMOUH[3]
[1, 2, 3] *Nnamdi Azikiwe University, Awka, Anambra State*

Abstract- The demand for electricity is continuously increasing due to the significant increase in the growing population, urbanization of regions and industrialization in developing countries, hereby making delivering of power at maximum efficiency a top priority. Losses in the system has continued to increase thereby limiting the amount of power delivered to end users. For in instance, the Nigeria electricity grid has a large proportion of transmission and distribution losses and these amounts to a whopping 40%. This study was intended to evaluate possible solutions to problems in the transmission line and instability of power systems. This study was guided by the following objectives: Improve voltage profile at the buses thereby minimizing of technical losses in transmission line Collect network and line parameters data for Nigeria 330kV transmission Network. To Carry out load-flow analysis on the existing Nigerian 330kV transmission grid system to investigate the current operation of the system and also to determine if voltage, frequency and power factor are within the specified limits and to Develop a model and algorithm and carry out simulation of the developed model for technical losses and come up with recommendations to minimize losses with respect to specific improvement to the existing system. The study majorly focused on ways to achieve power system stability by employing FACT devices (STATCOM) on the transmission lines through voltage compensation. Newton Raphson load flow method was used for AC load flow analysis to help calculate the accurately the power flow from one bus to the other and determine the losses at the lines. Some tools were made use of to accurately validate the results gotten by the use of PSAT software validated with MATLAB Simulink software. It was discovered after the analysis that the buses where the STATCOM device were installed experienced improvement in the voltage profile, ensuring stability, reliability and more controllability of the system. In this thesis STATCOM has overcome the challenges of power loss along the transmission lines and has inadvertently helped in the total conservation of energy in the power sector.

I. INTRODUCTION

It has been discovered that due to the increase in consumers of a product results to a considerable increase in the demand of the product. For the purpose of this study the Nigeria population has grown from 180 million to 206 million according to the National population Census (Bureau of Statistics 2019), that is 26 million increases in just a year. This has resulted to an increase in demand for Electrical Power across the nation. This has led to the nation making a conscious effort in investing in Nigeria's Electricity infrastructures through the privatization of the Generation sector (GENCO) and Distribution sector (DISCO). There has been a considerable achievement at the GENCOS where the generation capacity of the country grew from 5000MW to 8000MW from 2015-2020. But the nation is still faced with the problems of power outages in different regions of the country which has resulted in load shading of power in some certain areas. These power outages are mostly caused by the collapse of the transmission station due to voltage drop, technical losses along the transmission lines and poor infrastructures in the system. It has been discovered that the Nigeria electricity grid has recorded 40% losses in the transmission and distribution lines (Matsuno, K. 2012). Power sector of Nigeria has recorded energy losses ranging from 40 – 45% from generating to billing and low access to electricity by the populace (about 36%). Based on the (TCN) annual reports for the 2014 and 2015, the transmission line losses alone were estimated at 9.2% (TCN 2014 and 2015). Although the losses experienced in the power system can be as result of technical or non-technical losses; technical losses is as a result of heat dissipation from the power electrical components example the transformers, conductors, faults on the lines Etc while the non-technical losses may arise from non-payment of used energy by consumers and electricity theft by hoodlums. These losses have made the Generators record high financial loss in the energy generated which the electricity sector has placed the burden of the financial losses experienced on the consumers

With these losses recorded over the years it has become important to evaluate options on how to minimize losses encountered which will enable the system operate at optimum efficiency. These problems encountered is the reason for this research work which tends to solve the existing power loss problems in the Nigeria 330kv Transmission line. The thesis was able to resolve the problem of calculating the actual power transfer and the actual losses experienced in the system by simulating the present 330kv Nigeria transmission line in different software environment, which gave the actual parameters (voltage and current) useful to predict the electrical behaviour of the system and proffer solutions for reducing the losses in order to enhance the transmission line efficiency and maintain the stability in the system. Along these lines of deficiencies in the power distribution, the study was undertaken to perform load-flow analysis on the existing Nigerian 330KV using newton Raphson method of load flow analysis and to verify the current status of the system.

II. MATERIALS AND METHODS

The method/technique adopted in solving load flow problem which involved solving the set of non-linear algebraic equation is Newton Raphson Technique. In carrying out this analysis, the Newton Raphson iterative algorithm was adopted because of its fast convergence and accuracy with a small number of iterations. PSAT/MATLAB program were used to perform the load flow computation to optimize the computing time for corrective action to be taken in order to maintain stable and reliable power supply. From the Load flow result, low voltage buses are selected to integrate FACTS device called STATCOM. On insertion of STATCOM and by conducting load flow results it is seen that the voltages of all the weak buses increased to maintain the system stability.

The STATCOM in this work was used as a compensating device because it supplies both capacitive and the inductive compensation, and is capable of independently controlling the current output over the rated maximum inductive and capacitive range no matter the amount of voltage in the A.C system

The advantage the STATCOM device has over other FACT devices are its quick response time, higher operational flexibility, requires less space and very dynamic under various operating conditions.

III. NETWORK CONSTRUCTION

The electrical network is made up of different essential components which included a generator, the load, transmission line and transformers. For the purpose of this study, it is assumed that all data for the generator, load and transmission line parameters are set in per unit system and MVA base. After data have been collected, suitable software called MATLAB/SIMULINK was selected for the network design. This software offers both graphical, tabular data entry modes and single-line diagram drawing options. The constructed (simulated) 40-bus 330kV Nigerian Transmission network used as the case study is shown in fig 3.1 below. The network consists of 14 generating stations, 27 loads stations and 63 transmission Lines.

The Nigerian transmission system is divided into three 3 subsections geographically: - North, South-East and the South-West. The South-West is connected to the North by one triple circuit line along Jebba and Osogbo while the South-West is connected to the South-East through a transmission line running from Oshogbo to Benin and a double circuit line from Ikeja to Benin (Adebayo, Onohaebi, Apeh, 2007).

- NEWTON-RAPHSON ALGORITHM:

This approach uses iteration to solve the following set of nonlinear algebraic equations (J. J. Grainger, W. D. Stevenson)

$$f_1 = (x_1, x_2, \cdots, x_n) = 0$$
$$f_2 = (x_1, x_2, \cdots, x_n) = 0$$
$$\vdots \quad \vdots \quad \quad \vdots$$
$$f_N = (x_1, x_2, \cdots, x_n) = 0$$

Or $\mathbf{F}(\mathbf{X}) = \mathbf{0}$ (1.0)

Where F represents the set of n nonlinear equations and X is the vector of n unknown state variables.

The essence of the method consists of determining the vector of state variables X by performing a Taylor series expansion of F(x) about an initial estimate $X^{(0)}$

$$\mathbf{F}(\mathbf{X}) = \mathbf{F}\left(\mathbf{X}^{(0)}\right) + \mathbf{J}\left(\mathbf{X}^{(0)}\right)\left(\mathbf{X} - \mathbf{X}^{(0)}\right) + \textbf{higher} - \textbf{order terms} \tag{1.1}$$

Where $\mathbf{J}\left(\mathbf{X}^{(0)}\right)$ is a matrix of first-order partial derivatives of F(X) with respect to X and is called Jacobian which is evaluated at $X=X^{(0)}$. This expansion in equation (1.1) lends itself to a suitable formulation for calculating the vector of state variables X by assuming that $X^{(1)}$ is the value computed by the algorithm at iteration 1 and that this value is sufficiently close to the initial estimate $X^{(0)}$. Based on this premise, all high-order derivatives terms in the expression. (1.1) can be neglected. Hence,

$$\begin{bmatrix} f_1\left(X^{(1)}\right) \\ f_2\left(X^{(1)}\right) \\ \vdots \\ f_n\left(X^{(1)}\right) \end{bmatrix} \approx \begin{bmatrix} f_1\left(X^{(0)}\right) \\ f_2\left(X^{(0)}\right) \\ \vdots \\ f_n\left(X^{(0)}\right) \end{bmatrix} + \begin{bmatrix} \frac{\partial f_1(X)}{\partial x_1} & \frac{\partial f_1(X)}{\partial x_2} & \cdots & \frac{\partial f_1(X)}{\partial x_n} \\ \frac{\partial f_2(X)}{\partial x_1} & \frac{\partial f_2(X)}{\partial x_2} & \cdots & \frac{\partial f_2(X)}{\partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_n(X)}{\partial x_1} & \frac{\partial f_n(X)}{\partial x_2} & \cdots & \frac{\partial f_n(X)}{\partial x_n} \end{bmatrix}_{X=X^{(0)}} \begin{bmatrix} X_1^{(1)} - X_1^{(0)} \\ X_2^{(1)} - X_2^{(0)} \\ \vdots \\ X_n^{(1)} - X_n^{(0)} \end{bmatrix} \tag{1.2}$$

$$\underbrace{\qquad\qquad}_{\mathbf{F}\left(\mathbf{X}^{(1)}\right)} \quad \underbrace{\qquad\qquad}_{\mathbf{F}\left(\mathbf{X}^{(0)}\right)}$$

$$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad}_{\mathbf{J}\left(\mathbf{X}^{(0)}\right)}$$

$$\underbrace{\qquad\qquad}_{\mathbf{X}^{(1)} - \mathbf{X}^{(0)}}$$

In compact form, and generalizing the above expression for the case of
iteration (i),

$$\mathbf{F}\left(\mathbf{X}^{(i)}\right) \approx \mathbf{F}\left(\mathbf{X}^{(i-1)}\right) + \mathbf{J}\left(\mathbf{X}^{(i-1)}\right)\left(\mathbf{X}^{(i)} - \mathbf{X}^{(i-1)}\right) \tag{1.3}$$

Where i = 1, 2 ……. Furthermore, if it is assumed that $X^{(i)}$ is sufficiently close to the solution $X^{(*)}$

Then $\mathbf{F}\left(\mathbf{X}^{(\mathbf{i})}\right) \approx \mathbf{F}\left(\mathbf{X}^{(*)}\right) = \mathbf{0}$

Hence the equation (1.0) can be written as

$$\mathbf{F}\left(\mathbf{X}^{(i-1)}\right) + \mathbf{J}\left(\mathbf{X}^{(i-1)}\right)\left(\mathbf{X}^{(i)} - \mathbf{X}^{(i-1)}\right) = 0 \tag{1.4}$$

Now solving the equation (1.1) for $X^{(i)}$,

$$\mathbf{X}^{(\mathbf{i})} = \mathbf{X}^{(\mathbf{i-1})} - \mathbf{J}^{-1}\left(\mathbf{X}^{(\mathbf{i-1})}\right)\mathbf{F}\left(\mathbf{X}^{(\mathbf{i-1})}\right) \tag{1.5}$$

The iterative solution can be presented as a function of the correction vector

$$\Delta\mathbf{X}^{(\mathbf{i})} = \mathbf{X}^{(\mathbf{i})} - \mathbf{X}^{(\mathbf{i-1})},$$
$$\Delta\mathbf{X}^{(\mathbf{i})} = -\mathbf{J}^{-1}\left(\mathbf{X}^{(\mathbf{i-1})}\right)\mathbf{F}\left(\mathbf{X}^{(\mathbf{i-1})}\right) \tag{1.6}$$

and the initial realised estimates are updated using the following relations:

$$\mathbf{X}^{(\mathbf{i})} = \mathbf{X}^{(\mathbf{i-1})} + \Delta\mathbf{X}^{(\mathbf{i})} \tag{1.7}$$

The calculation is repeated as many times as required using the most up-to-date values of X in the above equation. This is done until mismatches $\Delta\mathbf{X}$ are within a prescribed small tolerance Similarly, analogy can be made for power flow equation as described above as the power flow equation is also a nonlinear algebraic equation consists of variables nodal voltage magnitudes V and phase angles θ. Thus, the power mismatches equations $\Delta\mathbf{P}$ and ΔQ are expanded around a base point $\left(\boldsymbol{\theta}^{(\mathbf{0})}, \mathbf{V}^{(\mathbf{0})}\right)$ and hence, the power flow Newton-Raphson algorithm is expressed by the following relationship

$$\begin{bmatrix}\mathbf{\Delta P}\\ \mathbf{\Delta Q}\end{bmatrix}^{(\mathbf{i})} = \begin{bmatrix}\dfrac{\partial \mathbf{P}}{\partial \boldsymbol{\theta}} & \dfrac{\partial \mathbf{P}}{\partial \mathbf{V}}\mathbf{V}\\ \dfrac{\partial \mathbf{Q}}{\partial \boldsymbol{\theta}} & \dfrac{\partial \mathbf{Q}}{\partial \mathbf{V}}\mathbf{V}\end{bmatrix}^{(\mathbf{i})} \begin{bmatrix}\mathbf{\Delta \boldsymbol{\theta}}\\ \dfrac{\mathbf{\Delta V}}{\mathbf{V}}\end{bmatrix} \tag{1.8}$$

Furthermore, this can be written as:

$$\begin{bmatrix}\mathbf{\Delta P}\\ \mathbf{\Delta Q}\end{bmatrix} = \begin{bmatrix}\mathbf{J_1} & \mathbf{J_2}\\ \mathbf{J_3} & \mathbf{J_4}\end{bmatrix} \begin{bmatrix}\mathbf{\Delta \boldsymbol{\theta}}\\ \dfrac{\mathbf{\Delta V}}{\mathbf{V}}\end{bmatrix} \tag{1.9}$$

where J_1, J_2, J_3 and J_4 constitutes the Jacobian matrix, each element of the order of (nb-1) x (nb-1).
nb= total number of buses

Thus, Jacobian matrix are written as:

$$\mathbf{J_1} = \frac{\partial \mathbf{P_k}}{\partial \boldsymbol{\theta}_\mathbf{m}}, \qquad \mathbf{J_2} = \frac{\partial \mathbf{P_k}}{\partial \mathbf{V_m}}\mathbf{V}_m \tag{1.10}$$

$$\mathbf{J_3} = \frac{\partial \mathbf{Q_k}}{\partial \boldsymbol{\theta}_\mathbf{m}}, \qquad \mathbf{J_4} = \frac{\partial \mathbf{Q_k}}{\partial \mathbf{V_m}}\mathbf{V_m} \tag{1.11}$$

where k = 1,2, ……,nb
and m = 1,2, ………,nb
but omitting the slack bus entries.
For clarity it is important to indicate that the correction terms $\mathbf{\Delta V_m}$ are divided by $\mathbf{V_m}$ to compensate for the fact that Jacobian terms $\left(\partial \mathbf{P_k}/\partial \mathbf{V_m}\right)\mathbf{V_m}$ **and** $\left(\partial \mathbf{Q_k}/\partial \mathbf{V_m}\right)\mathbf{V_m}$ are multiplied by $\mathbf{V_m}$. It is shown in the derivative terms given below that this artifice yields useful simplifying calculations. Consider the *l*-th elements connected between buses k and m for which self and mutual Jacobian terms are given below:

For $k \neq m$:

$$\frac{\partial P_{k,l}}{\partial \theta_{m,l}} = V_k V_m [G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)] \tag{1.12}$$

$$\frac{\partial P_{k,l}}{\partial V_{m,l}} V_{m,l} = V_k V_m [G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)] \tag{1.13}$$

$$\frac{\partial Q_{k,l}}{\partial \theta_{m,l}} = -\frac{\partial P_{k,l}}{\partial V_{m,l}} V_{m,l} \tag{1.14}$$

$$\frac{\partial Q_{k,l}}{\partial V_{m,l}} V_{m,l} = \frac{\partial P_{k,l}}{\partial V_{m,l}} \tag{1.15}$$

For $k = m$

$$\frac{\partial P_{k,l}}{\partial \theta_{k,l}} = -Q_k^{cal} - V_k^2 B_{kk} \tag{1.16}$$

$$\frac{\partial P_{k,l}}{\partial V_{k,l}} V_{k,l} = P_k^{cal} + V_k^2 G_{kk} \tag{1.17}$$

$$\frac{\partial Q_{k,l}}{\partial \theta_{k,l}} = P_k^{cal} - V_k^2 G_{kk} \tag{1.18}$$

$$\frac{\partial Q_{k,l}}{\partial V_{k,l}} V_{k,l} = Q_k^{cal} - V_k^2 B_{kk} \tag{1.19}$$

In general, for a bus k containing n transmission elements *l*, the bus self-elements take the following form :

$$\frac{\partial P_k}{\partial \theta_k} = \sum_{l=1}^{n} \frac{\partial P_{k,l}}{\partial \theta_{k,l}} \tag{1.20}$$

$$\frac{\partial P_k}{\partial V_k} V_k = \sum_{l=1}^{n} \frac{\partial P_{k,l}}{\partial V_{k,l}} V_{k,l} \tag{1.21}$$

$$\frac{\partial Q_k}{\partial \theta_k} = \sum_{l=1}^{n} \frac{\partial Q_{k,l}}{\partial \theta_{k,l}} \tag{1.22}$$

$$\frac{\partial Q_k}{\partial V_k} V_k = \sum_{l=1}^{n} \frac{\partial Q_{k,l}}{\partial V_{k,l}} V_{k,l} \tag{1.23}$$

After the convergence of the power flow solution, we get the final value of state variables i.e., voltage magnitudes and phase angles have been calculated. Then active and reactive power flows throughout the transmission system are determined quite straightforwardly.

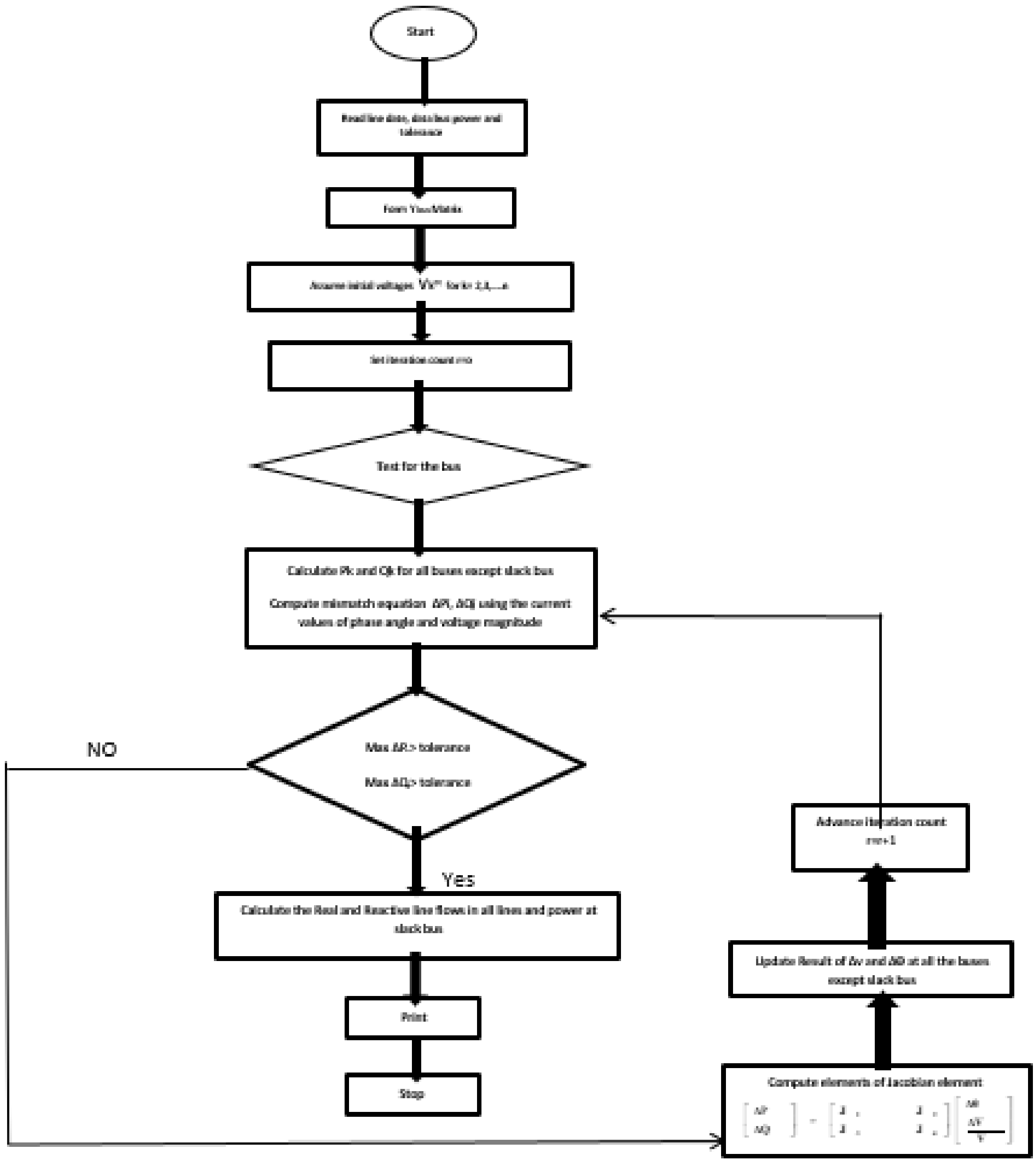

Fig 1.1a Newton Raphson Algorithm method for load flow without STATCOM

- Power flow model with STATCOM:

The power flow equations for the STATCOM are derived below from first principle and assuming the following voltage source representations.

$$E_{rR} = V_{rR}\,(\cos\delta_{rR} + j\sin\delta_{rR}) \qquad (1.24)$$

Based on the shunt connection shown in figure 3.6a, the following may be written as

$$S_{vR} = V_{vR}\, I^*_{vR} = V_{vR}\, Y^*_{vR}(V^*_{vR} - V^*_{K}) \qquad (1.25)$$

The simplified model of active and reactive power equations are stated, for a converter and bus K, respectively:

$P_{vR} = V^2_{vR}G_{vR} + V_{vR}\ V_k\ [G_{vR}\cos\ (\delta_{vR} - \theta_k) + B_{vR}\sin\ (\delta_{vR} - \theta_k)],$ (1.26)

$Q_{vR} = -V^2_{vR}B_{vR} + V_{vR}\ V_k\ [G_{vR}\sin\ (\delta_{vR} - \theta_k) - B_{vR}\cos\ (\delta_{vR} - \theta_k)],$ (1.27)

$P_k = V^2_kG_{vR} + V_k\ V_{vR}\ [G_{vR}\cos\ (\theta_k - \delta_{vR}) + B_{vR}\sin\ (\theta_k - \delta_{vR})],$ (1.28)

$Q_k = -V^2_kB_{vR} + V_k\ V_{vR}\ [G_{vR}\sin\ (\theta_k - \delta_{vR}) - B_{vR}\cos\ (\theta_k - \delta_{vR})].$ (1.29)

$$\begin{pmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{pmatrix} = \begin{pmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k V_k}{\partial V_k} & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k V_{vR}}{\partial V_{vR}} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k V_k}{\partial V_k} & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k V_{vR}}{\partial V_{vR}} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR} V_k}{\partial V_k} & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial PvRVvR}{\partial V_{vR}} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR} V_k}{\partial V_k} & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial QvRVvR}{\partial V_{vR}} \end{pmatrix} \begin{pmatrix} \Delta\theta_k \\ \frac{\Delta V_k}{V_k} \\ \Delta\delta_{vR} \\ \frac{\Delta V_{vR}}{VvR} \end{pmatrix}$$

(1.30)

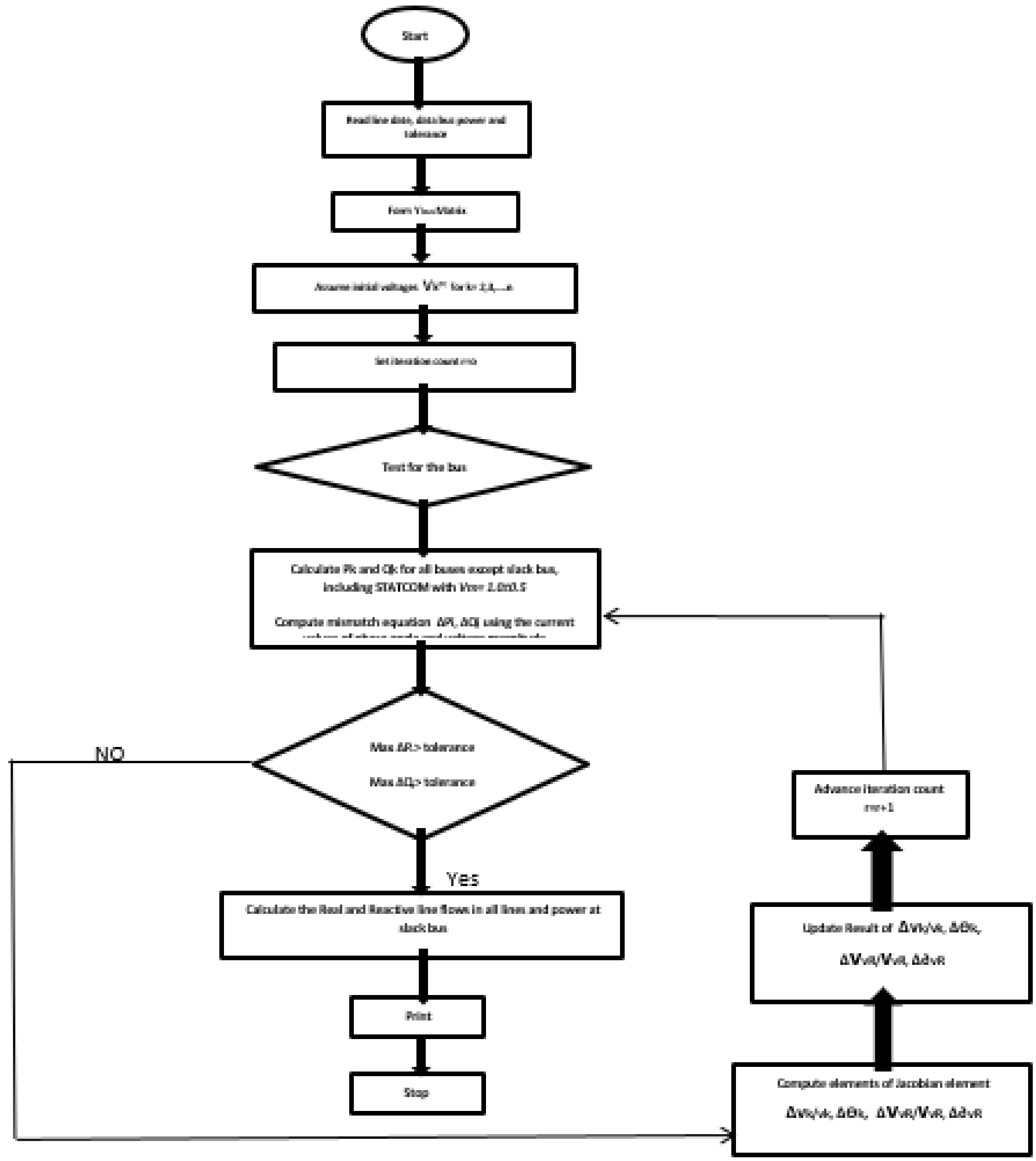

Fig 1.1b Newton Raphson Algorithm Method for Load Flow with Statcom

IV. RESULTS

The Network diagram of the Nigeria Transmission System shown below consist of 14 generating stations, 27 load stations and 63 transmission lines. During the process of simulation of the Nigerian Grid System with the use of PSAT software, the following results in Table 3.1 were obtained when STATCOM was not inserted at the buses.

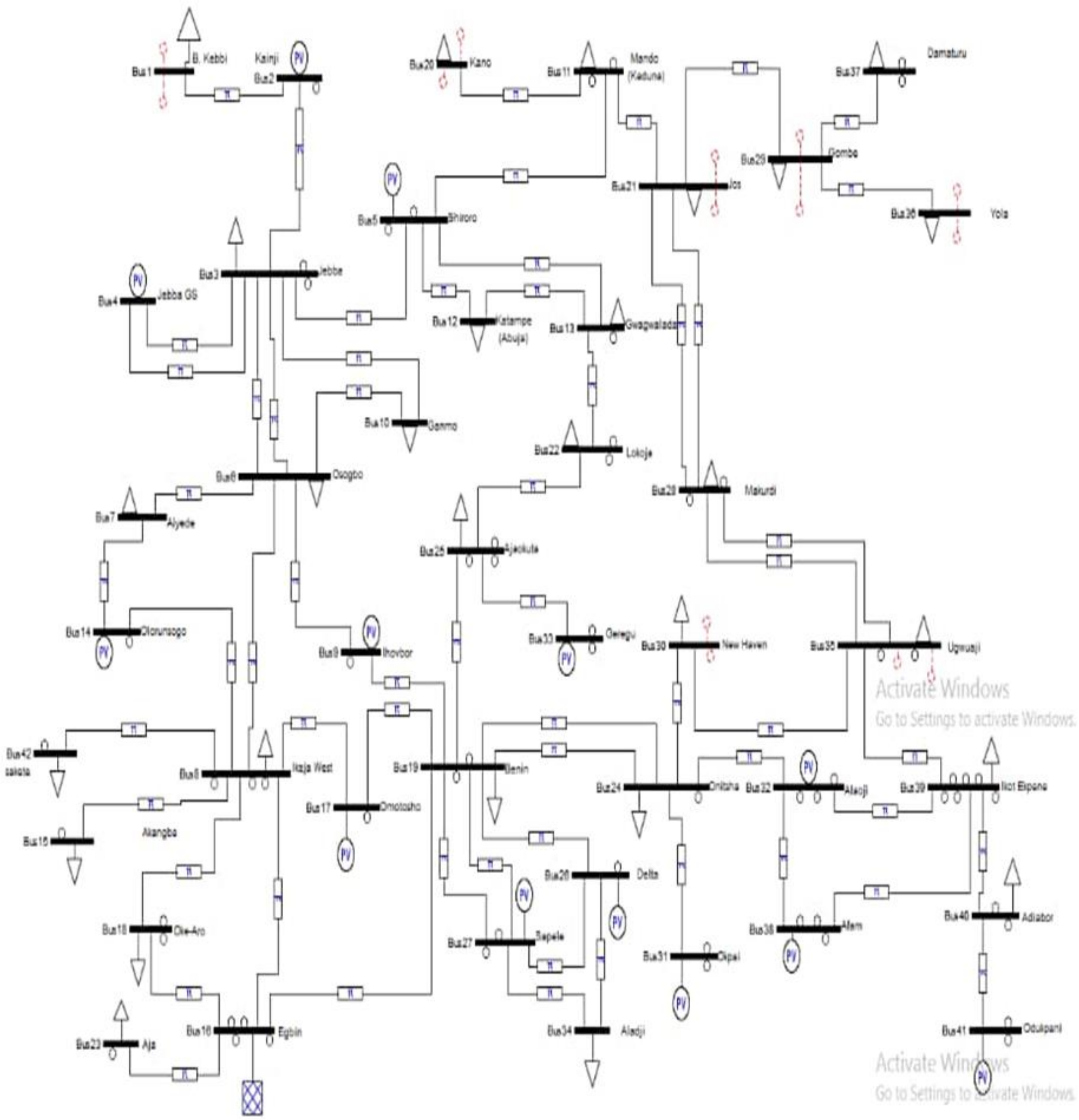

Fig 3.1 Line diagram of 40 bus Nigeria grid system without STATCOM drawn with PSAT software

TABLE 3.1: POWER FLOW SIMULATION RESULT FOR NIGERIA 40 BUS GRID SYSTEM

Bus Number	Bus Name	V [kV]	Phase [rad]	P gen [MW]	Q gen [MVar]	P load [MW]	Q load [MVar]
Bus1	B. Kebbi	304.6824	-0.05702059	-6.66E-14	-2.00E-13	162	122
Bus10	Ganmo	332.655225	0.002520663	-8.88E-14	1.69E-12	100	75
Bus11	Mando	316.402618	-0.19781192	6.92E-11	8.42E-12	142	107
Bus12	Katampe	308.854983	-0.2097121	6.66E-13	2.75E-12	303	227
Bus13	Gwagwalada	312.193636	-0.20034983	7.11E-13	3.15E-12	220	165
Bus14	Olorunsogo	317.13	0.008080513	296	-73.8410781	0	0

Bus15	Akangba	314.950965	-0.06791247	5.33E-13	4.44E-13	203	152
Bus16	Egbin	340.23	0	1071.38924	836.975116	0	0
Bus17	Omotosho	330	0.020007391	211	- 98.2210824	0	0
Bus18	Oke-Aro	322.279012	-0.04658682	9.99E-13	5.83E-12	120	90
Bus19	Benin	333.726229	-0.07799458	6.37E-12	1.12E-11	144	108
Bus2	Kainji	330	0.100870636	715	- 232.998959	0	0
Bus20	Kano	306.573581	-0.20433322	3.62E-12	2.11E-12	194	146
Bus21	Jos	297.590699	-0.32449004	-1.30E-09	1.33E-10	72	54
Bus22	Lokoja	318.355453	-0.1805935	2.66E-13	-1.55E-13	120	90
Bus23	Aja	338.908384	-0.0040586	-4.22E-13	-3.76E-12	115	86
Bus24	Onitsha	328.379487	-0.03416918	1.51E-11	6.76E-12	100	75
Bus25	Ajaokuta	323.66228	-0.1560263	5.55E-13	3.85E-12	120	90
Bus26	Delta	333.96	-0.07996738	105	71.1619967	0	0
Bus27	Sapele	333.96	-0.07582492	115	5.86023366	0	0
Bus28	Makurdi	302.39383	-0.2496001	1.59E-11	2.14E-11	160	120
Bus29	Gombe	254.346736	-0.61870817	8.74E-10	8.36E-11	97.4616554	53.835962
Bus3	Jebba	337.884479	0.032806018	2.98E-12	3.09E-11	260	195
Bus30	New Haven	307.434716	-0.13936575	2.18E-11	4.62E-12	196	147
Bus31	Okpai	333.96	0.003631633	438	121.694677	0	0
Bus32	Alaoji	330	0.028267986	65	42.8241485	0	0
Bus33	Geregu	330	-0.14204092	56	64.8467285	0	0
Bus34	Aladji	330.919411	-0.08901068	-4.00E-13	2.26E-12	210	158
Bus35	Ugwuaji	306.886743	-0.14493302	1.26E-11	9.95E-12	175	131
Bus36	Yola	246.206954	-0.67648269	7.78E-10	4.69E-10	86.9746673	47.836067
Bus37	Damaturu	247.823425	-0.67675305	2.93E-10	3.30E-10	83.7144563	38.7730113
Bus38	Afam	330.99	0.045482589	446	75.1730973	0	0
Bus39	Ikot Ekpene	324.444706	0.005563141	4.11E-12	-4.77E-12	165	127
Bus4	Jebba GS	339.9	0.038013445	506	455.664525	0	0
Bus40	Adiabor	326.414703	0.030506328	1.44E-13	2.05E-12	90	68
Bus41	Odukpani	328.02	0.041167324	223	70.5789155	0	0
Bus5	Shiroro	330	-0.12163527	554	340.136276	0	0
Bus6	Osogbo	331.178664	-0.01110144	5.55E-13	2.49E-12	127	95
Bus7	Aiyede	317.220712	-0.02832183	1.78E-13	1.04E-12	174	131
Bus8	Ikeja West	318.219765	-0.05732726	3.55E-13	-5.15E-12	847	635
Bus9	Ihovbor	330	-0.00912092	93	- 120.236801	0	0

In figure 4.1, A Bus operating range is between 0.95 to 1.05 pu. The buses that fall within that category are Kebbi, Kano, Jos, Makurdi, Gombe, New Haven, Ugwuaji, Yola and Damaturu. These listed bus fall below the operating voltage. The average voltage is 0.9742 per-unit.

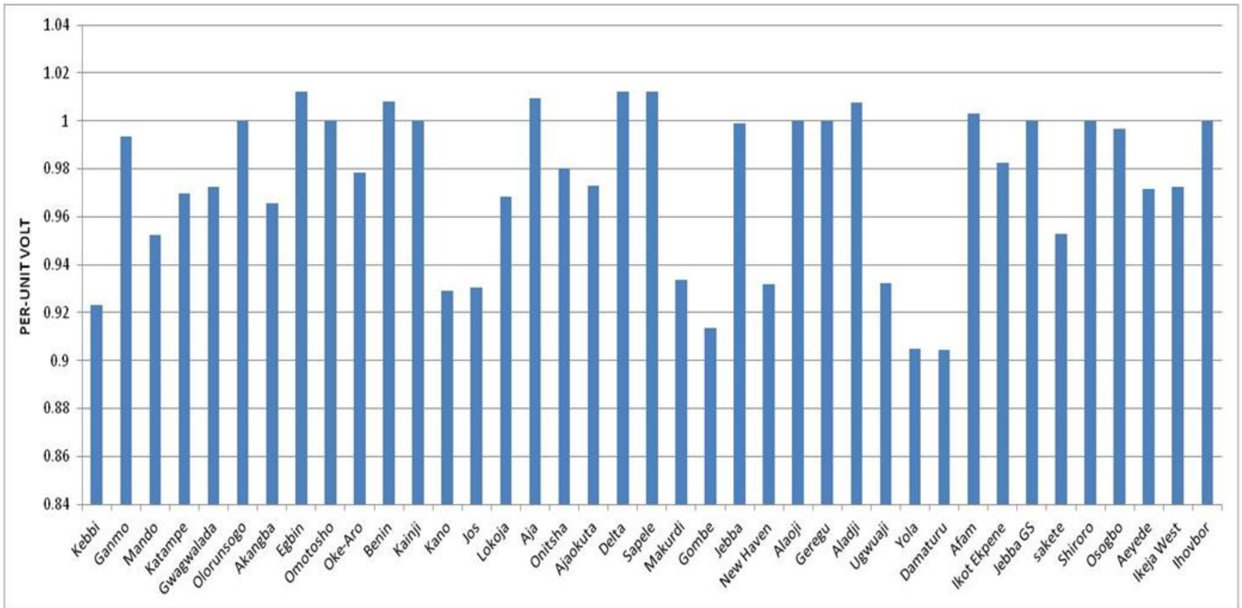

FIGURE 3.1: A bar chart of the operating voltage of Nigeria bus grid system

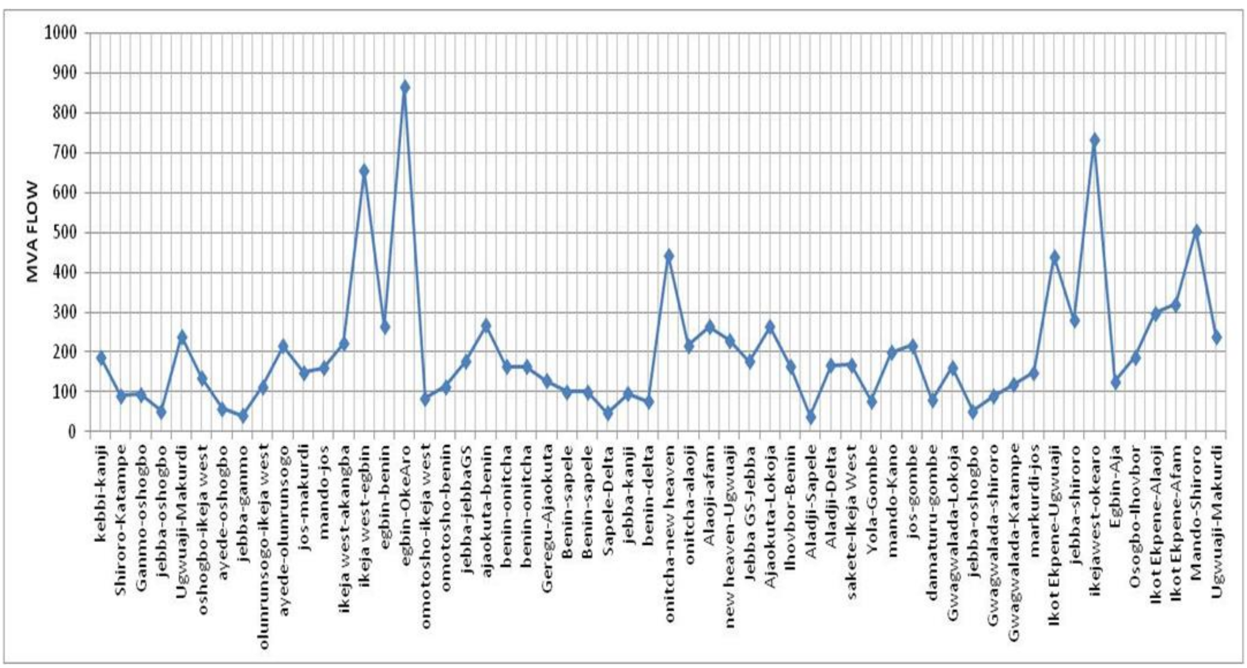

Figure 3.2: MVA loading of the transmission line

The maximum limit on the transmission line is 777.3MVA. The transmission line that meet between 80% to 100% of its limit are Ikeja West-egbin, Egbin-OkeAro and Ikejawest-okearo.

TABLE 3.2: LIST OF BUSES THAT FELL BELOW THE OPERATING VOLTAGE

Bus1	Bus Name	Voltage (KV)	Load (MW)	Load (Mvar)
Bus12	B. Kebbi	304.57358087	162	122
Bus13	Katampe	308.8549825	303	227
Bus20	Gwagwalada	312.193636	220	165
Bus21	Kano	306.57358087	194	146
Bus28	Jos	297.5906992	72	54
Bus29	Makurdi	302.3938295	160	120
Bus30	Gombe	254.3467362	97.46165537	53.83596201
Bus35	New Haven	307.4347106	196	147
Bus36	Ugwuaji	306.8867434	175	131
Bus37	Yola	246.2069539	86.97466734	47.83606704
	Damaturu	247.823425	83.71445629	38.77301134

Figure 3.3 shows the effect of the STATCOM connected the bus at Kebbi. The per-unit voltage of the bus at Kebbi increased to from 0.92328PU to 1.0138PU. The connection of STATCOM to the lind led to the increase of the average voltage from 0.9742PU to 0.9766PU which is about 0.25% increase.

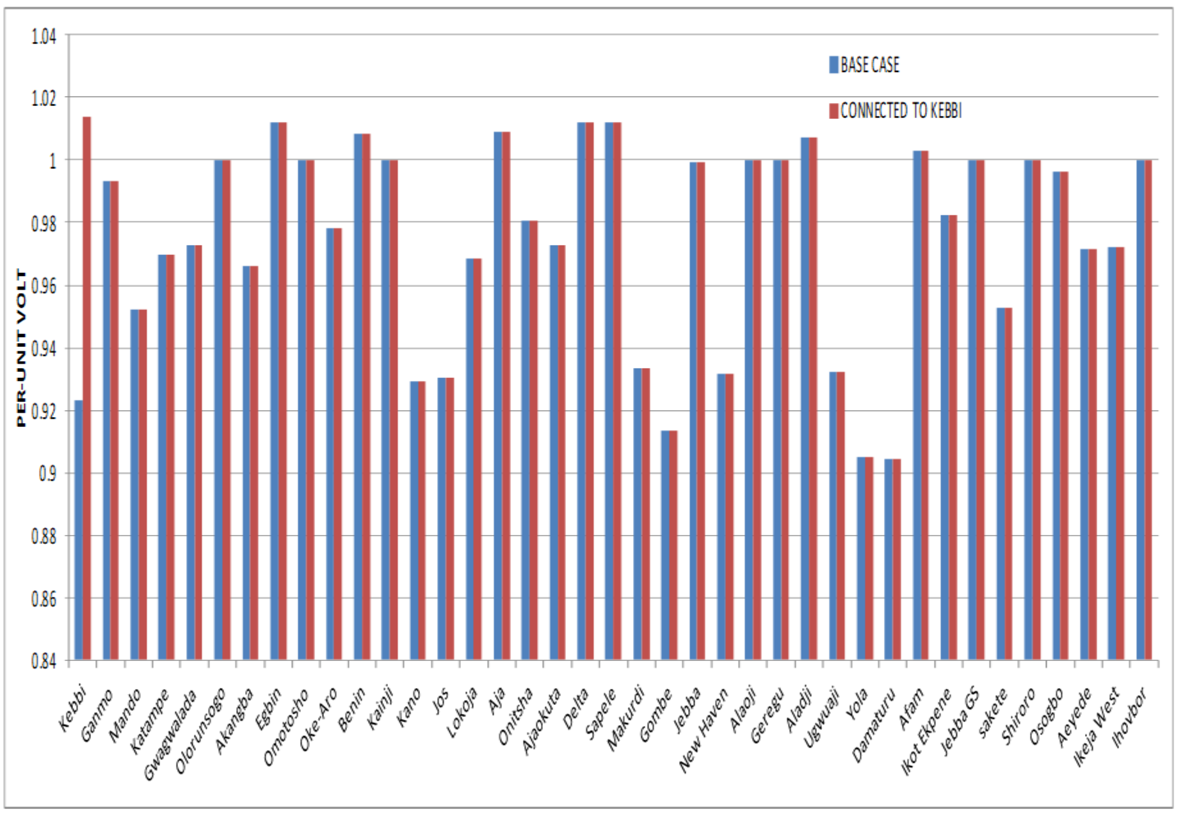

Figure 3.4: When the STATCOM Was Connected to Kebbi

Figure 3.4 shows the MVA flow on the transmission line. In this figure, it is observed that there is no significant change on the power flow on the transmission line. The total loss reduced from 127.02 MW to 126.3MW which is about 0.57%.

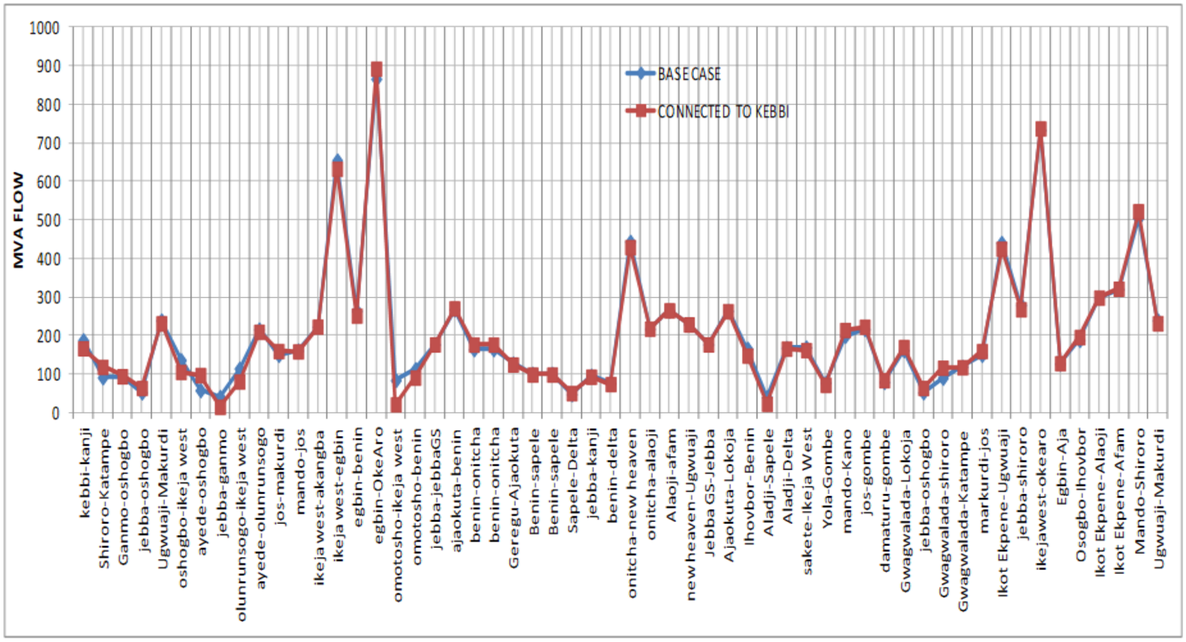

Figure 3.4: MVA loading of the when statcom is connected to the bus of kebbi and kano

Figure 3.4 shows the effect of the STATCOM connected to the bus at kebbi and Kano. The per-unit voltage of the bus at kebbi and kano increased from 0.92328PU to 1.0138PU and 0.92901PU to 1.038 respectively. The connections of the STATCOM to the affected buses led to the increase of the average voltage from 0.9742PU to 0.990951PU which is about 1.63% increase.

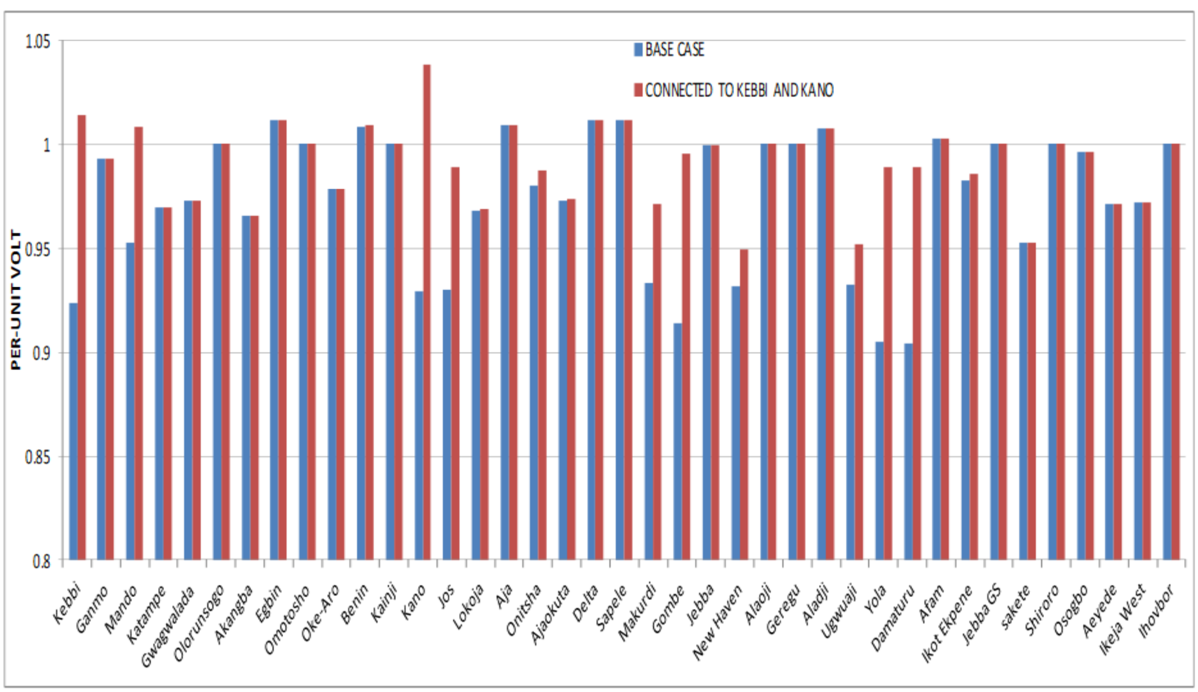

Figure 5: When the STATCOM was connected to kebbi and Kano.

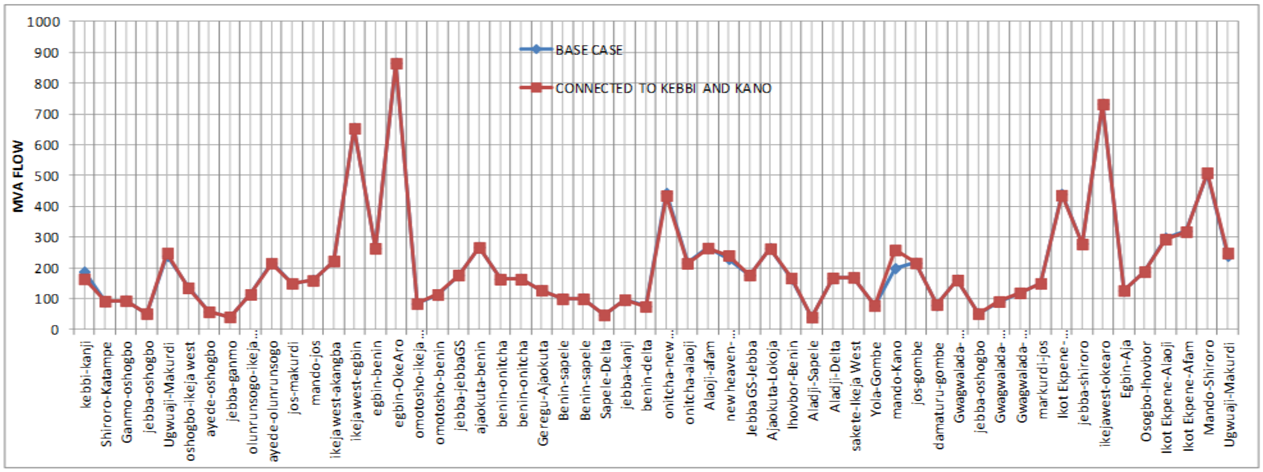

Figure 3.5 shows the MVA flow on the transmission line. In figure 4.5, it is observed that there is no significant change on the power flow on the transmission line. The total loss reduced from 127.02 MW to 123.53MW which is about 2.83%.

Figure 3.6 shows the effect of the STATCOM connected to the bus at Kebbi and Kano and New Haven. The per-unit voltage of the bus at Kebbi, Kebbi and New Haven increased from 0.92328PU to 1.0138PU, 0.92901PU to 1.0242 and 0.93162 to 1.018 respectively. The connections of the STATCOM to the affected buses led to the increase of the average voltage from 0.9742PU to 1.0051PU which is about 3.161% increase.

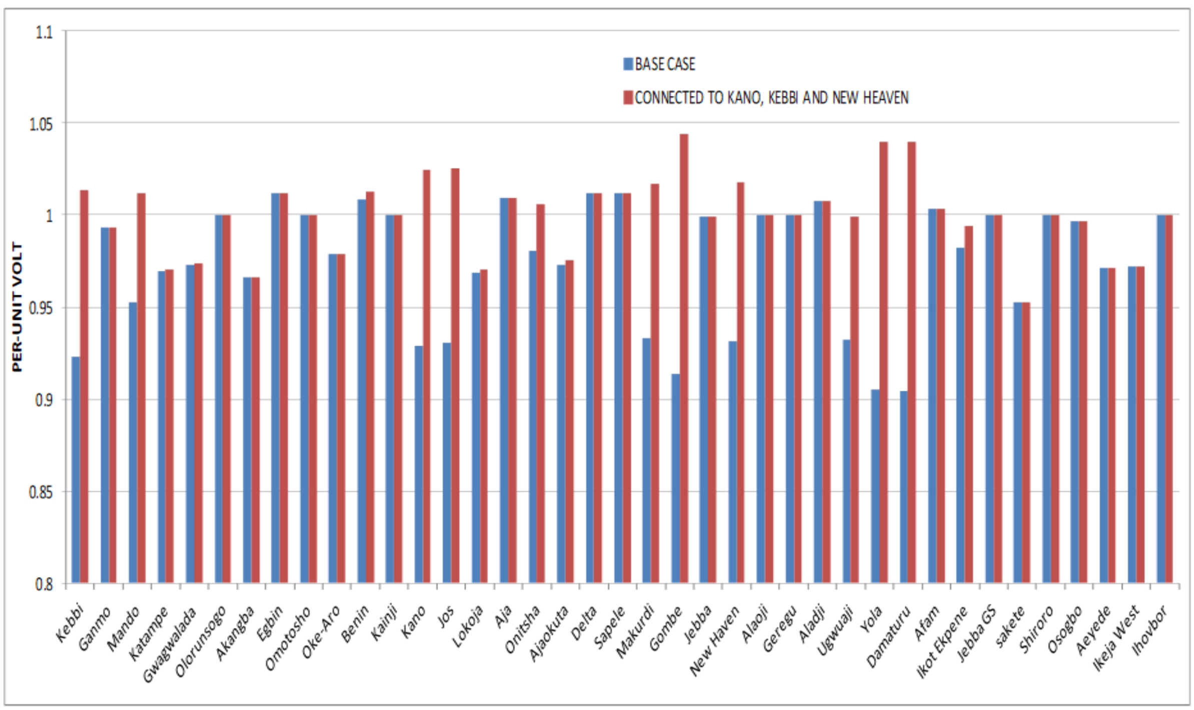

Figure 3.6: When the STATCOM was connected to kebbi and Kano and New Heaven.

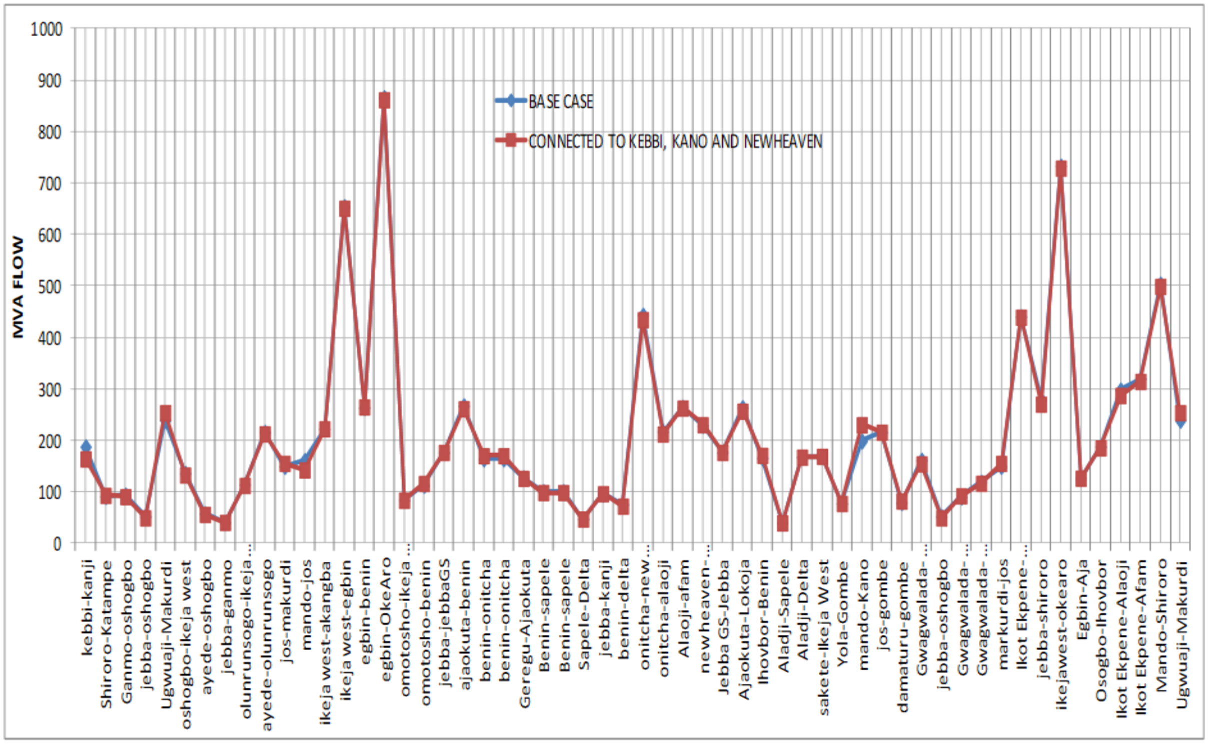

Figure 3.7 shows the MVA flow on the transmission line when the STATCOM was connected to Kebbi, Kano and New Haven. In figure 6, it is observed that there is no significant change on the power flow on the transmission line. The total loss reduced from 127.02 MW to 119.27MW which is about 6.53%.

Table 3.2: Power Simulation Result of 40 bus Nigeria Bus Grid System with STATACOM

Bus	V	phase	P gen	Q gen	P load	Q load
	[kV]	[rad]	[MW]	[MVar]	[MW]	[MVar]
Bus1	334.554	-0.0588	-6.7E-14	95.80499	162	122
Bus10	333.1712	-0.00339	2.89E-13	-3.1E-13	100	75
Bus11	322.9873	-0.21024	2.18E-12	2.1E-11	142	107
Bus12	323.9494	-0.21905	1.11E-12	9.33E-13	303	227
Bus13	330	-0.21142	1.2E-12	339.4753	220	165
Bus14	317.13	0.005618	296	-148.468	0	0
Bus15	330	-0.07248	-3.1E-13	400.5384	203	152
Bus16	340.23	0	1092.131	521.2171	0	0
Bus17	330	0.015467	211	-131.364	0	0
Bus18	328.3931	-0.0486	-1.5E-12	-5.8E-12	120	90
Bus19	334.9987	-0.08602	-5.3E-13	9.88E-12	144	108
Bus2	330	0.094755	715	-354.966	0	0
Bus20	342.54	-0.21666	4.88E-13	8.88E-14	194	146
Bus21	330	-0.34056	-3.4E-12	31.77076	72	54
Bus22	328.5981	-0.19009	1.58E-12	4.56E-12	120	90
Bus23	338.9084	-0.00406	-1.2E-12	-6.7E-12	115	86
Bus24	330.0758	-0.04854	-5.6E-11	1.69E-11	100	75
Bus25	329.5965	-0.1649	6.66E-13	6.11E-13	120	90

Bus26	333.96	-0.08751	105	59.13471	0	0
Bus27	333.96	-0.08336	115	-20.5347	0	0
Bus28	322.0999	-0.26598	2.05E-10	4.78E-11	160	120
Bus29	330	-0.58052	-5.6E-13	83.23824	105	58
Bus3	337.9479	0.026494	-4E-13	-2.1E-11	260	195
Bus30	335.94	-0.15615	-1.3E-10	7.69E-11	196	147
Bus31	333.96	-0.01033	438	64.38568	0	0
Bus32	330	0.012147	65	7.720809	0	0
Bus33	330	-0.14972	56	-1.49738	0	0
Bus34	330.9194	-0.09655	1.33E-13	9.77E-13	210	158
Bus35	315.8789	-0.162	6.94E-11	1.38E-10	175	131
Bus36	324.1385	-0.6198	-8.9E-14	-2.9E-13	100	55
Bus37	325.7339	-0.61958	1.55E-13	6.11E-14	95	44
Bus38	330.99	0.029229	446	57.45154	0	0
Bus39	325.5935	-0.01132	-4E-11	7.22E-12	165	127
Bus4	339.9	0.031722	506	439.3944	0	0
Bus40	326.6544	0.013849	8.88E-13	8.33E-12	90	68
Bus41	328.02	0.024589	223	55.83742	0	0
Bus5	330	-0.13105	554	-57.693	0	0
Bus6	332.2339	-0.01651	1.44E-12	6.87E-12	127	95
Bus7	317.7126	-0.03209	-5.1E-13	3.8E-12	174	131
Bus8	326.0926	-0.05975	3.55E-12	2.63E-11	847	635
Bus9	330	-0.01545	93	-130.231	0	0

V. DISCUSSION

In this work, an attempt has been made to simulate power system response to reactive power compensation in Nigerian Power system using MATLAB/PSAT. Since the electrical power system is dynamic in nature, and because of the complexity of the non-linear loads, different methods of instantaneous quantities need to be studied to predict discrepancies between the simulation and the actual data.

The Load flow studies are carried out with and without STATCOM and Newton-Raphson method is used in Load flow. The results indicated an overall improvement in network voltage profile. And in general, more reactive Power was available in the network with STATCOM installed than without and the generators increase its share of reactive power absorption when compared with the base case. The result of the load flow simulation with and without STATCOM proves that STATCOM minimizes losses and improves the stability of a System.

STATCOM (Static Synchronous Compensator) is an intergral device in the flexible A.C Transmission system. Its dynamism has made it a third generation of Var compensation device after FC, MCR, and TCR model of static Var Compensator. Its reactive current can be flexibly controlled and compensate reactive power for system automatically. It solves problem of harmonics interference in switching parallel capacitor banks. STATCOM possess far more superior advantages over other FACT devices in terms of speed response, voltage stabilization, power loss and harmonics reduction/increase in both transmission capacity and limit to transient voltage. It was observed that with STATCOM reactive power was compensated and losses reduced along the line. The THD analysis was done and can be seen that the losses in the grid side was much lower than in the load side.

In this thesis comprehensive study of reactive power compensation has been done by using shunt connected FACTS device i.e. STATCOM. The need to study reactive power compensation by STATCOM was studied and the following conclusions was arrived at:

1. Reactive power compensation is been used nowadays to increase the transmittable power in AC power systems. Fixed or mechanically switched capacitors and reactors are being employed to increase the steady state power transmission by controlling the voltage along the lines. However other compensating device find it difficult to provide high speed control. Furthermore, control cannot be initiated frequently because mechanical devices wear out quickly compared to static devices.
2. STATCOM is a controlled reactive-power source. It supplies the required reactive power generation and absorption all by the means of electronic processing of voltage and current waveforms in a voltage source converter (VSC).
3. STATCOM has number of advantages over conventional methods of compensation viz; quick response time, less space requirement, optimum voltage platform, higher operational flexibility and excellent dynamic characteristics under various operating conditions.
4. STATCOM is better device then SVC. For country like Pakistan having large interconnected system the SVC is better option from economic point of view but due to other aspects like stability margin, voltage improvement and power system performance, STATCOM is preferred.

VI. RECOMMENDATIONS

Over twenty journal papers and textbooks were reviewed in this thesis, the discussion of the papers were centered on loss reductions in transmission system through allocations of shunt capacitor. This research work was carried out on conditions of non-varying load, hence further studies need to be carried out to ascertain the performance of the network as the load varies dynamically.

CONTRIBUTION TO KNOWLEDGE

1. STATCOM should be implemented in Industrial plants, using arc furnaces that operate with large random peaks of reactive power demand and causing undesirable effects in the plant itself and in the ac power network.
2. The supplier of electric power charges the consumer also for reactive power demand so STATCOM should be implemented in distribution system applications to reduce the reactive power demand.
3. The future work should include introduction of the development of transient and steady state models to improve the, transient stability margin and steady state power transfer capacity respectively.
4. Current source convertor based STATCOM be further studied for improvement in the performance of STATCOM for various applications.

REFERENCES

[1] Adebayo H. Hazan-Nejad, Onge, C. M. Coordinating the DC Power Injections of a Multiterminal HVDC System for Dynamic Control of AC Line Flows, copyright 1985 IEEE, 85 SM 486-6, IEE/PES Summer Meeting, Vancouver, B. C., Canada, July 14-19, 2010

[2] Aditya Jayam Prabhakar (2008) "Application of STATCOM for improved Dynamic Performance of Wind farms in a Power Grid" Missouri University of Science and technology . Master's Thesis. Aided Distribution Planning" IE (I) Journal-EL, Vol. 80, PP 70-75,

[3] Afsari M., Singh S. P., Raju G. S., (2010) An Efficient Load Flow for Radial Distribution Network,

[4] Annapurna Bhargava, Vinay Pant and Biswarup Das "An Improved Power Flow Analysis Technique with STATCOM" IEEE conf. pp.1 2006 Applications" IEEE Transaction on power systems, 1988.

[5] Cho G.C., Choi N.S., Rim C.T., and Cho G.H., "Modelling, Analysis and Control of STATIC VAR Compensator using three level inverters", IEEE, Ind. Society, Annual Meet, pp. 837-843, 1992.

[6] Chong Han, Member, IEEE, Alex Q. Huang, Fellow, IEEE, Yu Liu, Student Member, IEEE and Bin Chen, Student Member, IEEE" A Generalized Control Strategy of Per-Phase DC Voltage Balancing for Cascaded Multilevel Converter-based STATCOM" 1-4244-0655-2/07/$20.00©2007 IEEE.

[7] Civanlar, S., Grainger, J. J., Yin.H. and Lee. S.S.H (2012) Volt/var Control on Distributions Systems with Lateral Branches Using Shunt

[8] Douglas J., Gotham, Heydt G.J. "Power flow control & powerflow studies with facts devices", IEEE Transactions on Power Systems. Vol.13, No.1, February, 1998

[9] Dussan Povh Siemens AG "Modeling of FACTS in Power system Studies" IEEE.

[10] Edris, A, (2000) "FACTS technology development: an update", Power Engineering Review, IEEE, Vol.20, Issue 3,, pp: 599 - 627

[11] Edward Song, Student Member, IEEE, Alan F. Lynch, Member, IEEE, and Venkata Dinavahi, Member, IEEE "Experimental Validation of Nonlinear Control for a Voltage Source Converter" IEEE transactions on control systems technology, VOL. 17, NO. 5, September 2009.

[12] Edward Song, Student Member, IEEE, Alan F. Lynch, Member, IEEE, and Venkata Dinavahi, Member, IEEE "Experimental Validation of Nonlinear Control for a Voltage Source Converter" IEEE transactions

[13] El-Moursi M.S., Sharaf A.M. 2006, Novel Reactive Power Controllers for the STATCOM and SSSC, IEEE Department of Electrical and Computer Engineering, University of NewBrunswick, Canada, Review Electric Power System Research,, p. 228-241.

[14] El-Moursi M.S., Prof. Dr. A. M. Sharaf, "Voltage Stabilization and Reactive Compensation Using A Novel FACTS-STATCOM Scheme" 0-7803-8886-0/05/$20.00 ©2005 IEEE CCECE/CCGEI, Saskatoon, May 2005.

[15] "FACTS. Modeling and Simulation in Power Networks", John Wiley & Sons, 2004. Grainger J. J., Stevenson W. D., Power System Analysis, McGraw-Hill, International Edition, 2011

[16] Gupta B.D. (2007): Mathematical Physics. Vikas Publishing House PVT Ltd., New Delhi.

[17] Kalyan K.Sen, "STATCOM- Static Synchronous Compensator: Theory, Modeling &Kimbark, "Power system stability", vol. 1

[18] Transmission Company of Nigeria (TCN) Reports. (2006): Plot 441, Zambezi Crescent, Maitama, Abuja, Nigeria.

[19] Ying Xiao and Y.Z. Sun, "Power Flow Control Approach to power systems with Embedded FACTS DEVICES". IEEE Transactions on power systems, Vol.17, No4: pp943-950, Nov.2002.