Explorematics
Journal of Innovative
Engineering and Technology

Volume: 03No: 01 | March-2019

ISSN (Online) 2636 – 590
ISSN (Print) 2636 - 591X

VOLTAGE PROFILE ENHANCEMENT AND LOSS MINIMIZATION IN THE 330KV NIGERIAN 28-BUS TRANSMISSION NETWORK USING FACTS DEVICES

IYIDOBI JONATHAN C.*[1], ABONYI DOROTHY O.[1], NNAJI ANTHONY[1]

1 Department of Chemical Engineering, Enugu State University of Science and Technology,

Abstract - This research work is born out of an effort to resolve the perennial problems facing the Nigeria transmission line grid network. The method applied in this paper addresses the low voltage profile power losses and voltage instability that has characterized the Nigeria transmission grid network over the years. The Nigeria 28 bus transmission network was used as the test network. Continuation power flow was used to identify the weak buses and the most vulnerable bus, were the compensator was connected. Synchronous static compensator (STATCOM) was used to achieve compensation on the line The Simulink model of the STATCOM was sourced in PSAT library and configured accordingly. A Simulink model of the 28 buses Nigeria 330kv transmission network was also developed in PSAT. To evaluate the performance of the STATCOM, continuation power flow was run on the 28 bus network using PSAT as a tool. The STATCOM model was then connected at the most vulnerable bus (Yola) before running another continuation power flow on the entire test network. The result obtained showed that the connection of STATCOM increased the voltage profile of seven defaulting buses to values within the IEEE acceptable voltage profile range of 0.95pu to 1pu. Also, network real power losses reduced from4.96pu to 0.409pu.
Reactive power loss was also decreased from 19.1pu to - 11.057pu.

1 Introduction

Overviewof Electric Power Sector in Nigeria

The history of electricity generation in Nigeria as traced by Okoro (2007) started around 1896 when electricity was generated for the first time in Lagos. It is estimated that the maximum demand then was less than 60kW considering that the total capacity of the generators that time was 60kW. The Nigerian Government Electricity Undertaking under the auspices of the public works department (PWD) was instituted in 1946 to take charge the duty of electric supply in Lagos state.

The legislative council in 1950 facilitated the takeover of the responsibility of electricity supply and development by a central agency called the Electricity co-operation of Nigeria, (ECN). There were other agencies licensed to generate electricity in other parts of the country. One of such bodies was the Native Authorities and the Nigerian Electricity supply company (NESCO). By means of an act of parliament, the Niger Dams Authority (NDA) was instituted to take over the maintenance and construction of dams and other works on River Niger and other areas. The authority was also involved in generating electricity by means of hydro power (Okoro and Chikuni, 2007).

The 2004 vertical unbundling of NEPA into separate generation (GenCo), transmission (TranSysCo) and distribution (DisCo) companies; the transformation of NEPA into PHCN (Power holding company of Nigeria); the subsequent incorporation of PHCN and the commissioning of the regulating body Nigerian Electricity Regulation commission (NERC), in 2005; the incorporation of 18 new successor companies consisting of 6 generating companies, 11 distribution companies and one transmission company and the approval of market rule that will guide the electricity market in 2008 (Onagoruwa, 2010). These were the reform activities that led to the eventual full deregulation that happened in

2014. For the average Nigerian, the first four years of the deregulation era did not bring any sustainable improvement in quality and quantity of power supply in Nigeria. The DisCo, the TranSysCo and the GenCo companies have not demonstrated the capacity to effectively generate, transmit and distribute the enough power for the teaming population of Nigerians. The entire power network in Nigeria is still characterized by poor generation, weak transmission and distribution infrastructure and frequent and long outages. This situation has no doubt impacted negatively on the socio economic development of the country. The quest to resolve the long standing poor electricity supply in Nigeria over the years formed the decision to use the Nigerian 330kV Grid network as a case study for implementing the continuation power flow for improving voltage stability of the Nigerian power Network.

To effectively implement any system compensation in the Nigerian power network; it is important to first identify the weak buses (buses with low voltage profiles). With this information, one is in a better position to know which buses and lines require compensation and how best the compensation will be done.

To identify the weak buses, a power flow study needs to be run on the Network. Here, a test case of the Nigerian 330KV 28-bus system will be used. The process involves the use of continuation power flow technique to run the power flow in a way that overcomes the convergence issues experienced at critical points when conventional techniques like Newton Raphson and Gauss Sided methods are used. Kundur (2004) noted that in conventional power flow algorithms, the Jacobian matrix becomes singular at the voltage stability margin and as such, there is no convergence at operating conditions near the stability limits. By reformulating the power flow equations making them well conditioned at all possible loading conditions, the continuation power flow overcomes this problem. With the continuation power flow analysis method; one are able to obtain load flow solutions at the critical points, at points approaching critical point and points beyond but close to the critical points. With this information, one is able to assess more accurately the stability margin and can tell how close or far a system is to the critical point measuring either from the stable or unstable region. During compensation, continuation power flow analyses do notonly equip us with information on which buses to improve, but avails us of the extent of compensation we need to do on weak or fragile buses.

2 Review of Literature

Mattew*et al* (2014) studied power systems voltage stability improvement using static VAR Compensator (SVC). According to them, traditional methods of reactive power compensation for voltage stability including: reconfiguration of system structure regulation of generator excitation, synchronous generator, transformer tap changing, series capacitor compensation and shunt capacitor/reactor compensation have been associated with slow response and tear and wear of the mechanical components. They observed that FACTS devices (SVC, TCSC, TCPS, STATCOM, SSSC, UPFC& IPFC) respond instantaneously and do not have issues of mechanical tear and wear since they are made up of solid semi-conductor components. Their paper studied the impact of static VAR Compensator (SVC) in stabilizing power systems voltage using Nigerian 28-bus 330KV using Simulink /MATLAB as their environment. Mattew*et al* (2014) connected the SVC as a configuration of thyristor controlled reactor fixed capacitor (TCR-FC). Using a transmission line model extracted from the Nigerian 28-Bus system, they arrived at mathematical model that minimizes the voltage drop between two buses by keeping the voltage at one of the buses constant and adjusting the reactive power at the other bus.

Nwohu (2015) worked on the use of STATCOM to improve the voltage profile of the North-East 330kV power system in Nigeria. Nwohu (2015) observed that the Nigerian power network is characterized by poor fragile equipment, poor control and dispatch infrastructure, low voltage profile, high transmission losses and frequent collapses especially in the northern region, hence the need for adequate reactive power organization. Their technique in improving the system stability involved running a load flow of the Nigerian grid system at contingency with and without the modeled STATCOM so as determine the effect on the bus voltage profile improvement after optimizing using the STATCOM model using ant colony technique. Result and analysis of simulation carried out on the faulty bus showed an improvement on the voltage stability of the system.

Wang *et al* (2011) studied VSC-HVDC and its state of the art potential applications. The research work presented a general overview and introduction to VSC-HVDC transmission. Here, HVDC was categorized into two, the VSC-HVDC and the current source converter based HVDC (CSC-HVDC). The authors observed that CSC switches with thyristor valves and therefore operates like a line commutated converter. This is because a thyristor can only be turned off if the current passing through it is taken to zero. Line voltage is therefore needed for its commutation. The work showed that CSC-HVDC is only suitable for bulk power and very long transmission lines with little or no capacitance effect on the long transmission line. However it was noted that VSC-HVDC uses a more advanced semiconductor technology, IGBT applied alongside pulse width modulation (PWM) control method and as such do not need ac voltage support for commutation. This is because it works like a forced commutated voltage converter. All these have made VSC-HVDC more attractive as it responds faster, minimizes switching loss and provides good sinusoidal waveform in the output especially when used with a new topology called modular multilevel converter (MMC). The study found VSC-HVDC as a viable technique for implementing a multi-terminal dc system for integrating large renewable energy sources (like wind farms, solar power etc.) into the grid system.

3 Facts Devices

STATCOM is a member of the FACTs device family. Flexible AC Transmission System (FACTS) is a new technological application used in power systems. A FACTS deviceemploys modern power electronic technology in controlling transmission system parameters. FACTS devices enhances existing transmission systems' power transfer capacity, minimizes line losses and cost of generation, give faster, reliable and flexible responses and in general improve the security and stability of a power network. Dong *et al* (2005) noted that the voltage drop occasioned by a contingency decreases reactive power generation and results in reactive power losses. There is therefore need to provide sufficient reactive power reserve to meet the VAR change following a disturbance. Use of FACTs devices is an effective means of doing this.

Common FACTS devices include: Interface Power Flow, Static VAR Compensator (SVC), ThyristorControlledSeries Capacitor (TCSC),Unified Power Flow Controller (UPFC), Static Phase Shifter (SPS), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), etc. (Aree, 2000).SATCOM stands for static synchronous compensator. It is one of the most recently developed FACTS devices. STATCOM is a reactive power compensator developed to overcome the high cost and technical shortcomings of SVC's. STATCOM was implemented using Gate-turn-off thyristor (GTO). It can be built to have the ability to absorb or supply reactive power. When compared with SVC, it responds more quickly damp disturbances in power networks and also provides better voltage support.

4 The Principle of Continuation Power Flow

As the critical point is approached, with the conventional load flow, the Jacbian matrix becomes singular and fails to converge (Marefatjou and sultan, 2013). Continuation power flow resolves this problemby reformulating the power flow equations to eliminatethe singularity of the Jacobian matrix and the associated numerical challenges (Magalhaes, 2012). The analysis method proposed by Kundur (2004) makes use of an iterative process that involves two steps: the predictor and corrector steps. For a specific pattern of increase in load, solution (B) is estimated using a tangent predictor from an initial known solution (A). By assuming a fixed system load and using a conventional load flow analysis, the exact solution (C) is determined using the corrector step. Based on a new tangent predictor; the voltages for a further increase in load are then predicted. Convergence will fail if the next estimated Load (D) is beyond the maximum load on the exact solution. To resolve this, a corrector step with a fixed voltage at the monitored bus is applied to locate the exact solution. To determine the exact solution on approaching the voltage stability limit, there is need for the load increase to be gradually reduced during successive predictor steps (Kundur, 2004).

The mathematical formulation of the continuation power flow analysis as developed by Kundur (2004) is given as follows:

The conventional power flow equation is first reformulated to make provision for increasing power generation with increase in load.

$$\lambda K = F(\theta, V) \qquad (1)$$

λ, represents the load parameter.

θ, represents voltage angle vector of the bus.

V, represents the voltage magnitude vector of the bus,

$'\lambda'$ value fulfilling the condition:

$$O < \lambda \leq \lambda_{crtical}$$

is specified to help in solving the above non-linear equations. The base load condition is given by:

$\lambda = 0$

and the critical loading given as:

$\lambda = \lambda_{crtical}$.

We can rearrange equation (1)above to give:

$$F(V, \theta, \lambda) = 0 \qquad (2)$$

The Predictor Step

According to Kundur (2004), for a change in one of the state variables (θ, V, λ), a linear approximation is used estimate the next solution.

Now, using an initial condition that corresponds to the state variables, the derivative ofequation(2) is taken on both sides to give:

$$F_\theta d_\theta + F_v d_V + F_\lambda d_\lambda = 0 \qquad (3)$$

In matrix form

$$\lfloor F_\theta \; F_V \; F_\lambda \rfloor \begin{bmatrix} d_\theta \\ d_V \\ d_\lambda \end{bmatrix} = 0 \qquad (4)$$

The introduction of an unknown variable 'λ' in the power flow equations makes it imperative that to solve the equations above, an additional equation is required. This is achieved by setting one of the tangent vectors to +1 or -1. This component is called the continuation parameter. Equation 4now becomes:

$$\begin{bmatrix} F_\theta F_v F_\lambda \\ e_k \end{bmatrix} \begin{bmatrix} d_\theta \\ d_v \\ d_\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ \mp 1 \end{bmatrix} \qquad (5)$$

Where exist a row vector in which all elements (except k^th^ element that is equal to 1) is equal to zero.

In following predictor steps, the state variables are selected as the continuation parameter. The highest rate of change being close to the solution given. The sign of the corresponding component of the tangent vector is determined by the slope of the state variable's rate of change.

As the maximum load is approached, a voltage will practically become the parameter with the greatest change At this point, the next solution's prediction is made and is will become:

$$\begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix} = \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} + \begin{bmatrix} \theta_0 \\ V_0 \\ \lambda_0 \end{bmatrix} \qquad (6)$$

At the beginning of the predictor step, the value of the state variable is identified by '0'. 'σ' is the chosen step size for a specified continuation parameter. It is subjected to adjustment until a power flow solution is obtained (Kundur, 2004).

The Corrector Step

Kundur (2004) here stated that one equation that outlined the state variable chosen as the continuation power flow parameter is used to augment the original set of equations represented by.

$$F\,(V, \theta, \lambda) = 0 \qquad (7)$$

The rearranged equation is given as:

$$\begin{bmatrix} F_\theta & F_V & F_\lambda \\ & X_k - \eta & \end{bmatrix} = [0] \qquad \textbf{(8)}$$

In the above equation, 'x_k' represents the state variable chosen as the continuation parameter and 'η' represents its value. A slightly modified Newton-Raphson's method can solve the above set of equations. The introduced additional equation that specifies $x_k$prevents non singularity of the Jacobian matrix at critical point. This makes it possible for load flow analysis to be continued beyond the critical point. The obtained solution (beyond the critical point) corresponds to the lower portion of the P-V curve. The tangent component of $\lambda, (d\lambda)$shows whether the critical point has been reached or not. The tangent component $(d\lambda)$ is greater than zero for the upper part of P-V curve, it is zero at critical point and less than zero at the lower part of the P-V curve. While responding to differential changes in load; state variables also experience differential changes. This change is represented by the elements of the tangent vector in the continuation load flow analysis (Kundur, 2004).

5 System Modeling and Simulation

The Nigerian 330kV 28-bus network modeled in PSAT/Simulink MATLAB is presented in fig 3.1. The developed model was loaded in PSAT as the data file. The continuation power flow was then run in PSAT. The solver selected for the running of the continuation power flow is the Newton Raphson load flow technique. The PSAT/Simulink blocks used to build the Nigerian 330kv network include: the real power and voltage specified (PV) generator block, slack bus, constant real and reactive power specified (PQ) load, transmission line and bus bar block. After building the network, each block was then configured with the corresponding parameter value and ratings.

Continuation load flow study is critical in identifying the weak buses in a network. The standard is to consider all buses with voltage level lower than 0.95pu to be vulnerable. The optimum bus voltage for stable operation is 1.0pu.

6 Results and Discussions

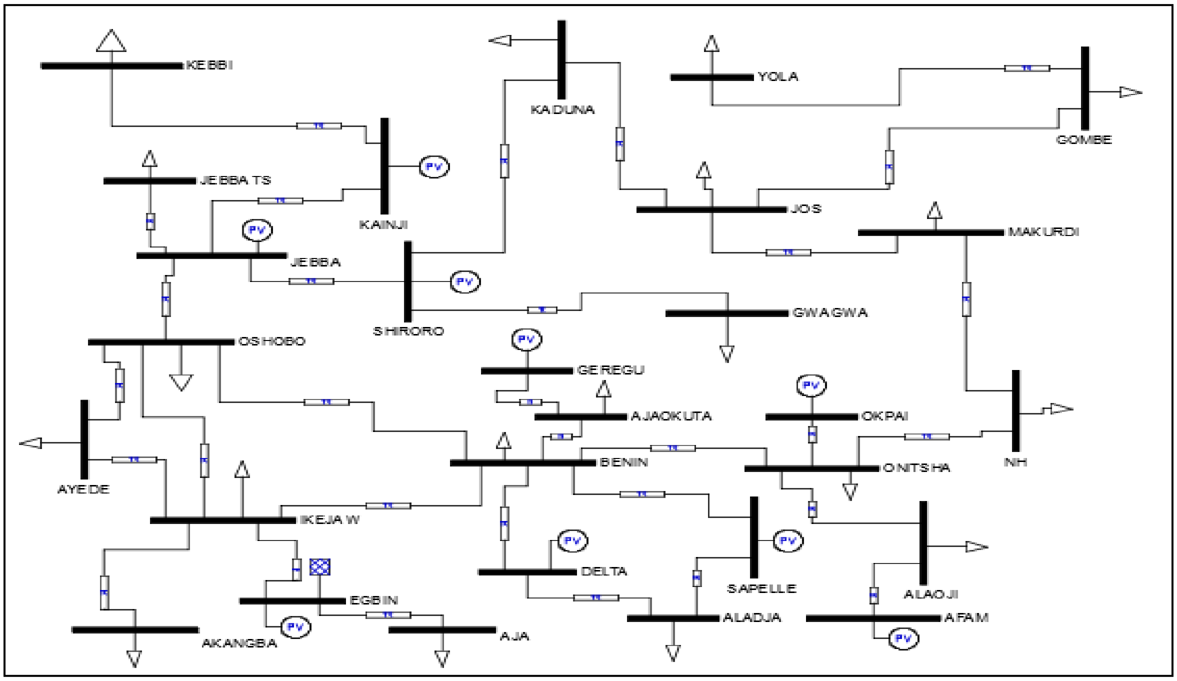

Figure 1: Simulink model of the Nigerian 28 bus transmission power network

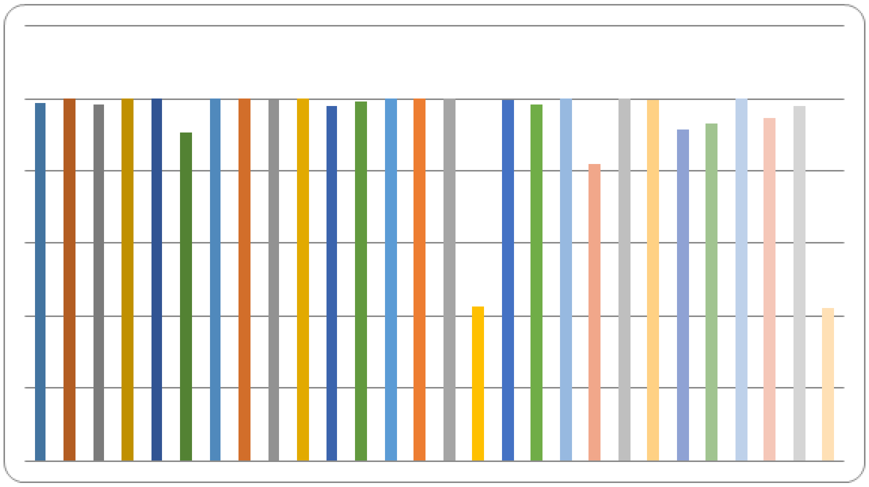

Figure 2: Plots of network Voltage profiles against buses before compensation

Table 1: Continuation Load flow result of Network before compensation

Bus No	Bus	V (pu)	phase (rad)	P gen (pu)	Q gen (pu)
1	ALAOJI	0.98771	0.0886	0	0
2	SAPELLE	1	0.07529	8.14977	5.13835
3	AKANGBA	0.98301	-0.00762	0	0
4	AJA	0.99927	-0.0013	0	0
5	JEBBA	1	0.25789	5.66409	1.29219
6	KADUNA	0.90448	0.1341	0	0
7	SHIRORO	1	0.18459	4.07489	18.11577
8	AFAM	1	0.08984	9.16849	5.76633
9	AJAOKUTA	0.99409	0.06811	0	0
10	ALADJA	0.99912	0.06964	0	0
11	AYEDE	0.97814	-0.01395	0	0
12	BENIN	0.99094	0.06698	0	0
13	DELTA	1	0.07151	5.09361	5.16707
14	EGBIN	1	0	6.72016	9.87568
15	GEREGU	1	0.07959	4.07489	1.62881
16	GOMBE	0.42462	0.08008	0	0
17	GWAGWA	0.9948	0.18356	0	0
18	IKEJA W	0.98427	-0.00555	0	0
19	JEBBA TS	0.99946	0.25704	0	0
20	JOS	0.81951	0.10273	0	0
21	KAINJI	1	0.281	11.77642	0.10559
22	KEBBI	0.99743	0.27515	0	0
23	MAKURDI	0.91421	0.10889	0	0
24	NH	0.93111	0.09079	0	0
25	OKPAI	1	0.10308	9.16849	17.88149
26	ONITSHA	0.94528	0.08043	0	0
27	OSHOBO	0.97888	0.01776	0	0
28	YOLA	0.4225	0.07708	0	0

Table 2: Continuation Load flow result of Network after compensation

Bus No	Bus	V (pu)	phase (rad)	P gen (pu)	Q gen (pu)
1	ALAOJI	1.00229	-0.00006	0	0
2	SAPELLE	1	0.00023	4	0.09448
3	AKANGBA	1.00435	-0.00058	0	0
4	AJA	1	0	0	0
5	JEBBA	1	0.00043	2.78	0.33292
6	KADUNA	1.00567	-0.00063	0	0
7	SHIRORO	1	0.0002	2	4.2601
8	AFAM	1	0.00292	4.5	-1.27035
9	AJAOKUTA	1.00201	0.00051	0	0
10	ALADJA	1.00042	0.00014	0	0
11	AYEDE	1.00426	-0.00059	0	0
12	BENIN	1.00248	-0.00011	0	0
13	DELTA	1	0.0002	2.5	0.77913
14	EGBIN	1	0	1.27214	3.43119
15	GEREGU	1	0.00076	2	0.00346
16	GOMBE	1.00938	-0.00125	0	0
17	GWAGWA	0.99998	0.0002	0	0
18	IKEJA W	1.00436	-0.00058	0	0
19	JEBBA TS	1	0.00042	0	0
20	JOS	1.00605	-0.00077	0	0
21	KAINJI	1	0.0005	5.78	0.02057
22	KEBBI	0.99999	0.00048	0	0
23	MAKURDI	1.00522	-0.00065	0	0
24	NH	1.00511	-0.00048	0	0
25	OKPAI	1	0.00022	4.5	3.80523
26	ONITSHA	1.00502	-0.00038	0	0
27	OSHOBO	1.00362	-0.00041	0	0
28	YOLA	1.00949	-0.00135	0	0

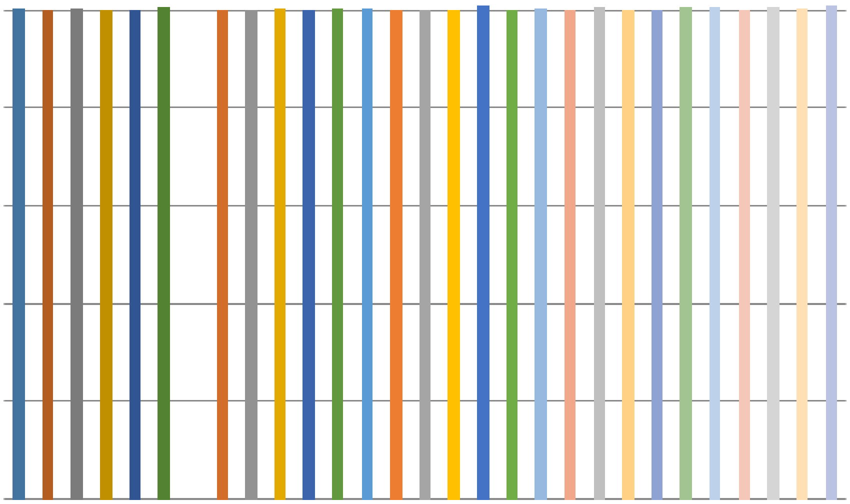

Figure 3: Plot of Network Voltage profile against buses after compensation

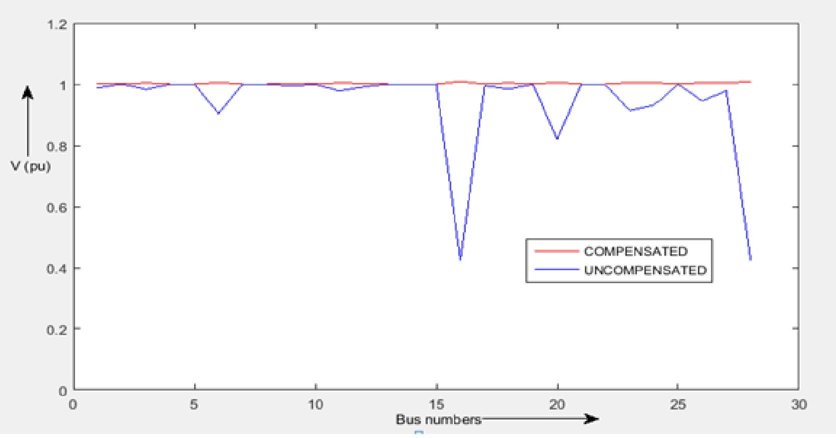

Figure 4: Plot of Network Voltage profile against buses before and after compensation

Table 3: Power Loss for Compensated and Uncompensated Network

	P LOSS (p.u.)	Q (p.u.)
Uncompensated	4.96184	19.10028
Compensated	0.40914	-11.05728

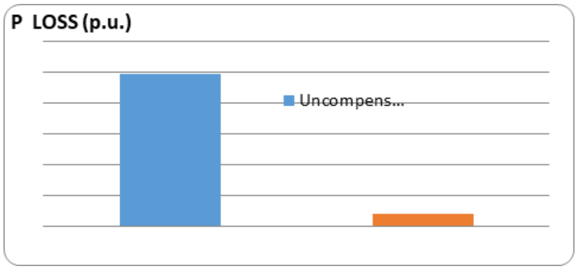

Figure 5: Bar chart showing Active Power Loss for Compensated and Uncompensated Network

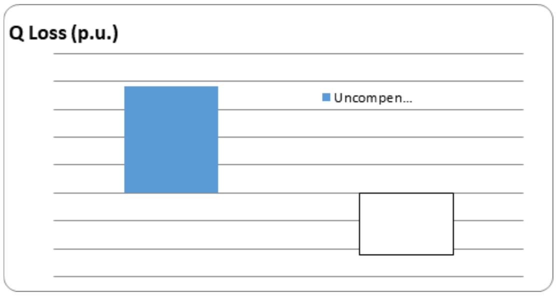

Figure 6: Bar chart showing Reactive Power Loss for Compensated and Uncompensated Network

7 Analysis of Result

Table 1 and figure 2 reveals that there are seven vulnerable buses in the network. The seven buses include: Jos, Yola, Gumbe, New Heaven, Makurdi, Kaduna and Onitsha. These buses are proclaimed vulnerable because their voltage profiles fell below the minimum acceptable level of 0.95p after continuation load flow.

Furthermore, Yola bus with the least voltage profile of 0.4225 is also selected as the weakest or most vulnerable bus. The most vulnerable (weakest) bus is usually the most suitable location for connecting a compensation device. The STATCOM was then connected to the Yola bus to archive optimum compensation that will deliver high voltage profile improvement and maximum power less reduction in the network.

Table 2 and figure 3 shows that after compensation, the voltage profile of all the buses (including the weak ones) improved to a level equal to or close 1pu. Since none of the bus voltages fell outside the standard acceptable range of 1.05pu to 0.95pu; the Yola bus network is not only adjudged to be strong; the entire network is also stable.

Figure 4 compares the voltage profile of all buses before compensation with the voltage profile after compensation. The graph clearly shows an impressive enhancement of bus voltage profile with STATCOM relative to the network without STATCOM.

Similarly, table 3 shows the active and reactive power loss in the network for compensated and uncompensated scenarios.

From table 3 and figure 5, it can be seen that real power loss before compensation was 4.96184pu as against 0.40914pu obtained after compensation. This result shows an appreciable reduction in real power loss in the network. Similarly, table 3 and figure 6 shows that reactive power loss of 19.10028pu was recorded for the network without STATCOM as against -11.057pu that was recorded with STATCOM connected. The negative reactive power value implies that reactive power was actually supplied to the network by the STATCOM.

8. Conclusion and Recommendation

From the result and discussion above, it can be concluded that continuation power flow is effective in determining weakest buses in a network and that the tool is also effective in evaluating networks voltage stability. It can also be concluded that STATCOM was very effective in enhancing the networks voltage profile stability and that STATCOM effectively reduced active and reactive power loss in the network.

It is recommended that STATCOM be connected to the Yola bus in the Nigeria 330kv network to help improve the bus voltage profiles and reduce power losses in the Nigeria 330kv network and indeed all power transmission networks. This will translate to an improved network stability, security and reliability in the power network. Continuation power flow is also recommended as a viable tool for determining most vulnerable bus (s) in a power network. This information is key to an appropriate placement of compensating devices for optimum result.

References

Aree .P. (2000) Small-signal Stability Modeling and analysis of power systems with electronically controlled compensation. PhD thesis. Available at: http://theses.gla.ac.uk/2600/1/2000areephd.pdf., accessed 11th March, 2015.

Kundur, P. (2004). Definition and Classification of Power System Stability' IEEE/CIGRE Joint Task Force on Stability Terms and Definitions available at: www.home.eng.iastate.edu/~jdm/ee554/TermsDefinitions2004.pdf, accessed: 10th March, 2015.

Mathew .S and Wara .S. (2014).Power System's Voltage Stability Improvement Using Static Var Compensator. *International Journal of Emerging Technology and Advanced Engineering*, Volume 4, Issue 1, January 2014, available at: http://www.ijetae.com/files/Volume4Issue1/IJETAE_0114_84.pdf., accessed 11th March, 2015.

Nwohu M.N. and Aribi. F, (2015). Voltage Profile Enhancement of the Nigerian North-East 330kV Power Network Using STATCOM', *International Journal of Advanced Research in Science, Engineering and Technology* Vol. 2, Issue 1, January 2015, available at: http://www.ijarset.com/upload/2015/january/1_IJARSET_MNNWOHU.pd, accessed 11th March, 2015.

Okoro O.I and Chikuni E. (2007). Power sector reforms in Nigeria: opportunities and challenges", available at: http://www.researchgate.net/profile/Poobalan_Govender/publication/237825169_POWER_SECTOR_REFORMS_IN_NIGERIA_OPPORTUNITIES_AND_CHALLENGES/links/540d89560cf2df04e754b690.pdf, accessed, accessed: 6th January 2011.

Okoro O.I and Chikuni E. (2007). Conventional Energy sources in Nigeria: a statistical approach, available at: http://timetable.cput.ac.za/_other_web_files/_cue/due/2008/PDF/Paper%20%20Okoro%20O.pdf, accessed: 6th January 2011.

Wang .Y. (2013)'Voltage Stability Assessment Using P-Q Region Incorporating Wind Power' Theses and Dissertations. Paper 176.available at: www.dc.uwm.edu/cgi/viewcontent.cgi?article=1179&context=etd, accessed: 5th March, 2015.