Simulation of Statcom for Voltage Improvement in an Electric Power Network

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***Abstract* - This research work illustrates the importance of STATCOM for Voltage improvement and stability in a power transmission network. A three bus network was first tested to observe the response of a transmission line when STATCOM was introduced to the network.**

The Nigerian 330kV line network was used as a case study to show the importance of STATCOM for voltage improvement. Firstly, two techniques (Newton Raphson's and Fast decoupled) were used to carry out a load flow study of the network .This was done to obtain the buses with low voltage magnitude. STATCOM installation was then simulated on the buses with low voltage magnitude.

It was observed after keen analysis that installation of STATCOM on bus 16 produced an optimal result. The other buses in which STATCOM was installed also showed some level of improvement in the voltage magnitude of some buses. STATCOM is a shunt FACTS device used to inject VAr into the network.

Keywords: STATCOM (Static Synchronous Compensator), Power System Network (PSN), Newton Raphson (NR), Fast Decoupled (FD), Real and Reactive Power.

INTRODUCTION

The function of a power system network (PSN) is to generate and transmit power to load centers at specified voltage and frequency levels and statutory limits exist for the variation about base levels. The nominal frequency shall be 50Hz ± 0.5%. Under system stress the frequency on the power system could experience variations within the limits of 50Hz ± 2.5% (i.e. 48.75 – 51.25 Hz and the nominal voltage shall be 330, 132kV ± 0.5% while Under system stress or following system faults, voltages can be expected to deviate outside the limits by a further ± 5% (excluding transient and sub-transient disturbances). As the system load changes, the resulting change in real and reactive power demands causes variation in the system voltage and frequency levels. The power system is equipped with controllers that reduce these variations to acceptable levels well within the statutory limits. In the operation and control of a power system network (PSN), voltage stability is a major concern to the power system engineer as the PSN nowadays operates very close to its stability limits [1][2].

This is due to increasing load demand, industrialization, environmental and economic factor which hampers the construction of new transmission lines and generating stations. This has caused most PSNs to be weak, heavily loaded and prone to voltage instability [3].

Voltage stability can be defined as the ability of a power system to maintain steady and acceptable voltage at all buses in the system at normal operating conditions, after being subjected to a disturbance. It is desired that the power system remains in the equilibrium state under normal conditions, and reacts to restore the status of the system to acceptable conditions after a disturbance, i.e. the voltage after a disturbance is restored to a value close to the predisturbance situation [4].

MATHEMATICALMODELLING OF STATCOM FOR LOAD FLOW ANALYSIS

The equivalent circuit diagram for STATCOM is shown in fig 1

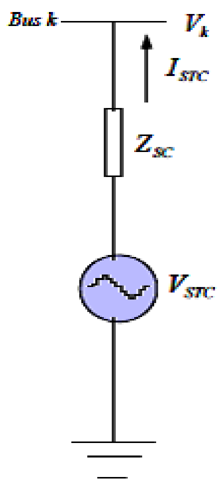

Figure 1: Equivalent circuit for STATCOM

$$V_{stc} = V_k + Z_{sc} I_{stc} \quad 1$$

$$I_{stc} = I_N - Y_{stc} V_k \quad 2$$

Where

$$I_N = Y_{stc} V_{stc}$$

In these expressions, V_k represents bus k voltage and V_{stc} represents voltage source inverter

I_N is the Norton current while I_{stc} is the current in the inverter.

Z_{sc} and Y_{sc} are the transformer impedance and short circuit admittance respectively.
The STATCOM voltage injection V_{stc} bound constraint is as follows

$V_{stc\ min} \leq V_{stc} \leq V_{stc\ max}$.3

Where $V_{stc\ min}$ and V_{stcmax} are the STATCOM's minimum and maximum voltage.

$$S_{stc} = V_{stc}(I_N^* - Y_{sc}^* V_k^*) \quad 5$$

$$S_{stc} = V_{stc}(Y_{sc}^* V_{stc}^* - Y_{sc}^* V_k^*) \quad 6$$

$$S_{stc} = V_{stc}^2 Y_{sc}^* - V_{stc} Y_{sc}^* V_k^* \quad 7$$

$$S_k = V_k I_{stc}^* \quad 8$$

$$S_k = V_{stc} Y_{sc}^* V_k^* - V_k^2 Y_{sc}^* \quad 9$$

METHODOLOGY

A three bus system with 330kV line network was first considered in order to properly visualize the effect of STATCOM model on the network. The STATCOM model

The current expression in 1.2 is transformed into power expression by the VSC and the power is injected into bus k as shown in equation 1.7 and 1.9.

$$S_{stc} = V_{stc} I_{stc}^* \quad 4$$

is simulated on the line for voltage compensation. A twenty-seven bus system was later analyzed for load flow using Newton Raphson and fast decouple techniques. The voltages whose magnitude was less than or more than 5% of its magnitude was considered for the simulation of STATCOM. The improvement on the line is observed. MATLAB 7.5 was used for the simulation for 0.4sec.

CASE STUDY

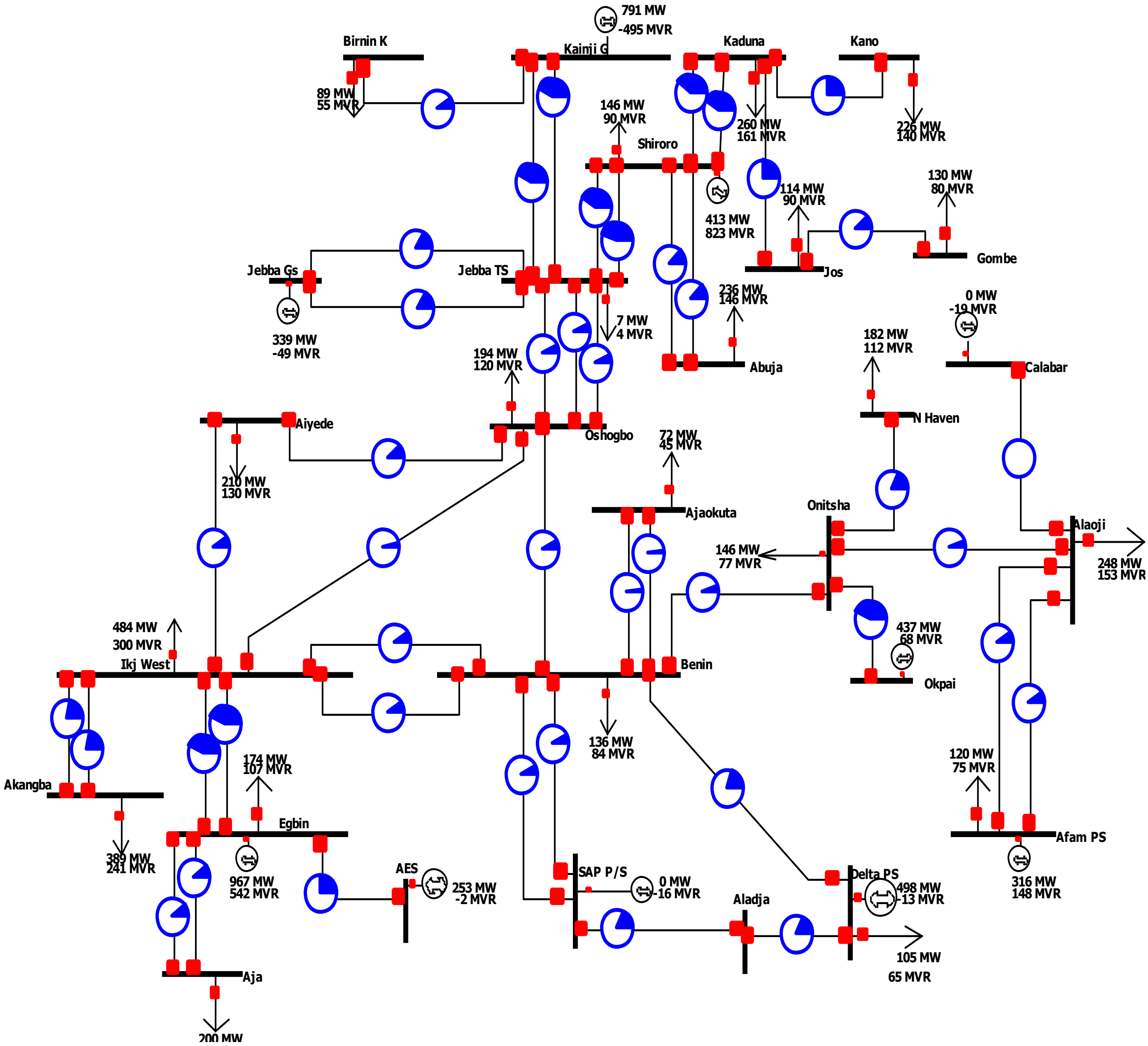

Figure 2: 330kV Line of Nigeria Power Network

The system may be divided into three major sections: - North, South-East and the South-West sections. The North is connected to the South through one triple circuit lines between Jebba and Oshogbo while the West is linked to the East through one transmission line from Oshogbo to Benin and one double circuit line from Ikeja to Benin. The data of the Nigerian transmission system were sourced from the National Control Centre of Power Holding Company of Nigeria, Oshogbo, Nigeria. According to [5] and [6], the datas for the one-line diagram in figure 2 were obtained.

SIMULATION RESULT AND ANALYSIS

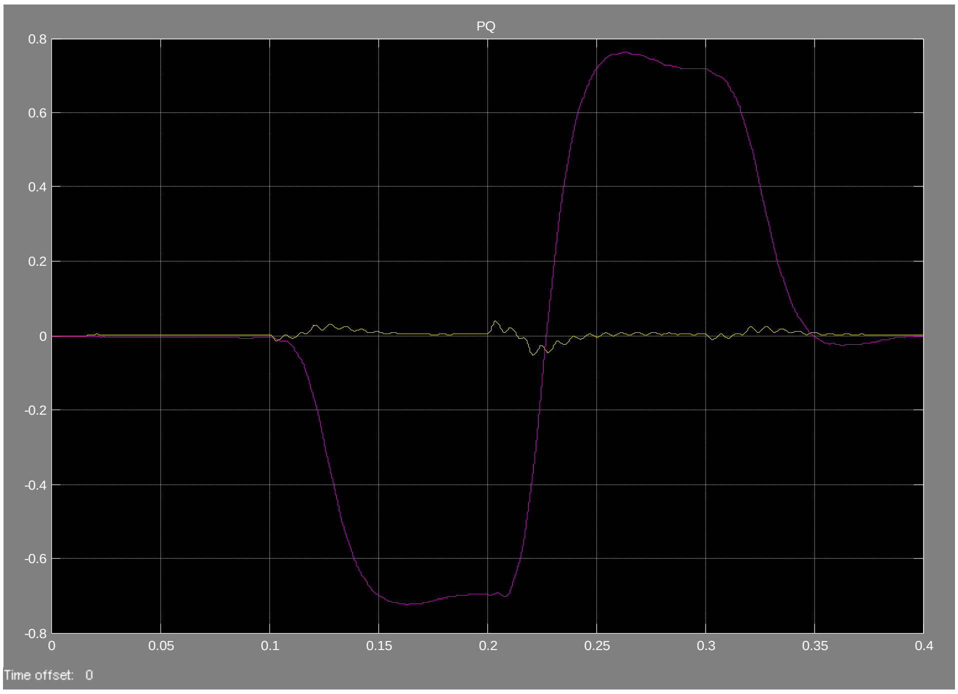

Figure 3: The Real and Reactive Power Response Curve in Bus 1

The real and reactive power in fig 3 is in per unit (pu) value. The reactive power curve is of importance because it gives a picture of the variation in voltage at bus 1.From Figure 3, after a simulation time of 0.108 second, the reactive power demand on line 1 increases and hence, the STATCOM begins to inject reactive power into the network. This continues till the simulation time approaches approximately 0.218 second. At this point, the reactive power increases sharply to approximately 0.76pu, then, the STATCOM begins to demand reactive power from line 1 linking bus 1.The injection and demand of reactive power by the STATCOM, regulates the voltage magnitude of the BUS 1.

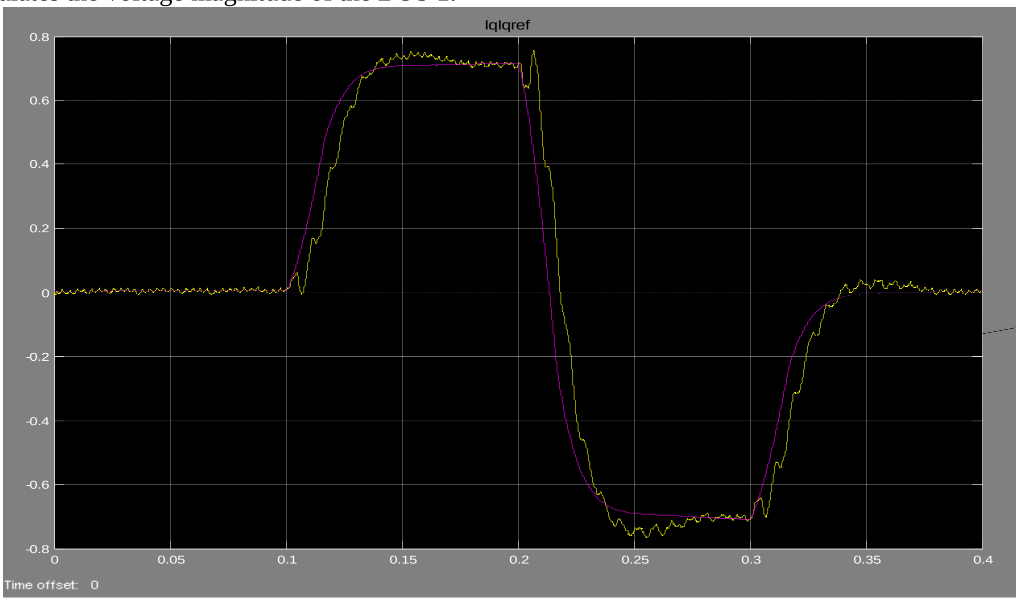

Figure 4: Simulation graph for the quadrature current and quadrature current reference

The quadrature current through bus1 is inversely proportional to the bus1 voltage. From figure 4, it can be seen that the quadrature current began to increase at 0.1 second. It continued till it approached approximately 0.7pu and then it remained constant for about 0.06second .It reduced considerably and then achieved a steady state at 0.35second.At this point, the reactive power demand and generation is approximately equal.it should also be noted that as the current increased, the voltage decreased at almost similar rate.

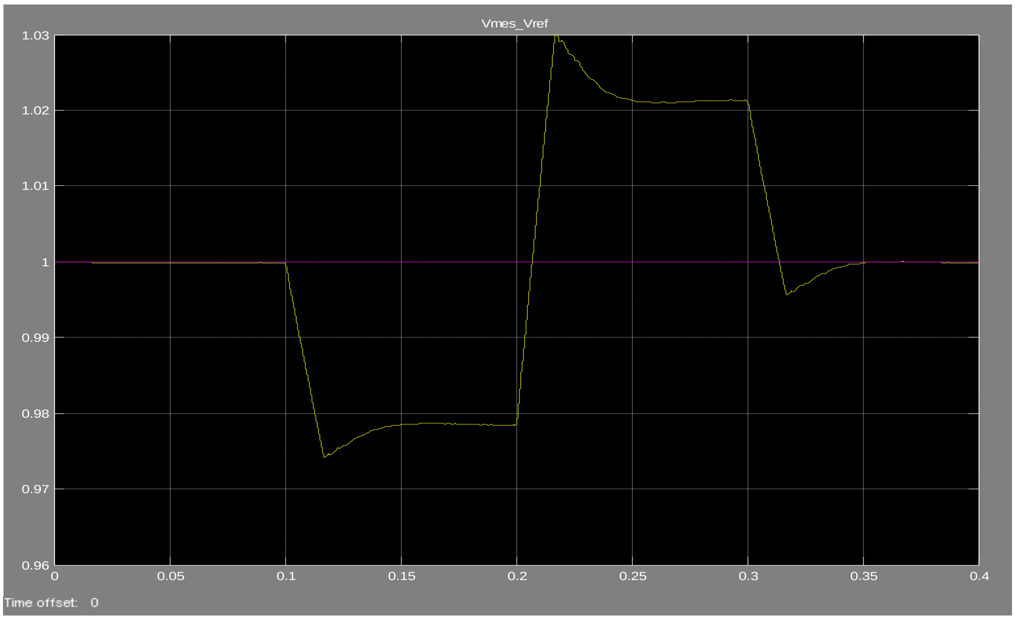

Figure 5:Simulation Graph of the Measured and Reference Voltage

From Figure 5, it can be seen that at approximately 0.1 second, the voltage magnitude at bus1 began to reduce. This was as a result of the reduction in the reactive power generated by the transmission line linking bus1.At about 0.2second of the simulation, the voltage began to increase. This was as a result of the reactive power injected by the STATCOM into bus1.The voltage approaches steady state at 0.35second of the simulation time.

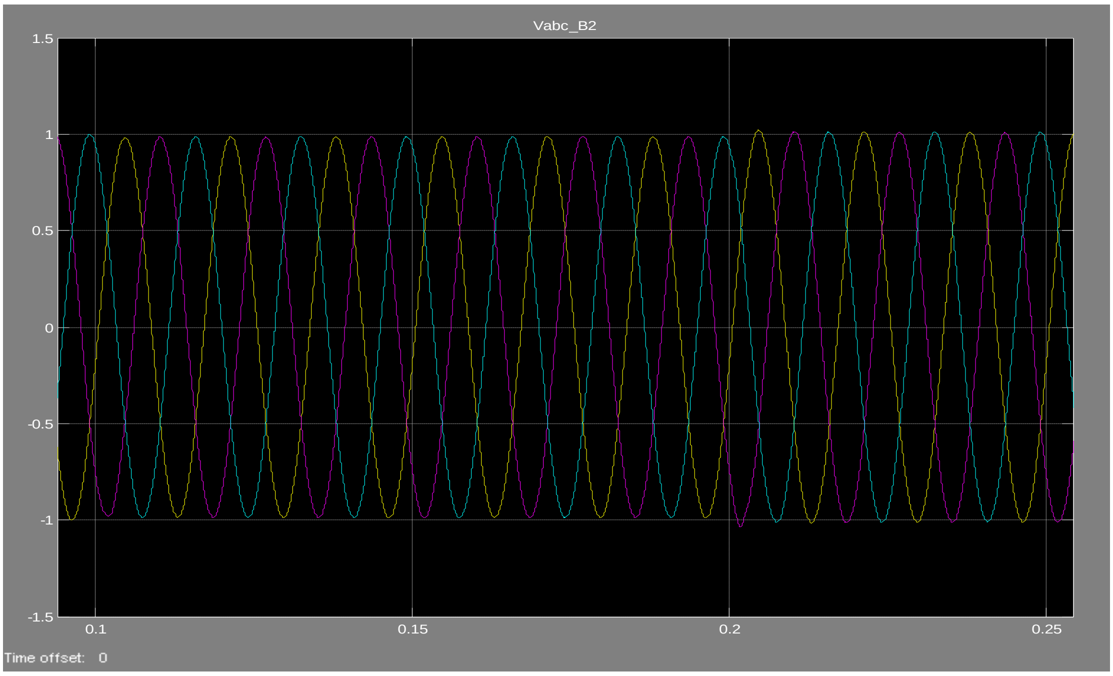

Figure 6 Simulation Graph of the Three Phase Voltage in Bus 2

From Fig 6, it can be seen that the three phase voltage in bus2 is balanced and out of phase by 120^0.

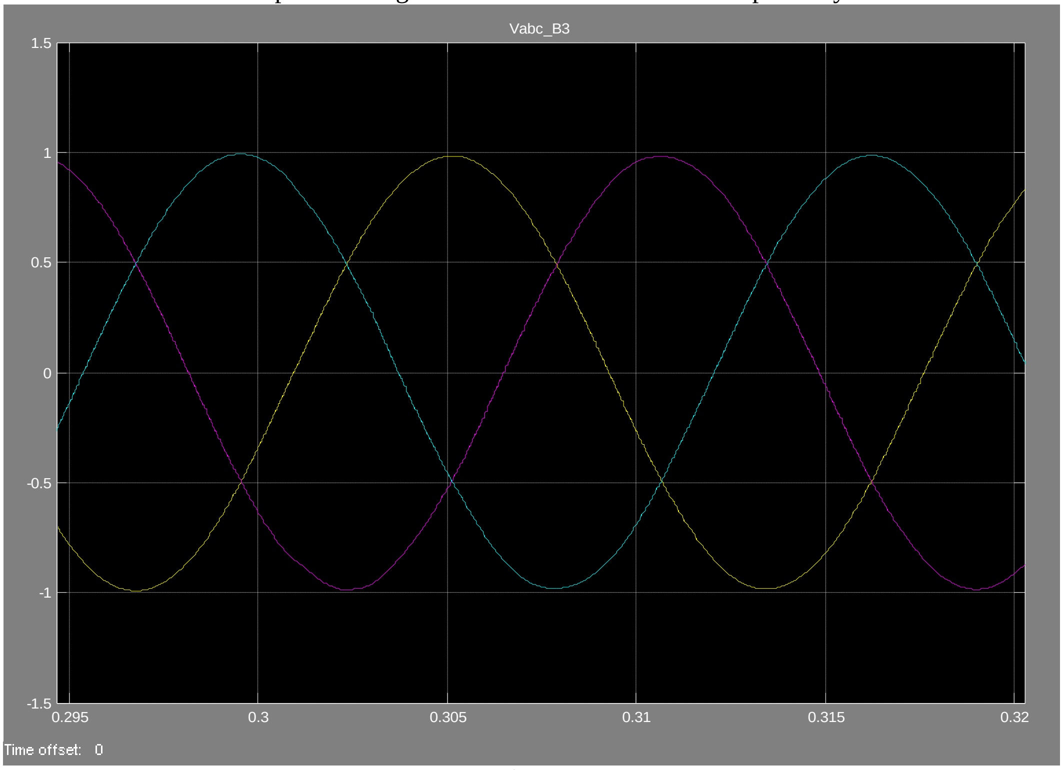

Figure 7: Simulation Graph of the Three Phase Voltage in Bus 3

From Fig 7, it can be seen that the three phase voltage in bus2 is balanced and out of phase by 120^0.

Result from Load Flow Study using Fast decouple Technique

Bus No.	Voltage Magnitude	Generation		Load	
		P(MW)	Q(MVAR)	P(MW)	Q(MVAR)
1	1.000	1066.88	-214.72	------	---------
2	1.000	413.00	923.83	------	---------
3	1.000	339.00	151.20	------	---------
4	0.966	------	-------	------	---------
5	1.000	967.00	871.54	------	---------
6	1.000	316.00	276.56	------	---------
7	1.000	498.00	173.05	------	---------
8	1.000	235.00	-42.57	------	---------
9	0.979	--------	--------	----	--------
10	0.974	--------	--------	89.00	55.00
11	0.825	--------	--------	226.00	14.00

12	0.815	--------	--------	114.00	9.00
13	0.769	--------	--------	130.00	80.00
14	0.881	--------	--------	260.00	161.00
15	0.973	--------	--------	7.40	3.79
16	0.922	--------	--------	236.00	146.00
17	0.902	--------	--------	194.00	120.00
18	0.921	--------	--------	72.00	45.00
19	0.878	--------	--------	182.00	112.00
20	0.802	--------	--------	210.00	130.00
21	0.854	--------	--------	484.00	300.00
22	0.946	--------	--------	136.00	84.00
23	0.918	--------	--------	146.00	77.00
24	0.978	--------	--------	248.00	153.00
25	0.700	--------	--------	389.00	241.00
26	0.955	--------	--------	200.00	124.00
27	0.989	--------	--------	4.80	2.46
Total		3834.88	2138.89	3328.20	1857.25

Fast-decoupled power flow converged in 28 P-iterations and 28 Q-iterations after 0.12 second.
From the load flow analysis, the following buses have voltage magnitude less than the 5% of the reference voltage magnitude (330kV).

Installation of STATCOM on Bus 11 (Kano)
STATCOM is installed on the Kano bus and the effect on the voltage of the remaining buses is shown in figure 8.

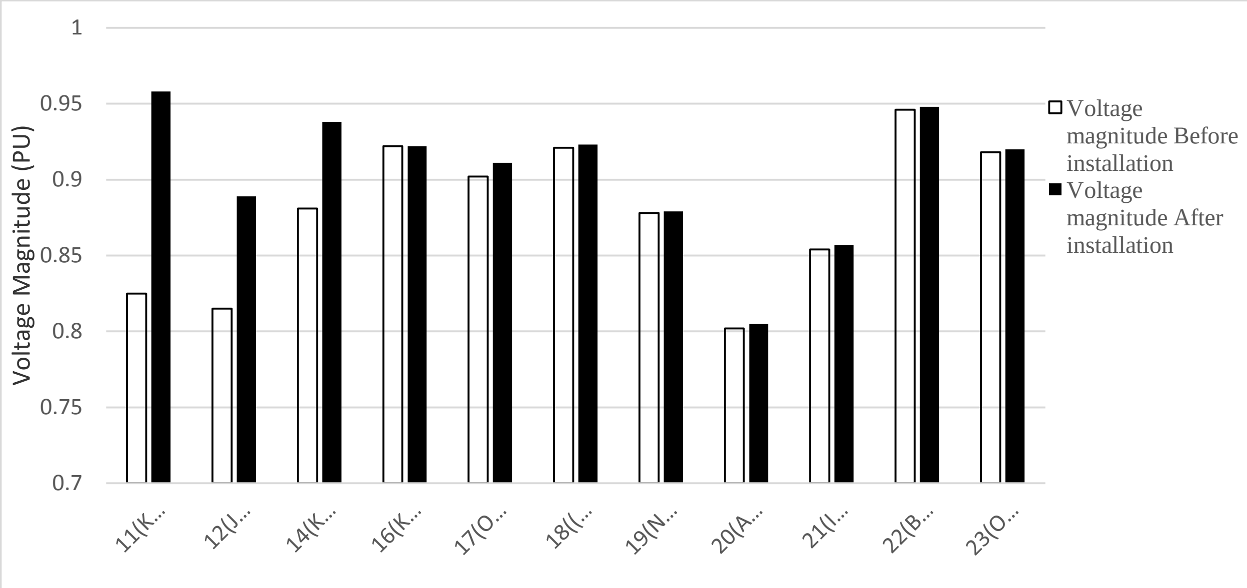

Figure 8: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 11

Installation of STATCOM on Bus 11(Kano) shows increase in voltage magnitude on buses 11(Kano), 12(Jos), 14(Kaduna), 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha), &25(Akangba) except bus 16(katampe) which no increase in voltage was recorded.

Installation of STATCOM on Bus 12 (Jos)
STATCOM is installed on the Jos bus and the effect on the voltage of the remaining buses is shown in figure 9.

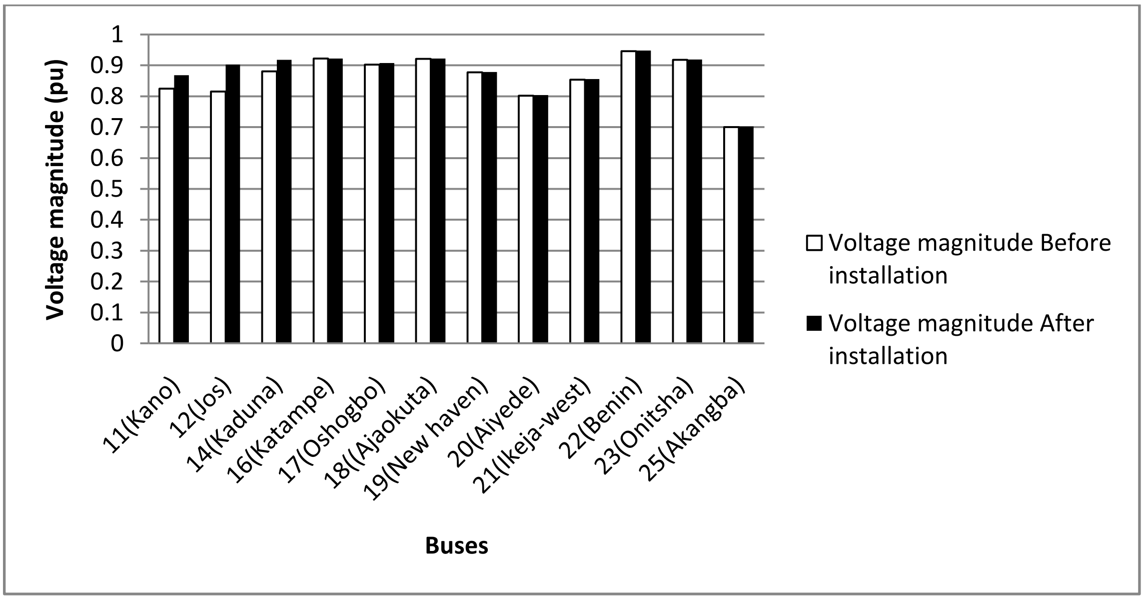

Figure 9: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 12

Installation of STATCOM on Bus12 (Jos) shows that bus 16(katampe) had no increase in voltage magnitude, but all others i.e. bus11 (Kano), 12(Jos), 14(Kaduna), 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) and 25(Akangba) showed reasonable increase in voltage magnitude.

Installation of STATCOM on Bus 14 (Kaduna)
STATCOM is installed on the Kaduna bus and the effect on the voltage of the remaining buses is shown in figure 10

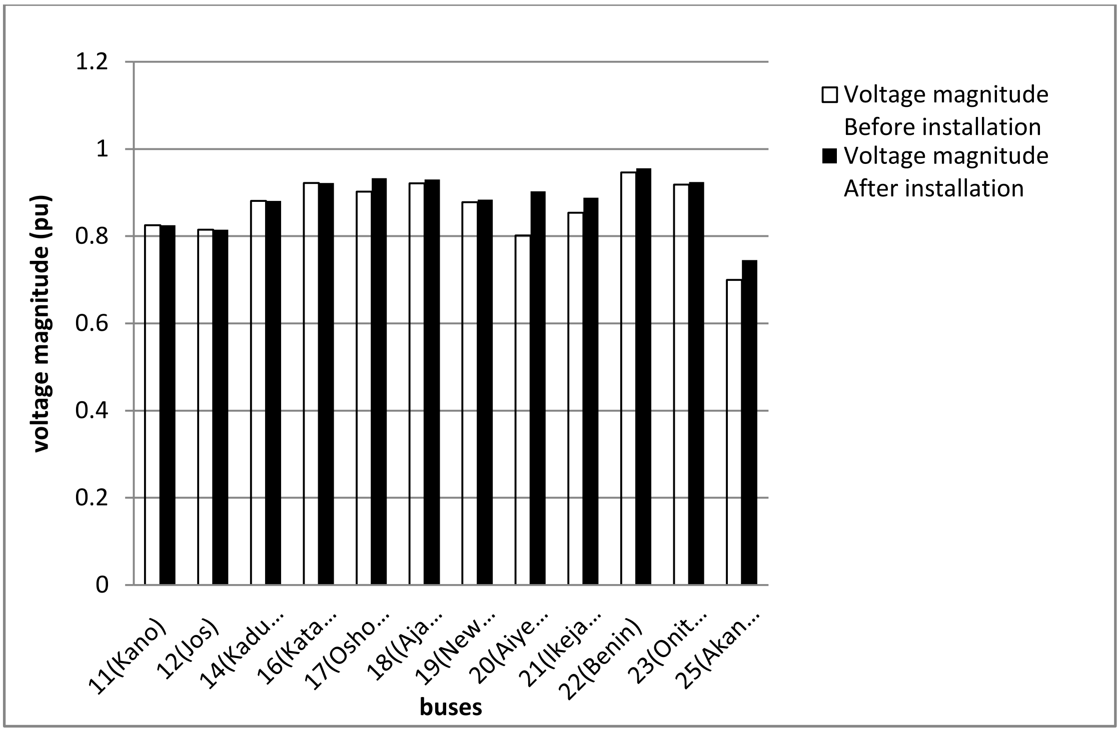

Figure 10: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 14

Installation of STATCOM on Bus14 (Kaduna) shows increase in voltage magnitude on buses11 (Kano), 12(Jos), 14(Kaduna), 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba), but bus 16(katampe) had no increase in voltage.

Installation of STATCOM on Bus 16 (Katampe)

STATCOM is installed on the Katampe bus and the effect on the voltage of the remaining buses is shown in figure 11.

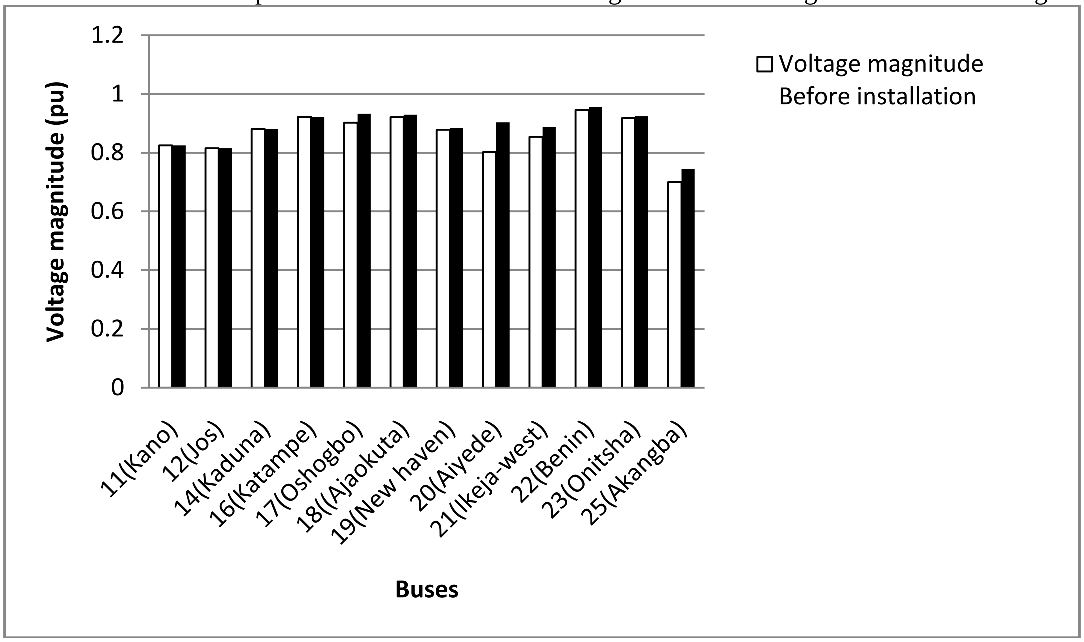

Figure 11: Chart of Bus Voltage before and the Installation of STATCOM at Bus 16

Installation of STATCOM on Bus16 (katampe) shows increase in voltage magnitude on all the buses.

Installation of STATCOM on Bus 17 (Oshogbo)

STATCOM is installed on the Oshogbo bus and the effect on the voltage of the remaining buses is shown in figure 12.

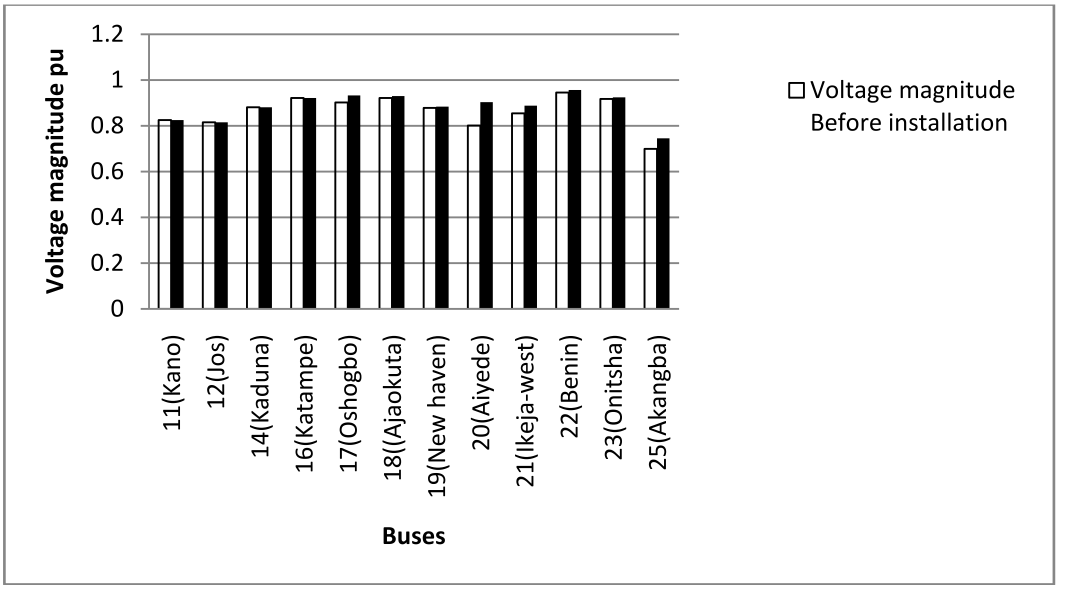

Figure 12: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 17

Installation of STATCOM on Bus17 (Oshogbo) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

Installation of STATCOM on Bus 18 (Ajaokuta)

STATCOM is installed on the Ajaokuta bus and the effect on the voltage of the remaining buses is shown in figure 13.

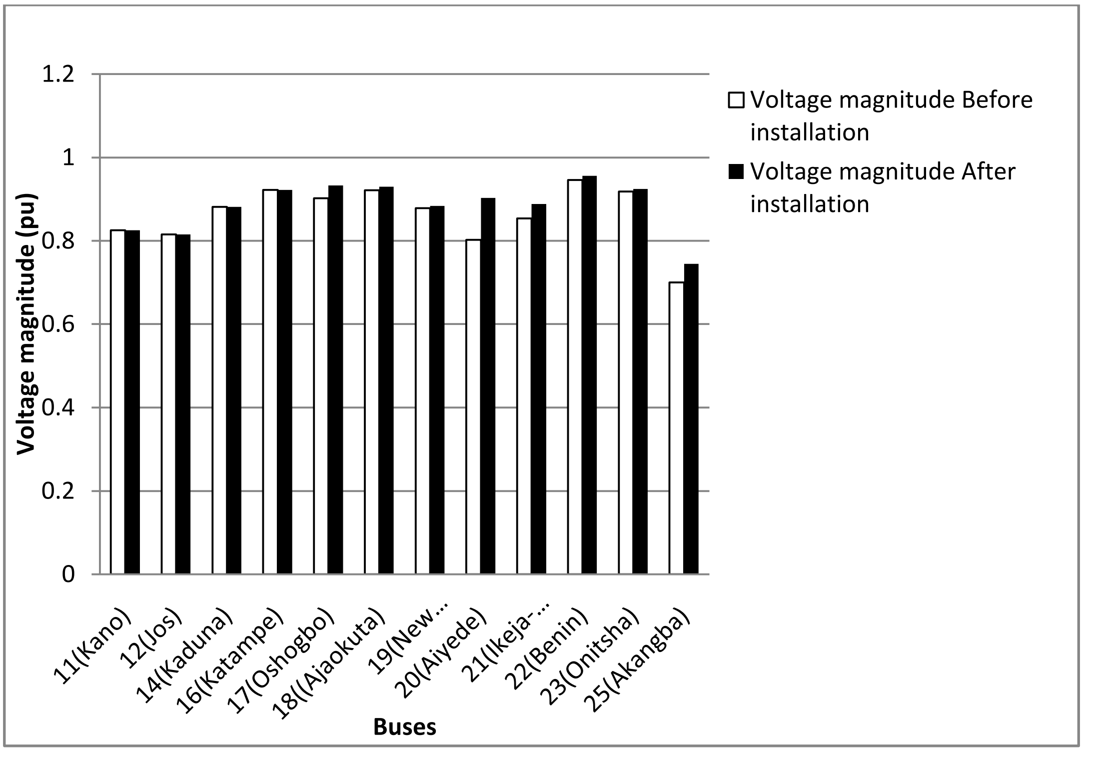

Figure 13: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 18

Installation of STATCOM on Bus18 (Ajaokuta) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

Installation of STATCOM on Bus 19 (New heaven)
STATCOM is installed on the New heaven bus and the effect on the voltage of the remaining buses is shown in figure 14

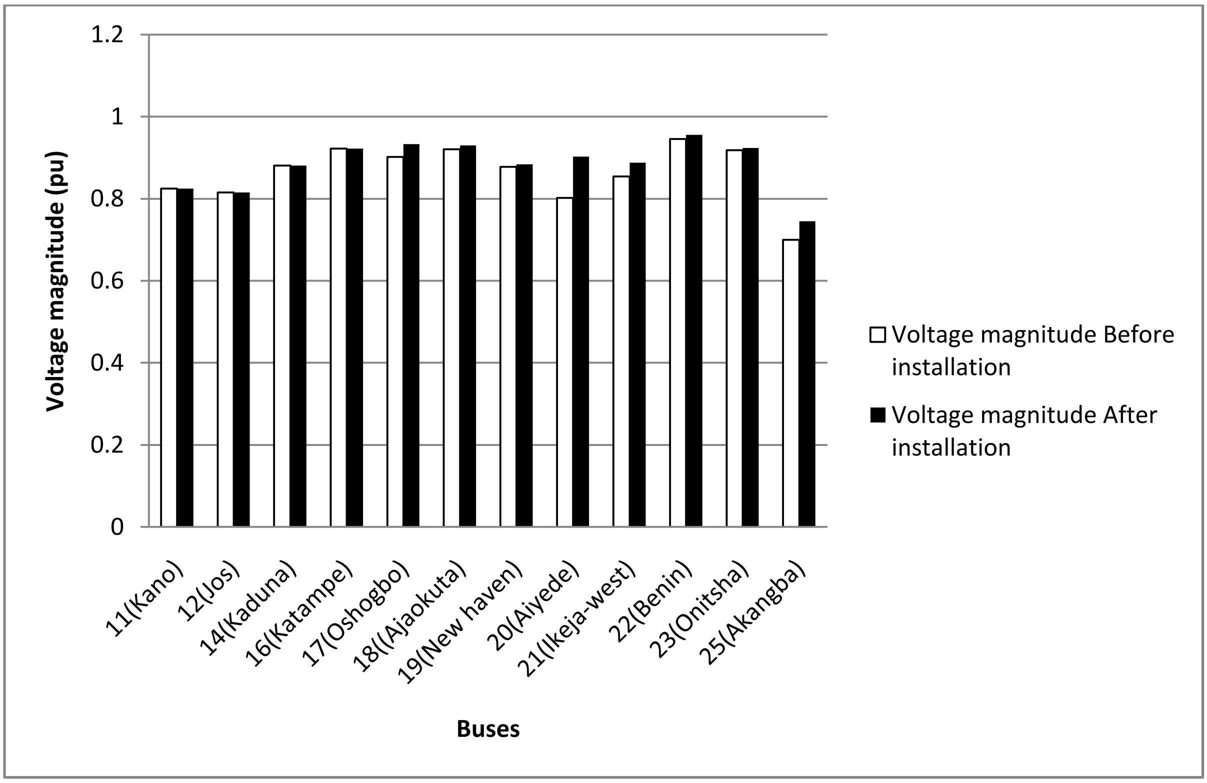

Figure 14: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 19

Installation of STATCOM on Bus19 (New haven) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

Installation of STATCOM on Bus 20 (Aiyede)
STATCOM is installed on the Aiyede bus and the effect on the voltage of the remaining buses is shown in figure 15.

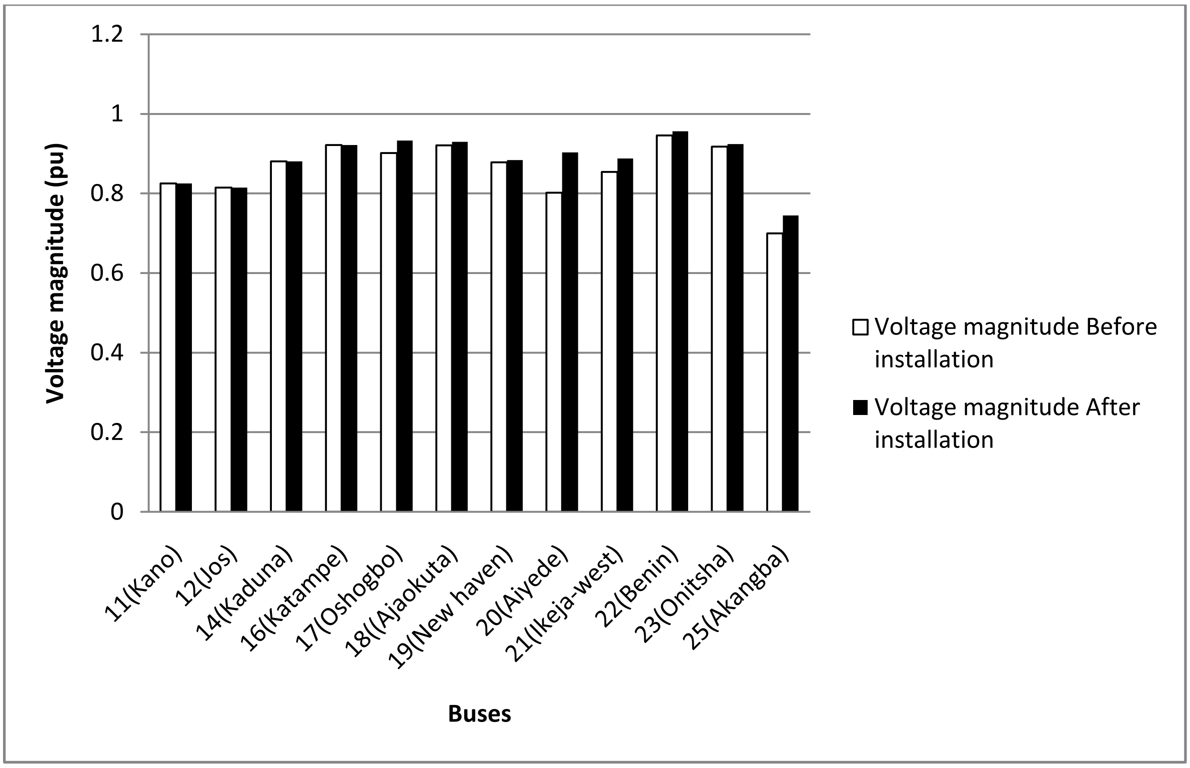

Figure 15: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 20

Installation of STATCOM on Bus20 (Aiyede) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

Installation of STATCOM on Bus 21 (Ikeja-West)

STATCOM is installed on the Ikeja-west bus and the effect on the voltage of the remaining buses is shown in figure 16.

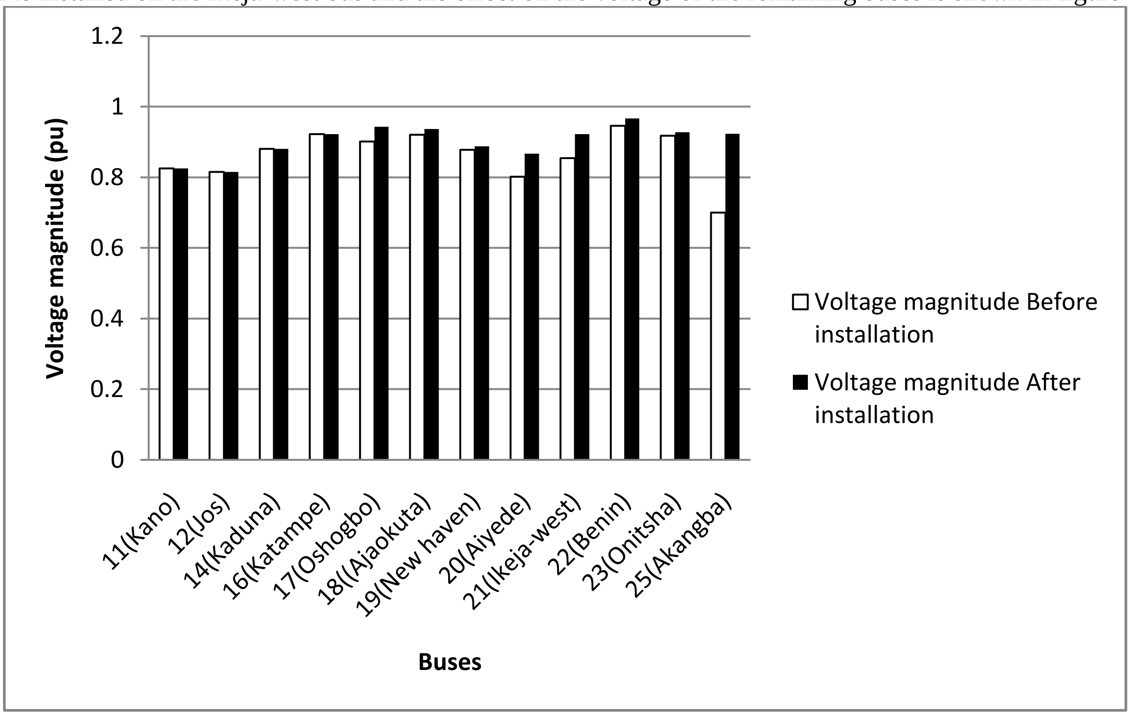

Figure 16: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 21

Installation of STATCOM on Bus21 (Ikeja-west) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

Installation of STATCOM on Bus 22 (Benin)

STATCOM is installed on the Benin bus and the effect on the voltage of the remaining buses is shown in figure 17.

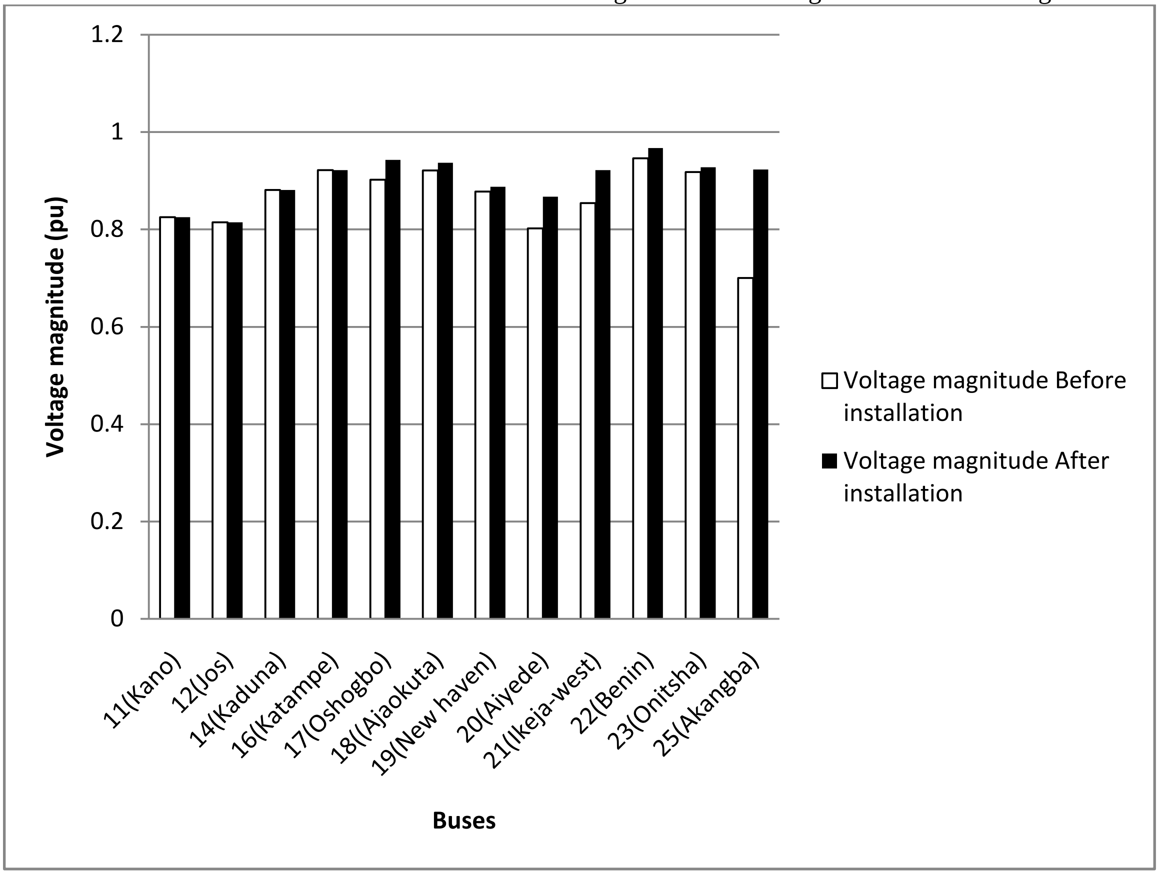

Figure 17: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 22

Installation of STATCOM on Bus22 (Benin) shows increase in voltage magnitude only on buses 11(Kano), 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha)&25(Akangba).

Installation of STATCOM on Bus 23 (Onitsha)

STATCOM is installed on the Onitsha bus and the effect on the voltage of the remaining buses is shown in figure 18.

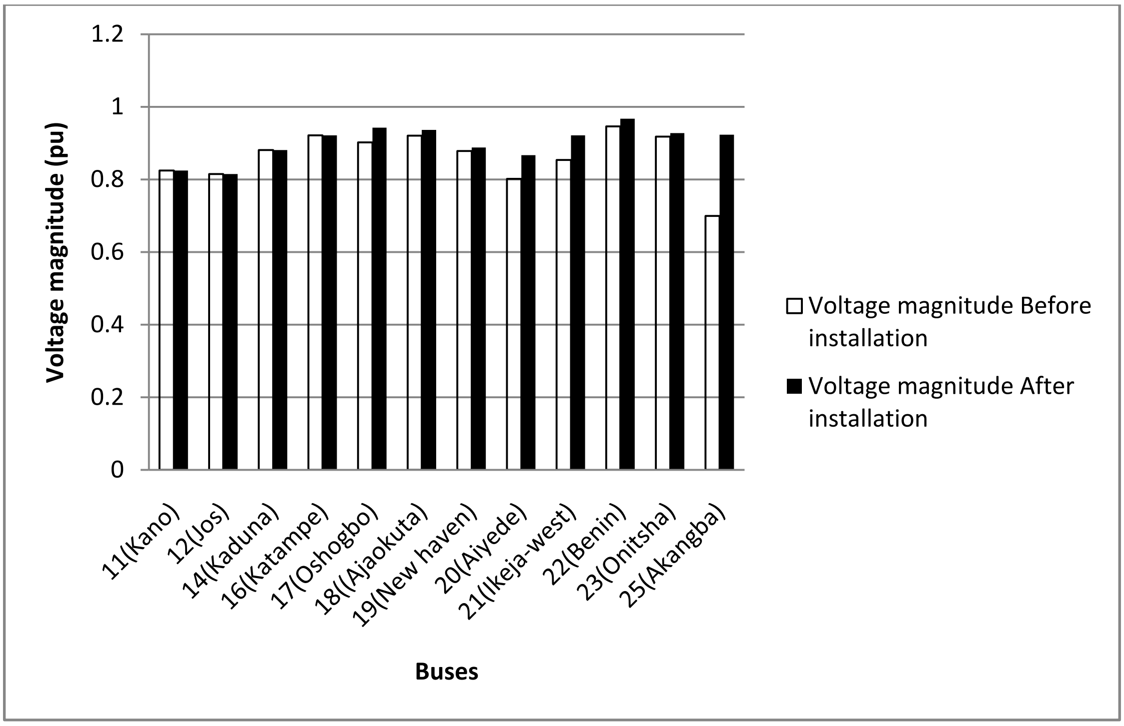

Figure 18: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 23

Installation of STATCOM on Bus23 (Onitsha) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

Installation of STATCOM on Bus 25 (Akangba)

STATCOM is installed on the Akangba bus and the effect on the voltage of the remaining buses is shown in figure 19.

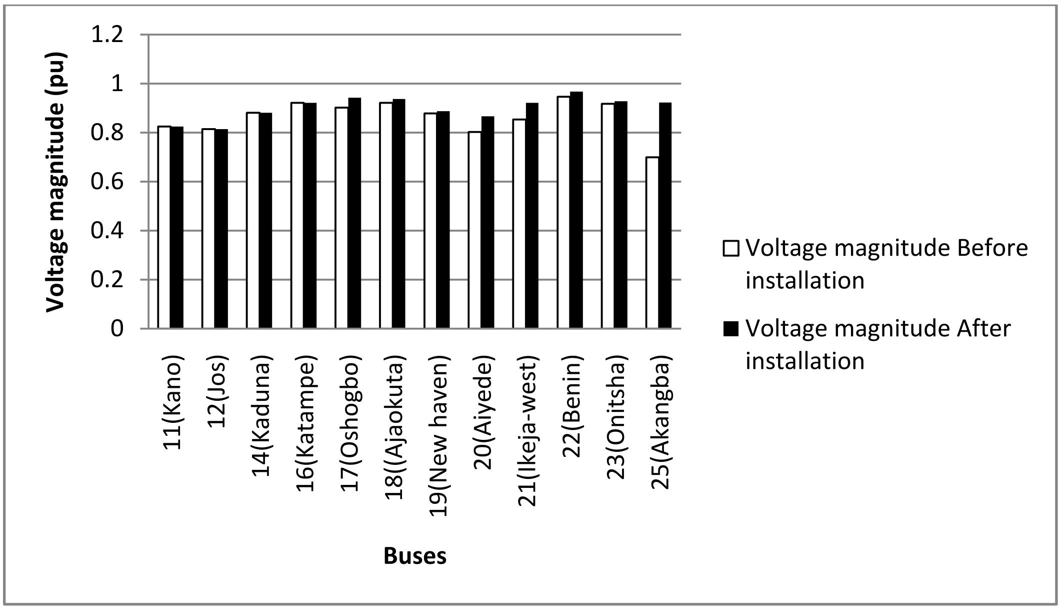

Figure 19: Chart of Bus Voltage before and after the Installation of STATCOM at Bus 25

Installation of STATCOM on Bus25 (Akangba) shows increase in voltage magnitude only on buses 17(Oshogbo), 18(Ajaokuta), 19(New haven), 20(Aiyede), 21(Ikeja-west), 22(Benin), 23(Onitsha) &25(Akangba).

CONCLUSION

This research work illustrates the importance of STATCOM for Voltage improvement and stability in a power transmission network. A three bus network was first tested to observe the response of a transmission line when STATCOM was introduced to the network.

The Nigerian 330kV line network was used as a case study to show the importance of STATCOM for voltage improvement. Firstly, two techniques (NR and FDLF) were used to carry out a load flow study of the network .This was done to obtain the buses with low voltage magnitude. STATCOM installation was then simulated on the buses with low voltage magnitude.

It was observed after keen analysis that installation of STATCOM on bus 16 produced an optimal result.

It is not economically viable to install STATCOM on all the buses with low voltage magnitude hence, it becomes necessary to obtain an optimal location for the installation of STATCOM. For optimal installation of STATCOM, Bus16 becomes an ideal bus because every other bus showed a noticeable increment in voltage magnitude when STATCOM was installed at Bus16.

RECOMMENDATIONS

Based on the findings of this research work, the following recommendations have been suggested.

a. STATCOM should be installed at bus 16 (Katampe) for optimal improvement of voltage in the network.
b. In order to successfully install and operate the FACTS device, adequate training should be given to the power system operators.
c. As the power network increases, load flow analysis should be regularly conducted in order to monitor the changes in voltage magnitude along buses.
d. For further research purposes, the benefit of other FACTS devices in voltage, power factor and transmission losses improvement should be studied.

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