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INVESTIGATING THE EFFECT OF STATCOM PLACEMENT ON THE ACTIVE AND REACTIVE POWER OF IKEJA – WEST 330KV POWER NETWORK USING GENETIC OPTIMIZATION META-HEURISTIC

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ABSTRACT
The important of investigating both the active and reactive power contents in the quality of power transmission on the Nigerian 330KV grid line cannot be over emphasized. This paper investigates the effect of FACTS devices (STATCOM) on the active and reactive content of Nigerian (Ikeja- West) 330 kV Network. It also demonstrated how STATCOM has successfully been applied on the Nigerian Ikeja- West Region 330 kV Transmission Network.The STATCOM is modeled and genetic algorithm optimization method was used in its placement on the network. Power system computer aided design (PS-CAD) was used in the simulation and the behaviours of the Network were investigated when STATCOM was connected and when it was not connected to the network. The result shows that active and reactive power losses were reduced with the STATCOM connected to the grid.

Keywords: *Facts, Statcom, Ps-Cad, Reactive Power, Active Power.*

Introduction

Demand is rising all the time and modern society would cease to function without access to electricity. As the volume of power transmitted and distributed increases, so do the requirements for high quality and reliable supply. At the same time, rising costs and growing environmental concerns make the process of building new power transmission and distribution lines increasingly complicated and time-consuming. Making existing lines as well as new ones more efficient and economical, then becomes a compelling alternative.

The global trend is towards ever larger power networks, longer transmission lines, and higher consumption. Energy is also becoming increasingly expensive. To cope, power transmission and distribution systems have to become more efficient. Optimum power transmission and distribution also entails the reduction of transfer losses and provision of adequate power quality and availability at the receiving end.

In Nigeria, Electrical Power System comprises three major areas, namely, generation, transmission and distribution. The transmission network which serves as a link between the generation and distribution network often suffers from partial or total breakdown. This could due to external disturbances, such as falling of trees on the transmission lines, insulators breakdown, high load demand or ageing of the system (PHCN Annual Report, 2005). Inadequate and unstable power supply in Nigeria (especially at the western region) has grossly affected electricity users in damaging their appliances and loss of goodwill, thus, resulting in the stagnation of the country's economy. Poor electrical services have forced most industrial customers and individuals to procure the stand alone generators (Onohaebi, 2009). However, the Nigerian Government as part of its power sector reform project is working on a range of policy initiatives to boost the electricity transmission network to 700kV super grid, in order to accommodate significant levels of generation from a range of different sources (PHCN Annual Report, 2005). Part of the reforms includes the privatization of the generation, transmission and distribution network, with the aim of achieving an efficient performance of the entire system. The application of power electronics-based device known as Flexible Alternating Current Transmission Systems (FACTS), offers the possibility of meeting such demands. FACTS devices are employed in order to enhance the power transfer capability of the interconnected network. The Use of FACTS device has been proven to be the most effective way for utilities to improve the voltage profile and voltage stability margin of the system (Hingorani and Gyugyi, 2000).FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impacts, and implementation time compared to the construction of new transmission lines.

The following FACTS devices, Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) provide fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage for a significant length of time. SVC and STATCOM also dampen power swings and reduce system losses by optimized reactive power control.(Igbinovia, e tal, 2015)

The amount of reactive power in an AC circuit depends on the phase shift between the voltage and the current. Reactive power provides the important function of regulating the system voltage, helping to move active power effectively through the utility grid and transmission lines to where it is required by the load. Loads like electric motor and other inductive loads require reactive power for their operation.

To improve the performance of alternating current (a.c) power systems, we need to manage this reactive power in an efficient way and this is known as reactive power compensation. Volt-ampere reactive (VAR) compensation is defined as the management of reactive power to improve the performance of AC power systems. Reactive power is positive when it is supplied and negative when it is absorbed (Juan e tal ,2010).

In recent years, static VAR compensators like the STATCOM have been developed. These quite satisfactorily do the job of absorbing or generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS). This allows an increase in transfer of apparent power through a transmission line, and improves stability by the adjustment of parameters that govern the power system, that is, current, voltage, phase angle, frequency and impedance [Abhijeet and Pradeep, 2010].

This paper therefore, intends to investigate the effect of **STATCOM** placement on the active and reactive power of Ikeja – West 330kV power network.

Methodology

This work on investigating the effects of STATCOM on Power Quality of Nigerian 330 kV Power Network in Ikeja West will be implemented using PSCAD/EMTDC 4.3.1 version software. The Nigerian 330 kV grid system of

Ikeja West Region would be modeled and simulated. The optimal placement of STATCOM will be realized by the genetic optimization technique.

Genetic Algorithms

GAs start with an initial set of random solutions called population. A population of candidate solutions, or individuals, is maintained, and individuals made to compete with each other for survival. Once evaluated, through the fitness function calculation, stronger individuals have a greater chance to contribute to the production of new individuals (the offspring) than weaker ones, which may not even contribute at all (selection procedure). Offspring are produced through recombination, whereby they inherit features from each of the parents, and through mutation, which can confer some truly innovative features as well. In the next selection step (next generation), offspring are made to compete with each other, and possibly also with their parents. Improvement in the population arises as a consequence of the repeated selection of the best parents, which are in turn more likely to produce good offspring, and the consequent elimination of low-performers the algorithm converges to the hopefully represents the optimal.

Overview of Nigerian Grid System

The present installed capacity of Nigerian Grid is about 6000MW, of which about 67% is thermal and 33% is hydro-based. By 2010, the transmission network consisted of 5000km of 330 kV lines, and 6000km of 132-kV lines (NERC, 2007).The 330-kV lines fed 23 substations employing transformer with voltage rating of 330/132- kV, the 132-kV lines fed more than 100 substations employing transformer with voltage rating of 132/33-kV. The system frequency is 50Hz and the transmission network is overloaded with a wheeling capacity less than 4,000 MW (PHCN, 2008). The single line diagram of the Nigerian (Northern) 330 kV power network as at 2007 is shown in Fig 1.

The Nigerian 330kV Grid System is zoned into four geographical areas in conformity with operational structure of the electric utility [Sadiq and Nwohu, (2013)]. The three hydro power stations are situated in Area 1 while Area 2 has thermal power station located in it and areas 3 and 4 have gas power stations located in them.

The Nigerian Grid is characterized by poor voltage profile in most parts of the network, especially, in the North where inadequate dispatch and control infrastructure, radial and fragile grid network, frequent system collapse, and exceedingly high transmission losses are prominent(Orihie, 2004). Also, because the Nigerian Grid System is highly stressed and weak, this makes it prone to voltage instability and eventual voltage collapse. As a result, the system often experience massive load shedding (Ibikunle *et al.*, 2012).

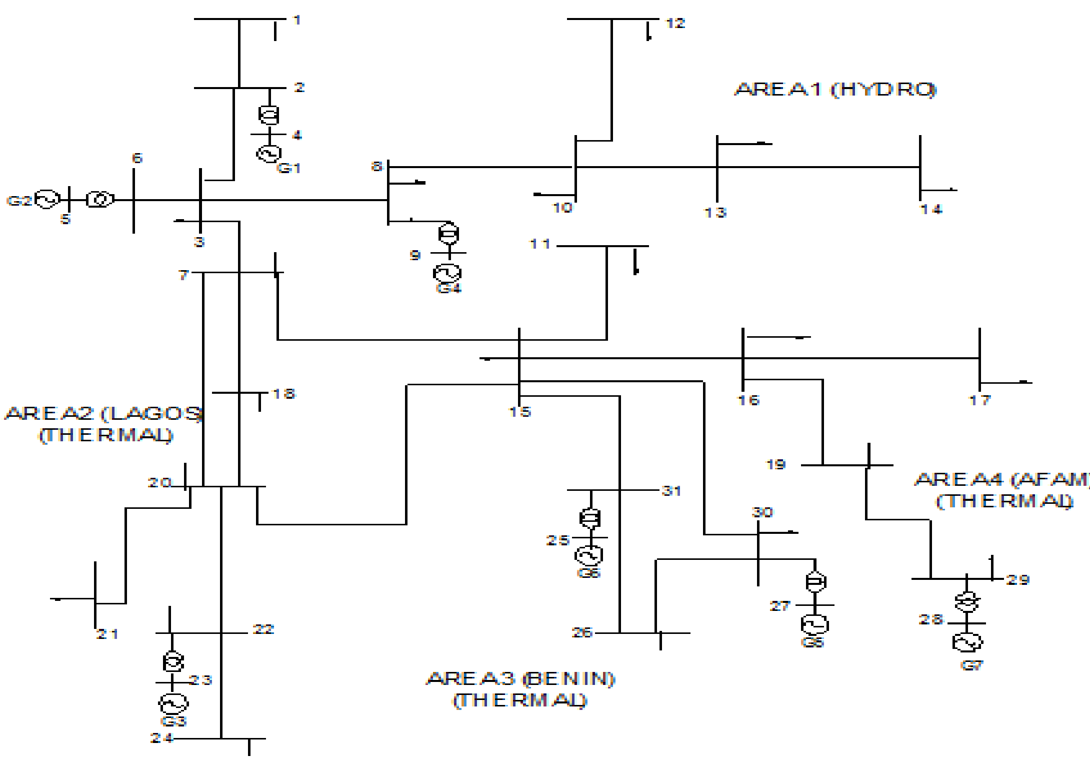

Fig. 1: Structure of the Nigerian Grid System as at 2007 (NERC, 2007)

Overview of Ikeja West Network System (Oluseyi etal 2017)

The IKEJA WEST 330/132kV transmission station is considered strategic and unique to the Nigerian National Grid. The station has seven (7) incoming 330kV lines, two (2) 330kV outgoing lines and fourteen (14) 132kV outgoing lines to step down transmission stations in the network. The 330kV lines connected to the IKEJA WEST Station are named according to nomenclature as

i. Oshogbo 330KV line (Cct H1W)

ii. Olorunsogo 330KV line (R1W) formerly known as Ayede 330KV line (Cct W2A)
iii. Omotosho 330KV line (M5W) formerly known as Benin 330KV line 1 (Cct B5W)
iv. EGBIN 330KV line 3 (N6W) formerly known as Benin 330KV line 2 (Cct B6W)
v. Oke-Aro 330KV line 1 (Cct N7W)
vi. Oke-Aro 330KV line 2 (Cct N8W)
vii. Sakete 330KV line (NW1BS)
viii. Akangba 330kV line
ix Sakete 330kV line

The transmission station is fed from both hydro power stations (supply from Osogbo) and thermal power generating stations i.e. Omotosho power station, EGBIN power station and AES power station. The transmission station consists of four (4) 150MVA step-down transformer (resulting in a total station capacity of 600MVA or 480MW) for stepping the incoming 330kV to 132kV. Transformer nomenclatures given as: T1A, T1B, T2A and T2B. Two (2) 75MX reactors R1 and R2 are connected to the 330kV bus-bar for voltage stability. Two earthing transformers (GT1A and GT2A) are attached to the transformers. GT1A is connected to the tertiary of T1A while GT2A is connected to the tertiary of T2A. The power transformers are connected to a breaker which operates to clear fault on the line and prevent further degradation/damage. The breakers are to safeguard the line by making or breaking contact when the need to isolate arises.

FACTS Devices

Power flow studies gives the steady–state operating condition of the power network, by finding the flow of active and reactive power, voltage magnitudes and phase angles at all nodes of the network. If the power flow study shows voltage magnitudes outside tolerable limit or it is beyond the power carrying capacity of the line, necessary control actions are taken to regulate it. Flexible AC transmission system device can be defined as a power electronic based system that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability (Piyush, 2012).FACTS technology is simply the collection of controllers applied to regulate and control variables such as impedance, current, voltage and phase angles. FACTS controllers can be divided into four (4) groups: Series Compensators, Shunt Compensators, Series–Shunt Compensators and Series-Series Compensators.

The benefits of STATCOM to power transmission:

I. Stabilized voltages in weak systems
II. Reduced transmission losses
III. Increased transmission capacity, to reduce, defer or eliminate the need for new lines
IV. Higher transient stability limit
V. Increased damping of minor disturbances
VI. Greater voltage control and stability
VII. Power oscillation damping

STATCOM Principle of Operation

STATCOM is a Voltage-Source Inverter (VSI), which converts a DC input voltage into AC output voltage in order to compensate the active and reactive power needed by power system network.

With reference to Figure 2, let V_1 be the voltage of power system and V_2 be the voltage produced by the voltage source converter (VSC).At steady state condition, V_2 produced by VSC is in phase with V_1, and in that case, only reactive power flows. If the magnitude of the voltage V_2 produced by the VSC is less than the magnitude of V_1, the reactive power flows from power system to VSC (that is, STATCOM absorbing the reactive power). If V_2 is greater than V_1, the reactive power is flowing from VSC to power system (the STATCOM is producing a reactive power). However, when V_2 equals V_1, the reactive power exchange equals zero in which case the STATCOM is said to be in a floating state. Thus, we can say that if $V_1 \leq V_2$, the STATCOM is drawing a capacitive current and if $V_2 \leq V_1$, the STATCOM produces inductive current as shown in Figure 3.The amount of reactive power can be expressed as shown in equation (1).

$$Q = \frac{V_1(V_1 - V_2)}{X} \quad (1)$$

where,

Q = Reactive power

X= reactance across the line transformer

V_1= the voltage of the power system

V_2= the voltage produced by the voltage source converter (VSC) (Enrique, Fuerte and Ambriz, 2004).

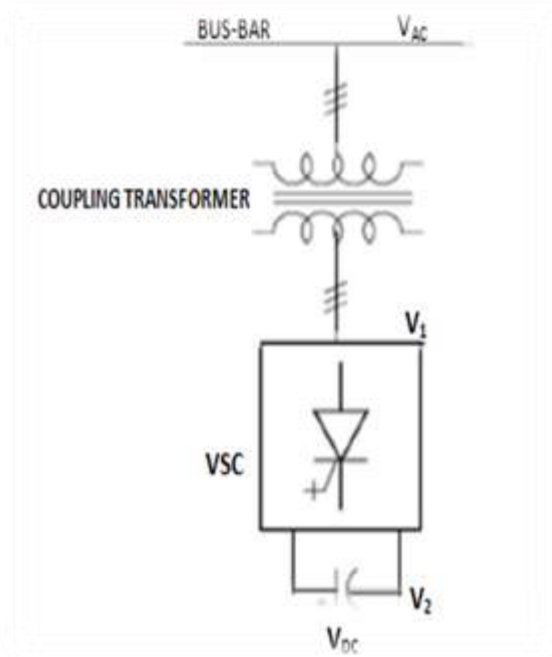

Figure 2 Configuration of STATCOM

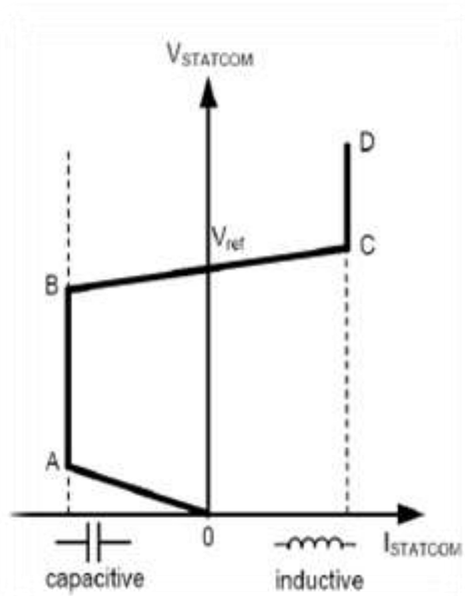

Figure 3 V-I Characteristics of STATCOM

STATCOM Power Flow Model

STATCOM power flow can be modeled using figure 1 below. STATCOM is FACTS controllers that operate on the principle of Voltage Source Converter (VSC). VSC generate a synchronous voltage of fundamental frequency and controllable magnitude and phase angle. Newton – Raphson method rectangular coordinate is used to model STATCOM controller. Figure 5 show the Thevenin equivalent circuit representing the fundamental frequency operation of switched-mode voltage sourced converter and its transformer.

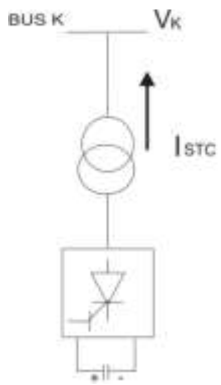

Fig. 5 THEVENIN EQUIVALENT CIRCUIT

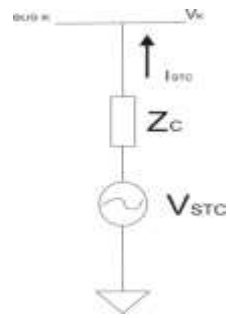

Fig.6 STATCOM EQUIVALENT CIRCUIT

$$V_{STC} = V_K + Z_{SC} I_{STC} \quad (2)$$

In Norton Equivalent form

$$I_{STC} = I_N - Y_{SC} V_K \quad (3)$$

Where V_{STC} is the voltage source inverter, I_N is the Norton's current, I_{STC} is the STATCOM current, Y_{SC} is the Transformer short circuit admittance, Z_{SC} is short circuit impedance.

$$Y_{SC} = \frac{1}{Z_{SC}} \quad (4)$$

$$Z_{SC} = (R_{SC} + X_{SC})^{1/2} \quad (5)$$

The STATCOM voltage injection V_{STC} is subject to the constraints

$$V_{STCMIN} \leq V_{STC} \leq V_{STCMAX}$$

Where V_{STCmin} and V_{STCmax} are the STATCOM's minimum and maximum voltages

Voltage source converter power and power injected into bus k can be expressed as shown in equation (6)

$$S_{STC} = V_{STC} I_{STC}^* = V_{STC}^2 Y_{SC}^* - V_{STC} Y_{SC}^* V_K^* \quad (6)$$

$$S_K = V_K I_{STC}^* = V_{STC} Y_{SC}^* V_K^* - V_K^2 Y_{SC}^* \quad (7)$$

Where I_{STC}^* is the complex conjugate of STATCOM current, V_{STC}^* is the complex conjugate of STATCOM voltage, Y_{STC}^* short circuit admittance.

Using the rectangular coordinate representation, voltage magnitude and phase angle can be expressed as shown in equation (8) and (9) respectively

$$V_K = e_K + jf_k$$

$$V_{STC} = e_{STC} + jf_{STC}$$

$$|V_{STC}| = (e_{STC}^2 + f_{STC}^2)^{\frac{1}{2}} \quad (8)$$

$$\delta_{STC} = \tan^{-1}\left(\frac{f_{STC}}{e_{STC}}\right) \quad (9)$$

Where $|V_{STC}|$ and δ_{STC} are the STATCOM voltage magnitude and angle respectively.

The Active and Reactive power for the STATCOM and the node k can be found using equation (10&11) and (12&13) respectively.

$$P_{STC} = G_{SC}\{(e_{STC}^2 + f_{STC}^2) - (e_{STC}e_K + f_{STC}f_K)\} + B_{STC}(e_{STC}f_K - f_{STC}e_K) \quad (10)$$

$$Q_{STC} = G_{SC}(e_{STC}e_K - f_{STC}e_K) + B_{SC}(-e_{STC}^2 - f_{STC}^2 + e_{STC}e_K + f_{STC}f_K) \quad (11)$$

And

$$P_K = G_{SC}\{e_K^2 + f_K^2 - (e_Ke_{STC} + f_Kf_{STC})\} + B_{SC}(e_Kf_{STC} - f_Ke_{STC}) \quad (12)$$

$$Q_K = G_{SC}(e_Kf_{STC} - f_Ke_{STC}) + B_{SC}\{(e_Kf_{STC} + f_Ke_{STC}) - (e_K^2 + f_K^2)\} \quad (13)$$

Where P_{STC} is the STATCOM real power, Q_{STC} is the STATCOM reactive power, G_{SC} is the short circuit conductance and B_{SC} is the short circuit susceptance.

Simulation

PSCAD/EMTDC 4.3.1 version software was used in modeling and simulation of Ikeja West 330KV transmission grid. The load system was run with STATCOM and without STATCOM placement. Results of simulations for the active-reactive power flow on the 13-Bus system carried out for STATCOM unconnected and STATCOM connected on the network are presented in Tables 1. The single line PSCAD representation of Ikeja West region 330 kV Transmission Network with STATCOM and without STATCOM is show in figure 11 and figure 12 respectively in appendix.

Results and Discussion

Power Quality Analysis without STATCOM

The system was subjected to a single line-neutral fault between 250 ms and 920 ms, with reference to bus 6 and 13, the network was found to have been distorted as indicated with blue line in figure 6, figure 7, figure 8 and figure 9 which affects the power quality of the network. As a result, the system suffers from instability which could result into system collapse if not abated. The optimum available transfer capability of the transmission line expected for active power transfer from sending to receiving end is also lessened in this case.

Power Quality Analysis with STATCOM

With reference to Table 1, it was found that the active power loss measured on the various buses of the transmission line decreases due to the reactive power compensation offered as a result of STATCOM connected to the network. The maximum available capability of the transmission line expected for active power transfer from sending end to receiving end was also boosted in this case, hence, a decrease in the active power loss. To this effect, the power quality of the network was improved. Figure 10 show the Active and Reactive Power loss with and without STATCOM at various Buses.

Table 1: Results of Active and Reactive Power loss Measured at Various Buses

BUS NAME	BUS NO	ACTIVE POWER LOSS WITHOUT STATCOM(MW)	ACTIVE POWER LOSS WITH STATCOM (MW)	REACTIVE POWER LOSS WITHOUT STATCOM (MVar)	REACTIVE POWER LOSS WITH STATCOM (MVar)
IKEJA WEST	1	0.200	0.189	0.206	0.226
OGBA	2	0.325	0.215	0.315	0.419
OOJO	3	0.024	0.011	0.143	0.250
OTTA	4	0.028	0.018	0.035	0.067
OMUWO ODOFIN	5	0.158	0.116	0.082	0.195
AKANGBA	6	0.418	0.302	0.221	0.263
APAPA	7	0.391	0.303	0.252	0.281
EGBIN	8	0.054	0.041	0.072	0.192
AJA	9	0.049	0.040	0.032	0.037
MARYLAND	10	0.398	0.379	0.204	0.222
IKORODU	11	0.723	0.512	0.587	0.901
ALAUSA	12	0.3380	0.330	0.140	0.151
LEKKI	13	0.436	0.422	0.159	0.271
	TOTAL	**3.584**	**2.878**	**2.448**	**3.475**

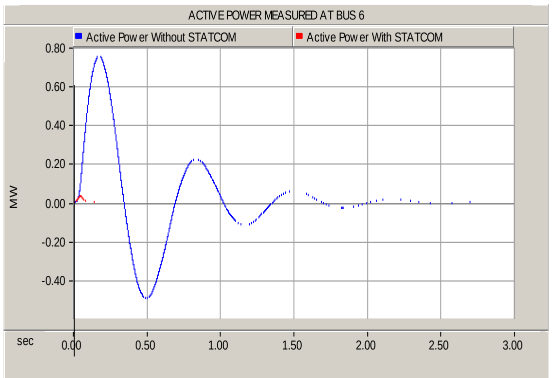

Fig 6: Active Power at Bus 6

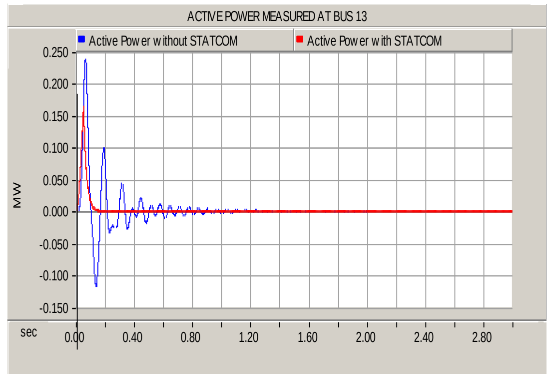

Fig 7: Active Power at Bus 13

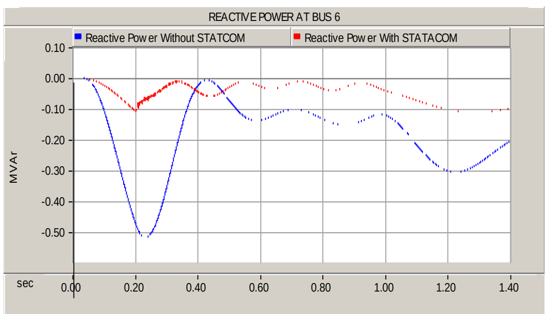

Fig 8: Reactive Power at Bus 6

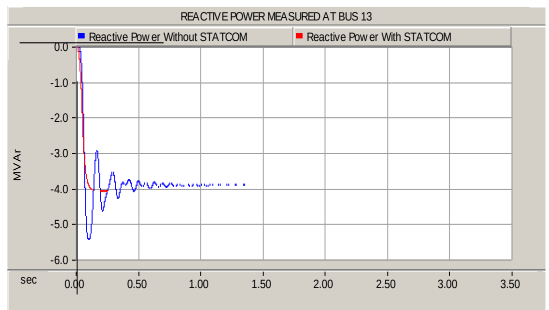

Fig 9: Reactive Power at Bus 13

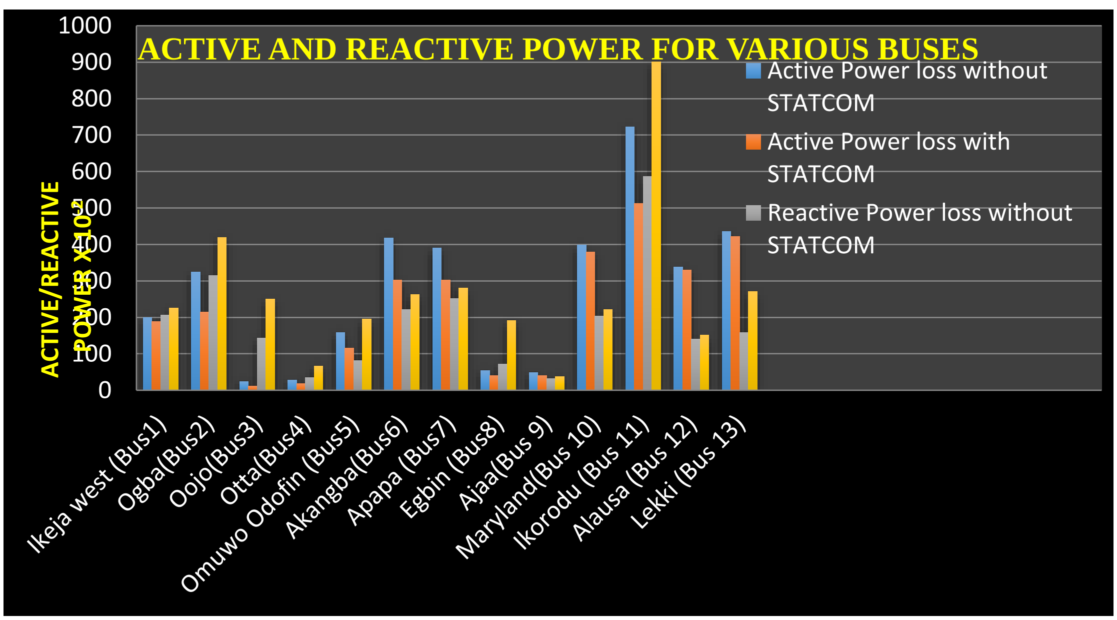

Fig 10. Active and Reactive Power loss with and without STATCOM at various Buses

Conclusion

The study revealed that with the appropriate placement of STATCOM, basic transmission line parameters such as line Impedance, Voltage magnitude, phase angle and frequency were regulated to operate within the maximum tolerable power carrying capacity of the lines. With the STATCOM, both the active and reactive power losses are drastically reduced, hence, improved the power quality of the network.

Recommendation

Having established that the placement of FACTS devices on power network of Ikeja West improves the power contents of the transmission network; it is therefore recommends that the government and the stakeholders in Nigeria electrical power system management should employed this FACTS devices on our power transmission network in order to improve the power qualities.

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APPENDIX

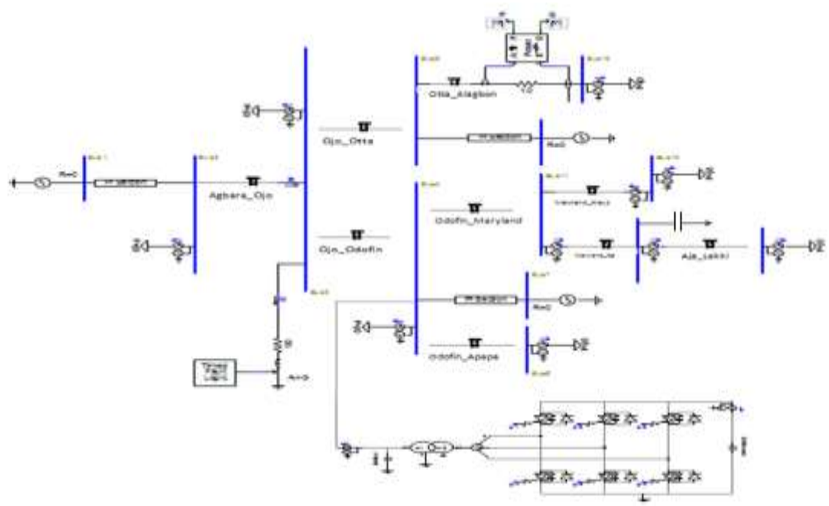

Fig 11. The Single Line PSCAD representation of Ikeja West 330 kV Transmission Network With STATCOM

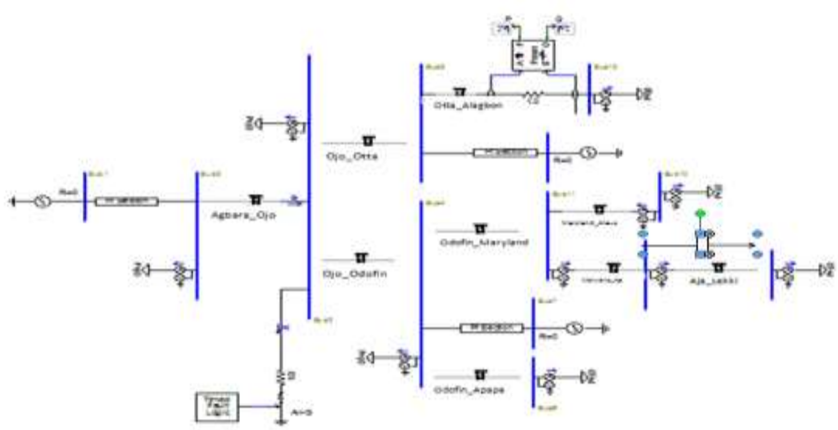

Fig 12. The PSCAD representation of Ikeja West 330 kV Transmission Network without STATCOM