International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

Power System's Voltage Stability Improvement Using Static Var Compensator

Matthew Simeon[1], Wara S. Tita[2], Adejumobi A. Isaiah[3], Ajisegiri E. S. A.[4], Olanipekun A. Joseph[5]
[1,2,3,4,5]*Federal University of Agriculture, Abeokuta*

***Abstract*— In alternating current systems, voltage fluctuation is a common phenomenon. Most of the voltage fluctuation problems result from the changes in the system's reactive power resulting from excessive supply or consumption of reactive power by the elements of the system and the variation in the consumers' loads. In this paper, the effect of Static Var Compensator (SVC) in stabilizing power system's voltage through effective reactive power compensation was investigated. Power flow equations involving voltage drop with/without SVC were developed. SVC modeling equations were also developed and used to determine its parameters. Based on the SVC parameters, SIMULINK blocks were used to implement the phase controlled Thyristor–Controlled-Reactor Fixed-Capacitor (TCR-FC) SVC. The Nigerian 28-bus power system used for the study was also modeled using SIMULINK/MATLAB. The 28-bus system was first simulated without SVC and then with two SVCs located at different buses to obtain the bus voltages in both cases. From the bus voltages the total voltage drops for the system with and without SVC were estimated and compared. The compared results clearly showed that, the system's voltage drop was reduced by 33.78% indicating a significant improvement in the system's voltage stability when SVCs were applied.**

***Keywords*—Reactive Power, SIMULINK, Static Var Compensator, Voltage Drop, Voltage Stability**

I. INTRODUCTION

Power systems suffer greatly from voltage instability especially due to excessive consumption or injection of reactive power by the system elements and the consumers' loads.

The voltage instability caused by the variation in the reactive power requirement of the system's elements and the consumers' loads either result in excessive high or low voltage which may cause damage to the system and the consumer's load since the system elements and the consumers' loads are design to operate within a specific voltage range.

The system's voltage goes high if there is excessive injection of reactive power by the system elements or the consumers' loads, but goes low if there is excessive consumption of reactive power by the system elements or the consumers' loads.

As a result the system's reactive power needs to be continuously adjusted through effective reactive power compensation if the variation in the system's voltage must be kept within the allowable range [6]. To achieve this several methods have been used. The traditional methods used include [7]: reconfiguration of system structure, generator excitation regulation, synchronous generator, changing the voltage by transformer tap to adjust the power flow in the grid, series compensation capacitor, switching in/out the shunt reactor or shunt capacitor.

With these methods the desired objectives were not effectively achieved with wear and tear in the mechanical components and slow response being the major problems. However, extensive research works were carried out recently leading to the discovery of FACTS devices which have been mainly used for solving various power system steady state control problems such as, voltage regulation, power flow control, and transfer capability enhancement with near-instantaneous response [1]. These FACTS devices include: Static VAR Compensator (SVC), Thyristor- Controlled Series Capacitor (TCSC), Thyristor-Controlled Phase Shifter (TCPS), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC),

All the FACTS devices exhibit near instantaneous response to system changes and are made up of solid semi-conductor component thereby eliminating the problems of mechanical wear and tear. However, this paper seeks to study the effect of the Static Var Compensator in stabilizing power system's voltage using the Nigerian 28-bus 330kV power system for the study and SIMULINK/MALAB as the simulation environment.

II. THE STATIC VAR COMPENSATOR

Static Var Compensators are shunt connected static generators/absorbers whose outputs are varied so as to control the voltage of the electric power systems [2]. They are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

In its simple form, SVC is connected as Thyristor-Controlled-Reactor Fixed Capacitor (TCR-FC) configuration as shown in Figure 1 with its equivalent circuit in Figure 2. Its major components include coupling transformer, thyristor valves, reactors, and capacitors (for harmonic filtering through tuning) [3].

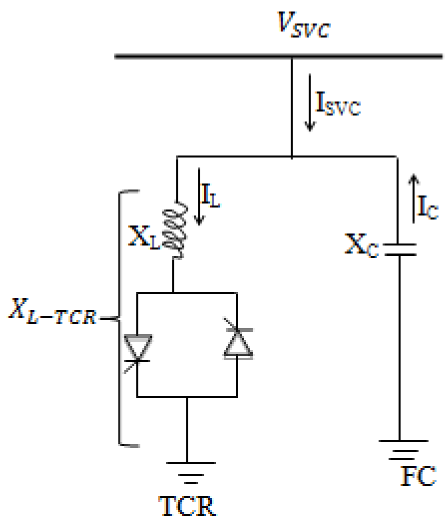

Figure 1: Functional diagram of a TCR-FC SVC [5]

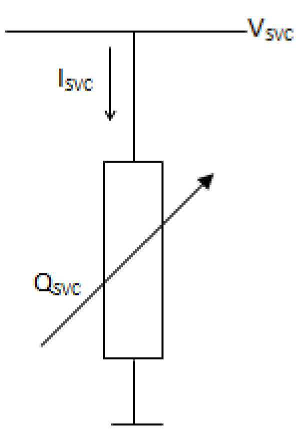

Figure 2: Equivalent circuit of the SVC [5]

III. The Power System Under Study

Figure 3, shows the Nigerian 330kV, 28-bus power system under study. It consists of twenty-eight (28) buses, nine (9) generation stations, and fifty-two (52) transmission lines.

The relevant Data of the PHCN network as obtained from PHCN Control Centre, Oshogbo is as shown in Table I.

A. SIMULINK Model of the Nigerian 28-Bus Power System under Study

Using Figure 3 and Table I, the SIMULINK model of the single line diagram of the Nigerian 330kV, 28-bus power system used for the study was obtained as shown in Figure 4. Each generation station was modeled as a voltage source and each transmission line represented by its equivalent resistance and reactance.

In the model, measurement apparatus (voltmeter, ammeter and wattmeter) and the modeled SVC were incorporated.

B. Bus Voltage and Voltage drop Equations

Consider a transmission line between any two given buses i and k extracted from the Nigerian 28-bus power system of Figure 4 and represented as shown in Figure 5.

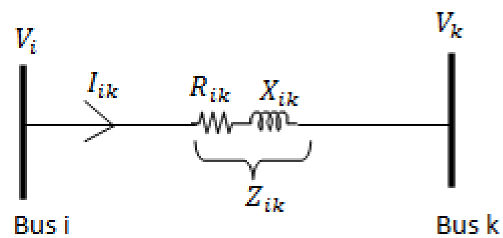

Figure 5: Transmission Line Model extracted from the Nigerian 28-Bus Power System

The symbols used in the transmission line model of Figure 5 are defined as follows

V_i= complex voltage at bus i

V_k= complex power at bus k

R_{ik}= resistance of the transmission line between buses i and k

X_{ik}= reactance of the transmission line between buses i and k

I_{ik}=complex current flowing from buses i to k

Z_{ik}= impedance of the transmission line between buses i and k

From Figure 5, the voltage drop (V_d) between buses i and k can be expressed as:

$$V_d = V_i - V_k \qquad (1)$$

By applying Ohm's law, the complex current flowing from bus i to k is expressed as:

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

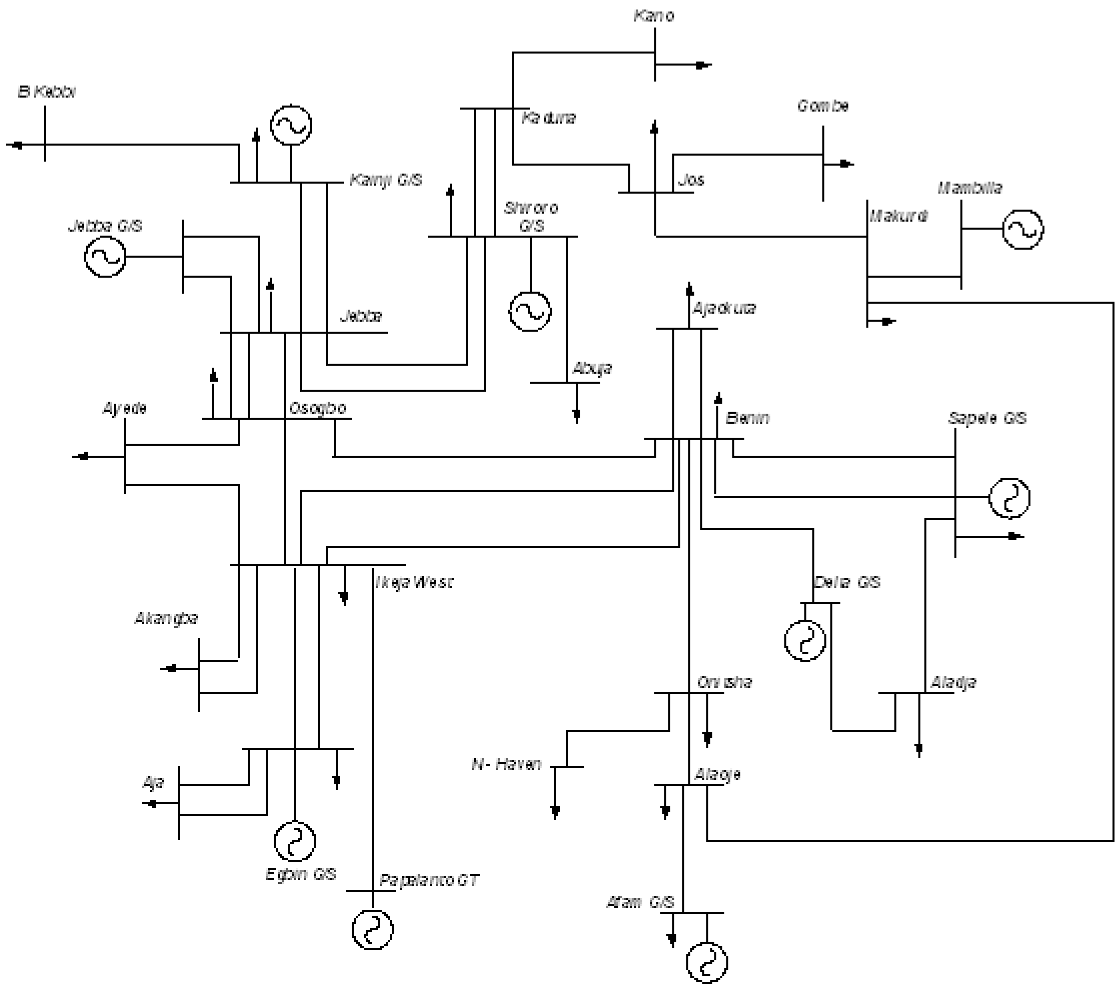

Figure 3: The Nigerian 28-bus power system

Source: (National Control Centre, Power Holding Company of Nigerian, 2012)

$$I_{ik} = \frac{V_i - V_k}{Z_{ik}} \quad (2)$$

Where: $Z_{ik} = R_{ik} + X_{ik}$

Equation (2) can be expressed in admittance form as:

$$I_{ik} = (V_i - V_k)Y_{ik} \quad (3)$$

Where: $Y_{ik} = \frac{1}{Z_{ik}}$ and is defined as the admittance of the transmission line.

Now, the complex power (S_{ik}) flowing from bus i to k is given by [4]:

$$S_{ik} = V_i I_{ik}^* \quad (4)$$

Expressing the complex power of equation (4) in real power (P) and reactive (Q) power form gives;

$$S_{ik} = P_{ik} + Q_{ik} = V_i I_{ik}^* \quad (5)$$

Taking the conjugate of equation (5) yields;

$$P_{ik} - Q_{ik} = V_i^* I_{ik} \quad (6)$$

From (6),

$$I_{ik} = \frac{P_{ik} - Q_{ik}}{V_i^*} \quad (7)$$

Comparing equations (1), (3) and (7) gives

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

$$\frac{P_{ik}-Q_{ik}}{V_i^*} = V_d Y_{ik} \qquad (8)$$

From equation (8),

$$V_d = \frac{P_{ik}-Q_{ik}}{Y_{ik}} V_i^* \qquad (9)$$

From equation (9), it could be seen that by adjusting the system's reactive power at bus k while keeping the voltage at bus i constant, the voltage between buses i and k can be regulated to minimizing the system's total voltage drop.

TABLE I
NETWORK DATA OF THE NIGERIAN 28-BUS POWER SYSTEM

Bus Identification		**Bus Loads**		**Transmission Lines Data**			
Name	**No**	**MW**	**MVAR**	**Bus**		**Resistance R(pu)**	**Reactance X(pu)**
				FROM	TO		
Egbin	1	68.90	51.70				
Delta	2	0.00	0.00	1	3	0.0006	0.0044
Aja	3	274.40	205.80	4	5	0.0007	0.0050
Akangba	4	244.70	258.50	1	5	0.0023	0.0176
Ikeja-West	5	633.20	474.90	5	8	0.0110	0.0828
Ajaokuta	6	13.80	10.30	5	9	0.0054	0.0405
Aladja	7	96.50	72.40	5	10	0.0099	0.0745
Benin	8	383.30	287.50	6	8	0.0077	0.0576
Ayede	9	275.80	206.8	2	8	0.0043	0.0317
Osogbo	10	201.20	150.90	2	7	0.0012	0.0089
Afam	11	52.50	39.40	7	24	0.0025	0.0186
Alaoji	12	427.00	320.20	8	14	0.0054	0.0405
New-Heaven	13	177.90	133.40	8	10	0.0098	0.0742
Onitsha	14	184.60	138.40	8	24	0.0020	0.0148
B/Kebbi	15	114.50	85.90	9	10	0.0045	0.0340
Gombe	16	130.60	97.90	15	21	0.0122	0.0916
Jebba	17	11.00	8.20	10	17	0.0061	0.0461
Jebba G	18	0.00	0.00	11	12	0.0010	0.0074
Jos	19	70.30	52.70	12	14	0.0060	0.0455
Kaduna	20	193.00	144.70	13	14	0.0036	0.0272
Kanji	21	7.00	5.20	16	19	0.0118	0.0887
Kano	22	220.60	142.90	17	18	0.0002	0.0020
Shiroro	23	70.30	36.10	17	23	0.0096	0.0271
Sapele	24	20.60	15.40	17	21	0.0032	0.0239
Abuja	25	110.00	89.00	19	20	0.0081	0.0609
Makurdi	26	290.10	145.00	20	22	0.0090	0.0680
Mambila	27	0.00	0.00	20	23	0.0038	0.0284
Papalanto	28	0.00	0.00	23	25	0.0038	0.0284
				12	26	0.0071	0.0532
				19	26	0.0059	0.0443
				26	27	0.0079	0.0591
				5	28	0.0016	0.0118

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

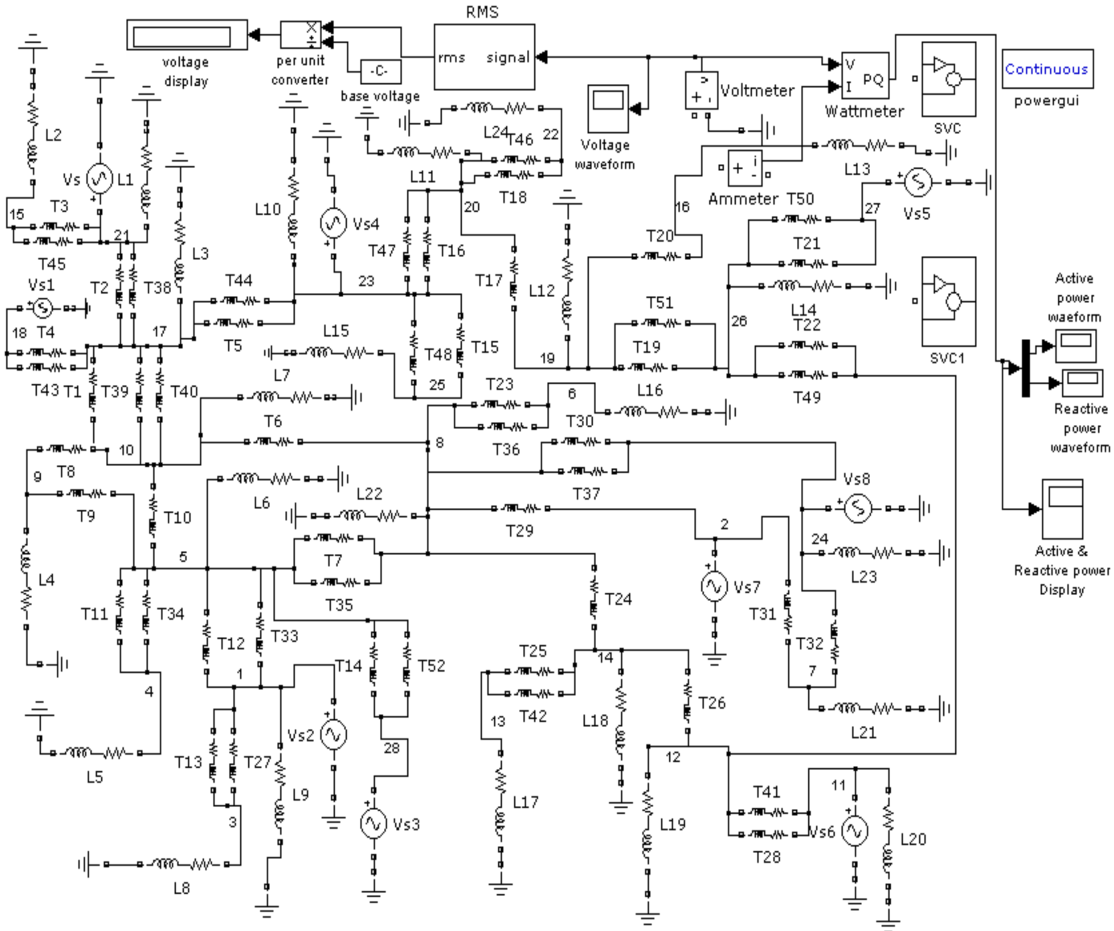

Figure 4: SIMULINK model of the Nigerian 28 bus power system

1) *Modeling of the Static Var Compensator:* The TCR-FC functional diagram and its equivalent circuit are as shown in Figures 1 and 2 respectively.

Figure 1 shows that one branch of the SVC is purely inductive while the other branch is purely capacitive. As a result the SVC consumes no active power. It either consumes (inductive) reactive power to reduce the system's voltage or injects reactive power to increase the system's voltage. Since the reactor consumes reactive power, the reactor current (I_L) is positive while the capacitor which inject reactive power into the system has its current (I_C) to be negative. Thus the SVC current (I_{SVC}) at maximum var could be expressed as follows:

$$I_{SVC} = I_L - I_C \qquad (10)$$

Where:

$$I_C = \frac{V_{SVC}}{X_C} \qquad (11)$$

$$I_L = \frac{V_{SVC}}{X_L} \qquad (12)$$

X_C =Capacitive reactance of the SVC

X_L =Inductive reactance of the SVC

C = Capacitance of the fixed capacitance of the SVC

f = Frequency of the system

V_{SVC} = Bus Voltage magnitude

From figure 1(b), assuming that no real power is consumed by the SVC (i.e. $P_{SVC} = 0$) then:

$$Q_{SVC} = I_{SVC} \times V_{SVC} \qquad (13)$$

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

By comparing equations (10) and (13) we have:

$$Q_{SVC} = (I_L - I_C) \times V_{SVC} \quad (14)$$

Combining equations (11), (12) and (14), we have:

$$Q_{SVC} = \left(\frac{V_{SVC}}{X_L} - \frac{V_{SVC}}{X_C}\right) \times V_{SVC} \quad (15)$$

$$Q_{SVC} = \left(\frac{1}{X_L} - \frac{1}{X_C}\right) \times V_{SVC}^2 \quad (16)$$

$$Q_{SVC} = \frac{X_C - X_L}{X_L X_C} V_{SVC}^2. \quad (17)$$

The SVC controller was designed in such a way that the TCR is switched off when the bus voltage becomes lower than the reference voltage and vice-versa. As a result, at maximum var absorption the FC and the TCR are in operation and as such;

$$Q_{SVC}^{max} = \frac{X_C - X_L}{X_C X_L} V_{SVC}^2 \quad (18)$$

And at minimum var absorption $I_L = 0$, so that;

$$Q_{SVC}^{min} = -\frac{1}{X_C} V_{SVC}^2 \quad (19)$$

2) SIMULINK Model of the Static Var Compensator: The TCR-FC Static Var Compensator of Figure 1(a) was modeled using SIMULINK blocks as shown in Figure 5, where:

FC = Fixed Capacitor; L = Reactor; Tr1 = Step down Transformer; Th = thyristor.

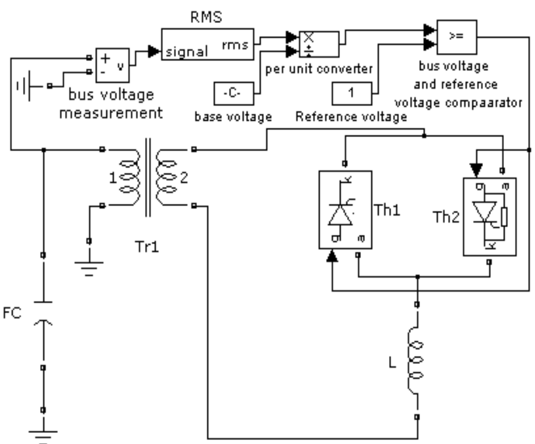

Figure 5: SIMULINK Model of SVC and its Controller

3) The Static Var Compensator Parameters and the System's Voltage: The SVC controller was designed in such a way that the Thyristor valve is phase controlled and operates only when the voltage of the bus to which the SVC is applied becomes higher than the base voltage.

By so doing, the bus voltage is being regulated near or at the base voltage.

Assuming that the SVC is applied at bus k, then equation (1) becomes;

$$V_d = V_i - V_{SVC} \quad (20)$$

Comparing equations (17) and (20) gives;

$$V_d = V_i - \sqrt{\frac{Q_{SVC} X_L X_C}{X_C - X_L}} \quad (21)$$

Equation (20) shows that if V_i is kept constant, then by keeping the bus $V_{SVC}(V_k)$ near or at the base voltage, the voltage drop is minimized and hence the system's voltage stabilized.

IV. Simulation Results And Discussion

Table 2 shows the bus voltages and the voltage drops without/with SVC

A. Comparison Between the Voltage Drops without/with SVC

To appreciate the effect of SVC on the power system's voltage, the system's voltage drops without/with SVC were compared using the data from Table 2 as shown in Figure 6 and 7.

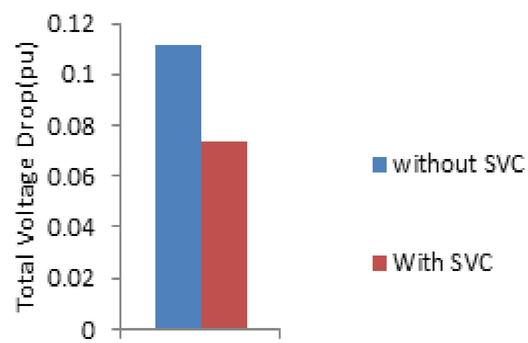

Figure 7: Bar Chart Showing the Total Voltage drops with/without SVC

Table II shows that the system's total voltage drop s were 0.1110 and 0.0735 p.u respectively when it was run without and with SVC. This shows that, with SVC the system's total voltage drop was reduced by 33.78%. In addition Figure 6 and 7 shows that the reduction in the system voltage drop when SVC was applied is appreciable.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

TABLE II
BUS VOLTAGES AND VOLTAGE DROPS OF THE 28-BUS POWER SYSTEM WITHOUT/WITH SVC

Bus		No SVC			With SVC at bus 5 and 13		
i	K	V_i(p.u)	V_k(p.u)	Voltage drop ($\lvert V_i - V_k \rvert$)(p.u)	V_i(p.u)	V_k(p.u)	Voltage drop ($\lvert V_i - V_k \rvert$)(p.u)
1	3	0.9997	1.0000	0.0003	0.9999	1.0000	0.0001
1	5	0.9997	0.9938	0.0059	0.9999	1.0000	0.0001
2	8	0.9997	0.9966	0.0031	0.9999	0.9980	0.0018
2	7	0.9997	1.0000	0.0003	0.9999	0.9994	0.0005
4	5	0.9931	0.9938	0.0007	1.0000	1.0000	0.0000
5	8	0.9938	0.9966	0.0028	1.0000	0.9980	0.0020
5	9	0.9938	0.9896	0.0042	1.0000	0.9934	0.0066
5	10	0.9938	0.9961	0.0023	1.0000	0.9971	0.0029
6	8	0.9965	0.9966	0.0001	0.9980	0.9980	0.0000
7	24	1.0000	0.9997	0.0003	0.9994	0.9999	0.0005
8	14	0.9966	0.9909	0.0057	0.9980	0.9954	0.0026
8	10	0.9966	0.9961	0.0005	0.9980	0.9971	0.0009
8	24	0.9966	0.9997	0.0031	0.9980	0.999	0.0019
9	10	0.9896	0.9961	0.0065	0.9934	0.9971	0.0037
15	21	0.9955	0.9997	0.0042	0.9957	0.9999	0.0042
10	17	0.9961	1.0000	0.0039	0.9971	0.9996	0.0025
11	12	0.9997	0.9983	0.0014	0.9999	0.9984	0.0015
12	14	0.9983	0.9909	0.0074	0.9984	0.9954	0.0030
13	14	0.9738	0.9909	0.0175	1.0000	0.9954	0.0046
16	19	0.9836	0.9921	0.0085	0.9827	0.9924	0.009
17	18	1.0000	0.9997	0.0003	0.9996	0.9999	0.0003
17	23	1.0000	0.9997	0.0003	0.9996	0.9999	0.0003
17	21	1.0000	0.9997	0.0003	0.9996	0.9999	0.0003
19	20	0.9921	0.9947	0.0026	0.9924	0.9947	0.0023
20	22	0.9947	0.9898	0.0049	0.9947	0.9898	0.0049
20	23	0.9947	0.9997	0.0050	0.9947	0.9999	0.0052
23	25	0.9997	0.9981	0.0016	0.9999	0.9991	0.0008
12	26	0.9983	0.9945	0.0038	0.9984	0.9957	0.0027
19	26	0.9921	0.9945	0.0024	0.9924	0.9957	0.0033
26	27	0.9945	0.9997	0.0052	0.9957	0.9999	0.0042
5	28	0.9938	0.9997	0.0059	1.0000	0.9999	0.0001
TOTAL				0.1110			0.0735

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 1, January 2014)

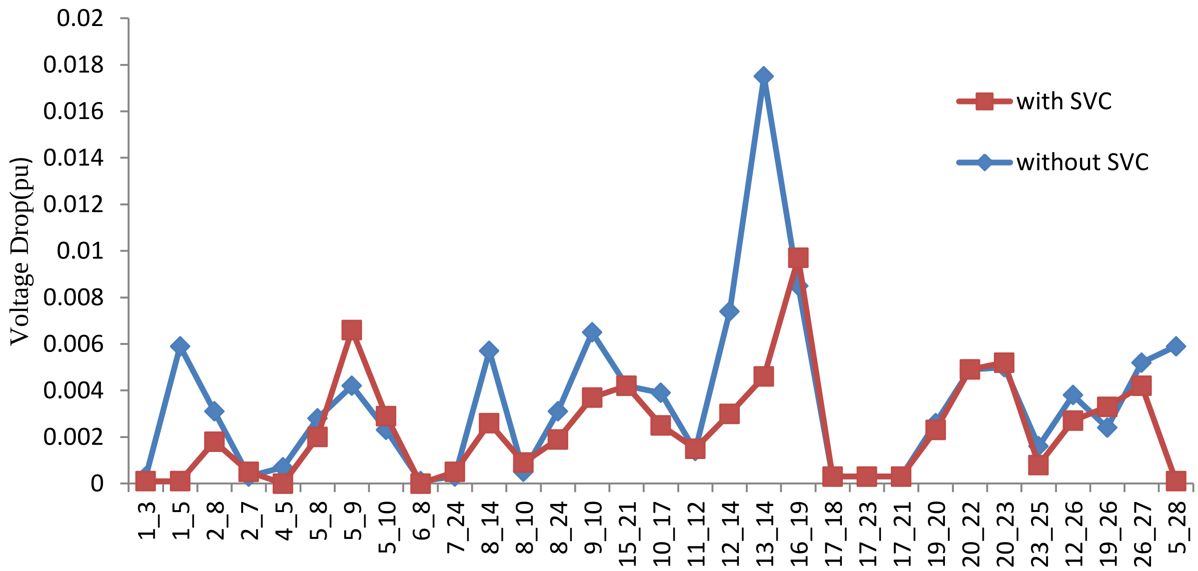

Figure 6: Graphical Representation of the Voltage with/without SVC

V. Conclusion

In this paper, the basic structure and model of Thyristor-Controlled-Reactor Fixed-Capacitor SVC were described. A single line diagram of the Nigerian 28-bus, 330kv power, system used for the study was also modeled and simulated without/with SVC. All the modeling and simulations were carried out in the SIMULINK/MALAB environment. From the simulation results and the resulting graph and bar chart, it was confirmed that SVC could be used to improve the voltage stability of power systems.

REFERENCES

[1] Abido M. A. 2009. Power System Stability Enhancement Using FACTS Controllers, The Arabian Journal for Science and Engineering, Volume 34, pp.153-172

[2] Banga A. and Kaushik S. S. 2011. Modeling and Simulation of SVC Controller for Enhancement of Power System Stability, International Journal of Advances in Engineering and Technology, Vol. 1, pp.79-84

[3] Biswas M. M and Kamol K. D. 2011. Voltage Level Improving by Using Static VAR Compensator, Global Journal of researches in engineering, Volume 11,pp.12-18

[4] Conejo A. J., 2011, Load Flow Lecture, University of Castilla – La Mancha

[5] Nwohu M. N. 2009. Voltage Stability Improvement using Static Var Compensator in Power Systems, Leonardo Journal of Sciences, Issue 14, pp. 167-17

[6] Pabla A. S. 2004. Electric Power Distribution, 5th edition, Tata McGraw-Hill Publishing Company LTD, New Delhi

[7] Tarik A. and Teleke S. 2006. Modeling and Comparison of Synchronous Condenser and SVC, Thesis presented for Master Programme in Electric Power Engineering, Chalmers University of Technology