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MODELING, SIMULATION AND PERFORMANCE ANALYSIS OF FACTS CONTROLLER IN TRANSMISSION LINE

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ABSTRACT

Flexible AC Transmission Systems (FACTS) devices have been used since 1970s for the development and improvement of dynamic performance of the modern power system. FACTS devices use power electronic components to improve system performance. FACTS controller includes Fixed Capacitor Thyristor Controlled Reactor (FCTCR), Static Synchronous Compensator(STATCOM), Thyristor Controlled Series Compensator TCSC), Static Series Synchronous Compensator (SSSC), Static VAR Compensator (SVC), Unified Power Flow Controller (UPFC), which are used in the transmission and distribution system to improve power transfer capability and to enhance power system stability. This study has been applied the performance of STATCOM and TCSC in transmission to improve voltage profile of the system. The mathematical model of power system equipped with a STATCOM and TCSC is systematically derived. The presented mathematical model shows that STATCOM and TCSC effects the voltage profile improvement and active and reactive power of the transmission line .This paper shows the result that show the performance of the system for each of the FACTS devices in improving the power flow in the transmission line. All the simulations has been carried out by using MATLAB/SIMULINK software. The simulation result shows the performance of FACTS controller in transmission line.

KEYWORDS: Modern Power System, Concepts and Technology, Flexible AC Transmission Systems

INTRODUCTION

Present power system is deregulated, under which power is produced by separate generation, transmission and distribution system to provide cheaper electricity. Electric power demand is growing day by day. Thus it is necessary to rely on utilization of existing generating unit and to load the existing transmission line to their thermal limits and also to maintain stability. It is also necessary to operate power system with minimum loss in the transmission line. Flexible AC Transmission System (FACTS) devices play an important role in controlling power and enhancing the usable capacity of existing lines. FACTS devices use power electronic component to enhance controllability and increase power transfer capability. Future electric transmission system can be made smart by using FACTS devices. A Static Synchronous Compensator (STATCOM) is a member of the FACTS family that is connected in shunt with system.

The STATCOM consists of a solid state voltage source converter with GTO thyristor and transformer. The STATCOM can electrically mimic reactor and capacitor by injecting a shunt current in quadrature with the line voltage. The reactive power (or current) of the STATCOM can be adjusted by controlling the magnitude and phase angle of the output voltage of shunt converter.

TCSC are used to improve power handling capability and reduce line losses in power systems. An additional feature of TCSC is its dynamic performance of power oscillation damping by varying the power flow in accordance with power oscillations. This behavior can be used to improve the stability of the system following a disturbance. In this paper mathematical modeling of STATCOM and TCSC is explained and result shows the performance of the system for the each of the FACTS devices in improving the power flow in the transmission line. By using MATLAB/SIMULINK software simulation is done to demonstrate the performance of the system for each of the FACTS devices STATCOM and TCSC in improving the power profile and there by voltage stability of the same. The performance of TCSC and STATCOM has also been discussed along with modeling and simulation of various FACTS devices (STATCOM, TCSC) has been done using MATLAB/SIMULINK software. By varying the capacitance value, line impedance is controlled and real and reactive power is measured.

Nomenclature

X_1=equivalent reactance b/w machine internal bus and bus m, X_2=equivalent reactance b/w bus m and infinite bus, E'=constant voltage source, X'_d=transient reactance, $P_{R=}$active power at bus m , θ_{m0}=voltage angle at bus m, Q_R=reactive power at bus m, V_{m0}=voltage magnitude at bus m, V_m =voltage magnitude at bus m with STATCOM, $X_L(\alpha)$=TCR reactance as a function of firing angle , α=firing angle, X_{TCSC}=fundamental impedance Of TCSC, X_L=inductive reactance, X_C=capacitive reactance , f=frequency

Static Synchronous Compensator STATCOM

A Static Synchronous Compensator (STATCOM) is a member of the FACTS family that is connected in shunt with system. The STATCOM consists of a solid state voltage source converter with GTO thyristor and transformer.

Mathematical Modeling of STATCOM

Mathematical Model: Figure 1a shows the single line diagram of Single Machine Infinite Bus (SMIB) system. Without a STATCOM and the corresponding equivalent circuit is shown in Figure 2b. Here X1 is the equivalent Reactance between the machine internal bus and the bus m and X2 is the equivalent reactance between bus m and The infinite bus. The generator is represented by a constant voltage source (E') behind transient Reactance (Xd').

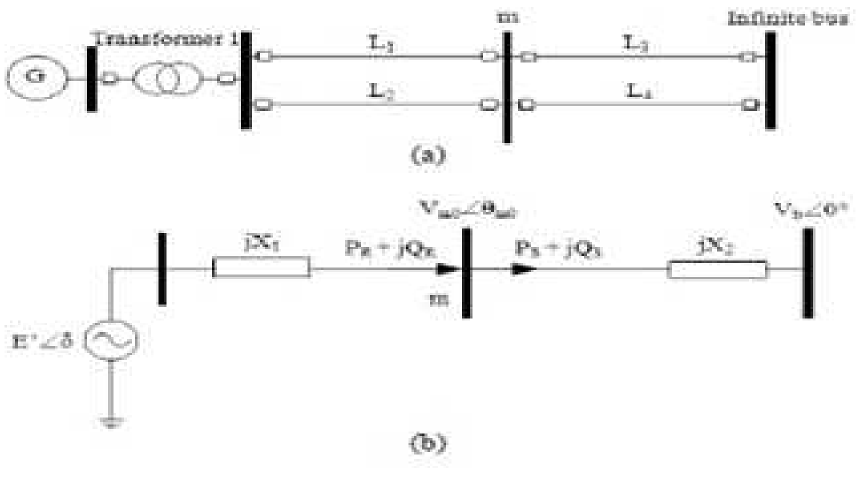

Figure 1: Single Machine Infinite Bus System
(a) Schematic Diagram (b) Equivalent Circuit

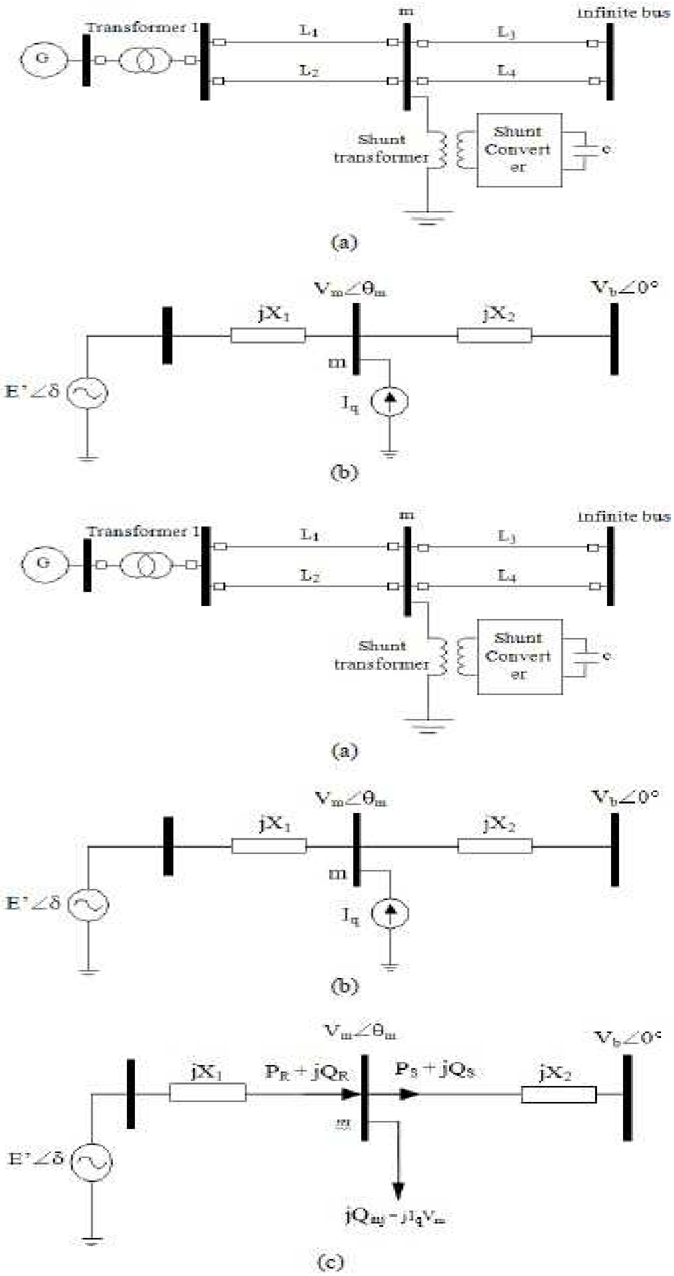

Figure 2: Single Machine Infinite Bus System with A STATCOM (a) Schematic Diagram (b) Equivalent Circuit of System with A STATCOM Represented by a Current Injection Model (c) Equivalent Circuit of System with A STATCOM Represented by a Load Injection Model

The active power balance at bus m is given by:

$$P_R = P_S \quad [1]$$

$$P_R = \frac{E'V_{m0}}{X_1}\sin(\delta - \theta_{m0}) \quad [2]$$

$$P_S = \frac{V_{m0}V_b}{X_2}\sin(\theta_{m0}) \quad [3]$$

After some mathematical manipulations of Eq. 1- Eq. 3, the voltage angle at bus m of the system without STATCOM is given by

$$\theta_{mo} = \tan^{-1}\frac{E'X_2\sin\delta}{E'X_2} \quad [4]$$

The reactive power balance at bus m is given by:

$$Q_{R=}Q_S \qquad [5]$$

$$Q_R = \frac{E'V_{m0}\cos(\delta-\theta_{m0})}{X_1} - \frac{V_{m0}^2}{X_1} \qquad [6]$$

$$Q_S = \frac{V_{m0}^2}{X_2} - \frac{V_{m0}V_b\cos\theta_{m0}}{X_2} \qquad [7]$$

After some mathematical manipulations of Eq. 5-7, the voltage magnitude at bus m of the system without STATCOM is:

$$V_{m0} = \frac{E'X_L\cos(\delta-\theta_{m0})+X_1V_b\cos\theta_{m0}}{X_1+X_2} \qquad [8]$$

It can observe from the Figure 2b and 3(a-c) that the STATCOM affect on the active power balance and then the voltage angle equation at bus m is written by:

$$\theta_m = \theta_{m0} = \tan^{-1}\left(\frac{E'X_2\sin\delta}{E'X_2}\right) \qquad [9]$$

However, the STATCOM affects on reactive power balance given by:

$$Q_R = Q_S + Q_{inj} \qquad [10]$$

$$Q_{inj} = -V_m I_q \qquad [11]$$

After some mathematical manipulations, the voltage magnitude at bus m of the system with a STACOM is given by:

$$V_m = \frac{E'X_L\cos(\delta-\theta_{m0})+X_1V_b\cos\theta_{m0}+X_1X_2I_q}{X_1+X_2} \qquad [12]$$

From Eq. 8 and 12, the voltage magnitude at bus m of the system with a STATCOM is given by:

$$V_m = V_{m0} + CI_q \qquad [13]$$

$$C= \frac{X_1X_2}{X_1+X_2}$$

$$I_q = K(V_m - V_{m0}) \qquad [14]$$

THYRISTOR Controlled Series Capacitor (TCSC)

A typical TCSC module consists of a fixed series capacitor (FC) in parallel with a thyristor controlled reactor (TCR). It is connected in series with the transmission line and is used to control the real power flow by controlling the electrical length of transmission line along with providing increased SSR stability. There may be one or more TCSC modules in series in a practical construction.

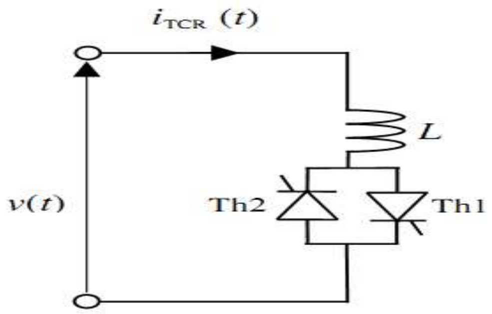

Figure 3: THYRISTOR Controlled Reactor

Mathematical Modelling of TCSC

TCSC IMPEDANCE

A TCSC is a parallel combination of TCR and a fixed capacitor. The TCR reactance as a function of firing angle is given by:

$$X_L\,(\alpha) \;= X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \tag{1}$$

The steady state fundamental impedance of the TCSC is given by:

$$X_{TCSC} = \frac{X_C \cdot X_L\,(\alpha)}{X_C - X_L\,(\alpha)} \tag{2}$$

Therefore by Varying the conduction angle of fundamental reactance of the TCSC can be controlled and can be made either capacitive or inductive.

Putting the value of $X_L(\alpha)$ in equation (2)

$$X_{TCSC}\,(\alpha) = \frac{X_C\,X_L\left(\pi/_{\pi-2\alpha-\sin 2\alpha}\right)}{X_C - X_L\left(\pi/_{\pi-2\alpha-\sin 2\alpha}\right)} \tag{3}$$

$$X_{TCSC}(\alpha) = \frac{X_C\,X_L\left(\pi/_{\pi-2\alpha-\sin 2\alpha}\right)}{\{(\pi-2\alpha-\sin 2\alpha)X_C - X_{L\pi}\}/(\pi-2\alpha-\sin 2\alpha)} \tag{4}$$

$$X_{TCSC}(\alpha) = -X_C + C_1\,\{2(\pi-\alpha) + \sin 2(\pi-\alpha)\} - C_2\,cos^2\;(\pi-\alpha)\varpi\tan\{\varpi(\pi-\alpha)\} - \tan(\pi-\alpha) \tag{5}$$

Where $X_{LC} = \frac{X_C \cdot X_L}{X_C - X_L}$

$C_1 = \frac{X_{C+}X_L}{\pi}$

$C_2 = 4\;\frac{X_{LC}^2}{\pi X_L}$

$\varpi = \sqrt{\frac{X_c}{X_L}}$

XL = Reactance of TCSC inductor = 2πFl

f = Supply frequency

Description of the System

A basic transmission (11KV) model has been employed in Matlab/Simulink program to study about the FACTS devices in detail. 11KV voltage is supplied from the ac voltage source to the system. The transmission line is considered to be a short transmission line hence capacitance of the line is neglected. The resistance of the line is 5Ω and the inductance is 0.06mH. The source impedance is (0.01+0.001) Ω and the load is kept constant at 25MW and 50MVAR .The current and voltage measurement blocks are used to measure the voltage and current at source. By the use of Active and Reactive Power Measurement Block, the real and reactive power in the load is measured.

SIMULATION RESULT

MATLAB simulation of uncompensated transmission line

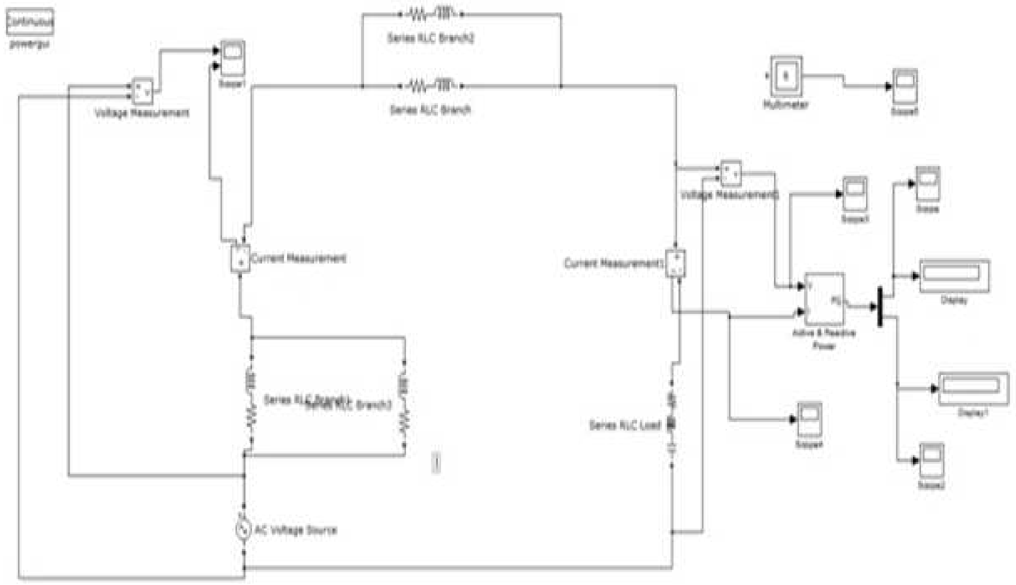

Figure 4: Simulation of Uncompensated Line

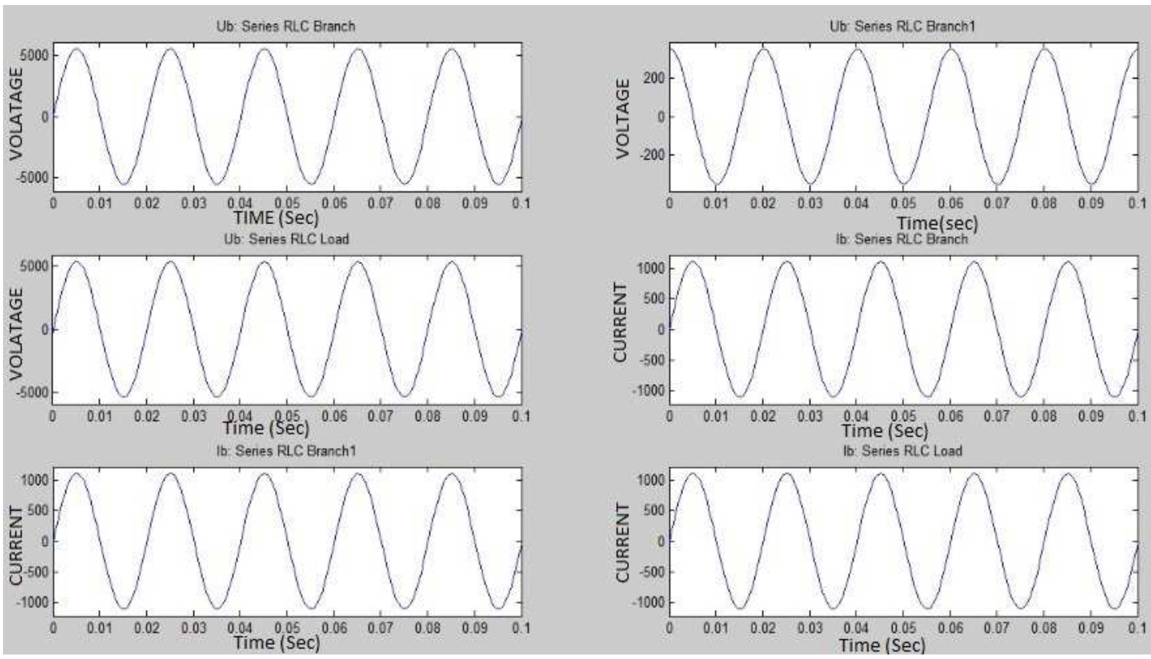

Figure 5: Voltage/Current Profile of Uncompensated Line

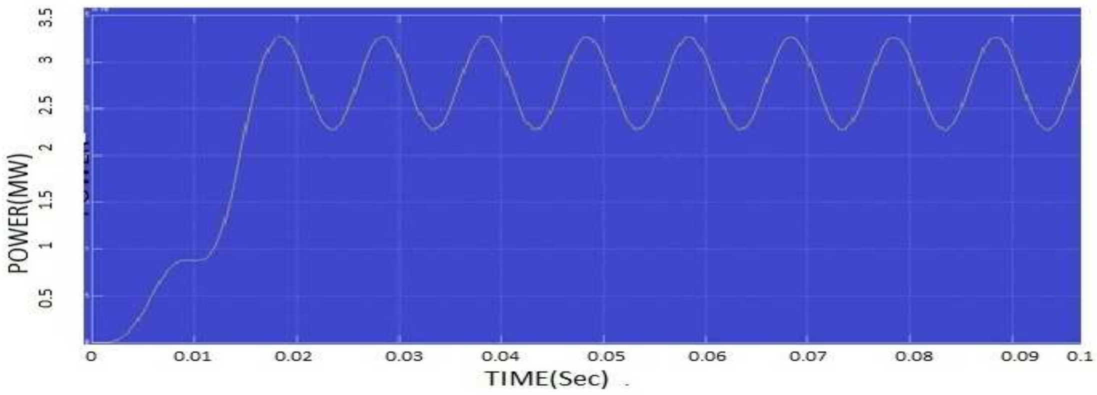

Figure 6: Active Power of Uncompensated Transmission Line

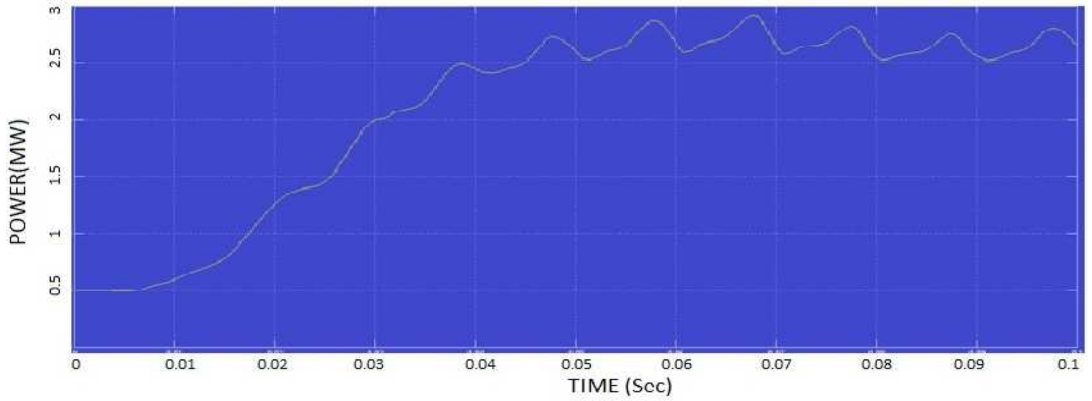

Figure 7: Reactive Power of Uncompensated Transmission Line

STATCOM Compensated System

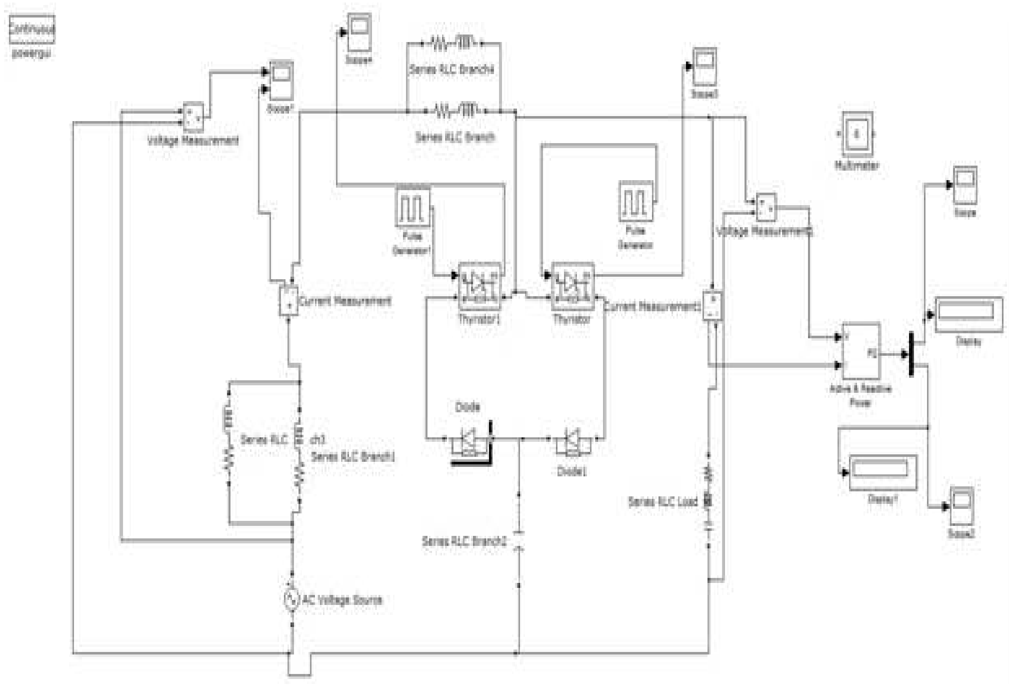

Figure 8: Simulink of Transmission Line with STATCOM

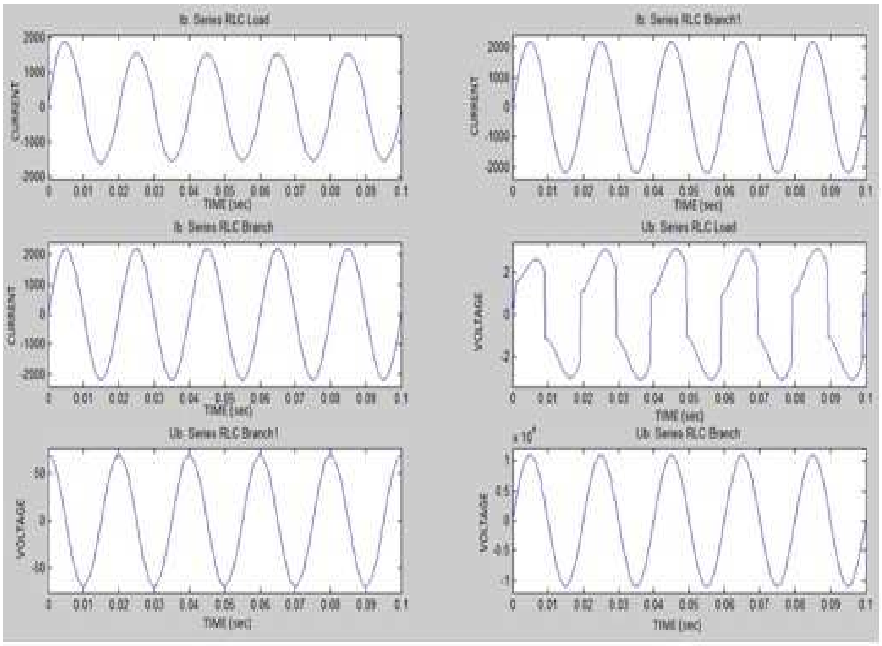

Figure 9: Voltage/Current of Transmission Line with STATCOM

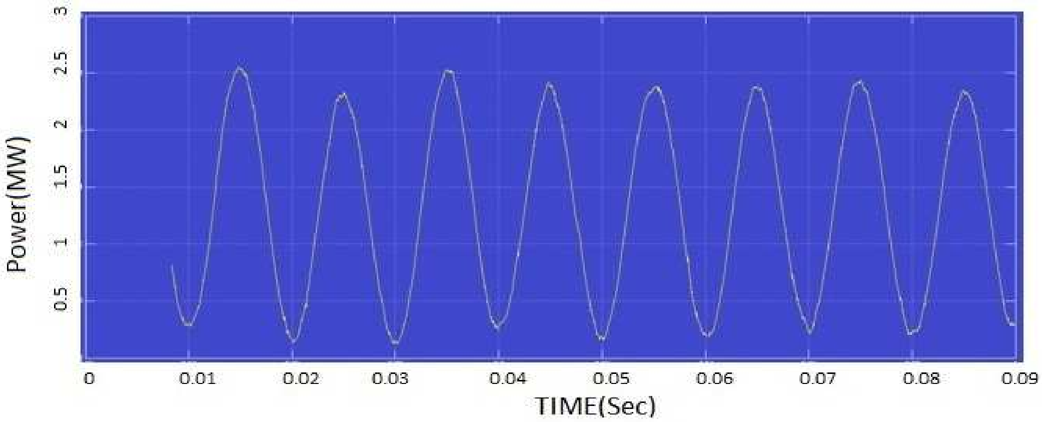

Figure 10: Active Power of Transmission Line with STATCOM

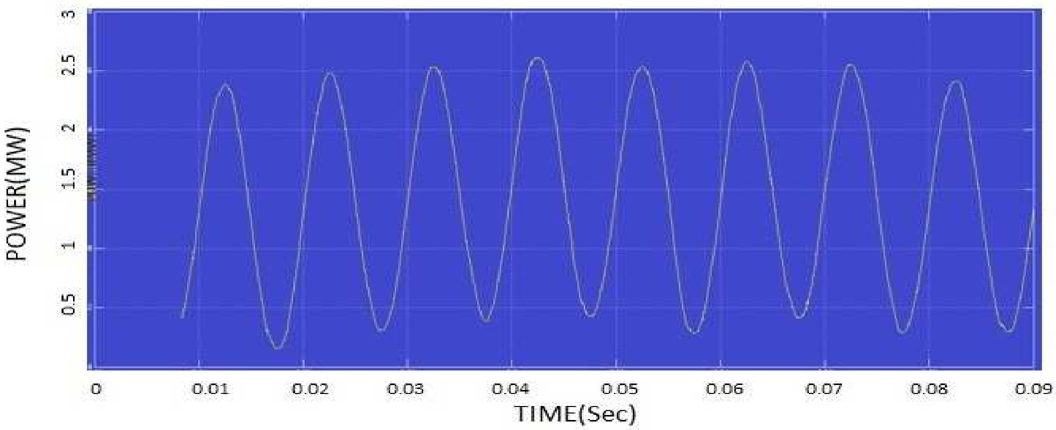

Figure 11: Reactive Power of Transmission Line with STATCOM

Variation of Power Flow with Change of Capacitance

Table 1

S.No	Capacitance	Active Power(Mw)	Reactive Power (Mvar)
1	20	0.0245	0.0084
2	30	0.0245	0.0084
2	50	0.0246	0.0085
3	100	0.0247	0.0087
4	200	0.0246	0.0086
5	300	0.0243	0.0082
6	400	0.0237	0.0075
7	500	0.023	0.0074

From the above table it is seen that both active and reactive power increases with the increase in capacitance Value up to 100μF. Beyond this value both real and reactive power starts decreasing. So the better compensation is obtained at a capacitor value of 100μF.

TCSC Compensated System

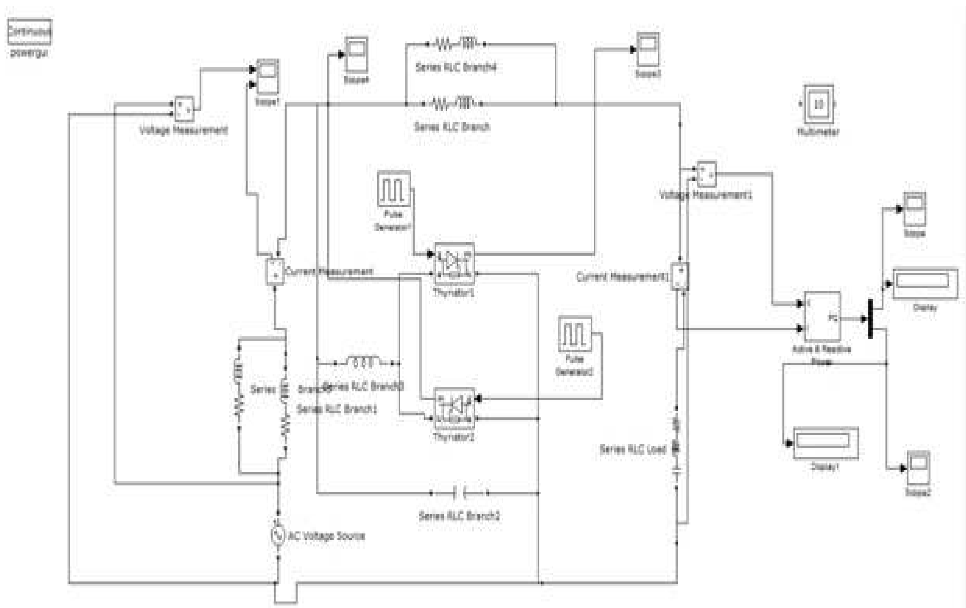

Figure 12: MATLAB/ SIMULINK of Transmission Line with TCSC

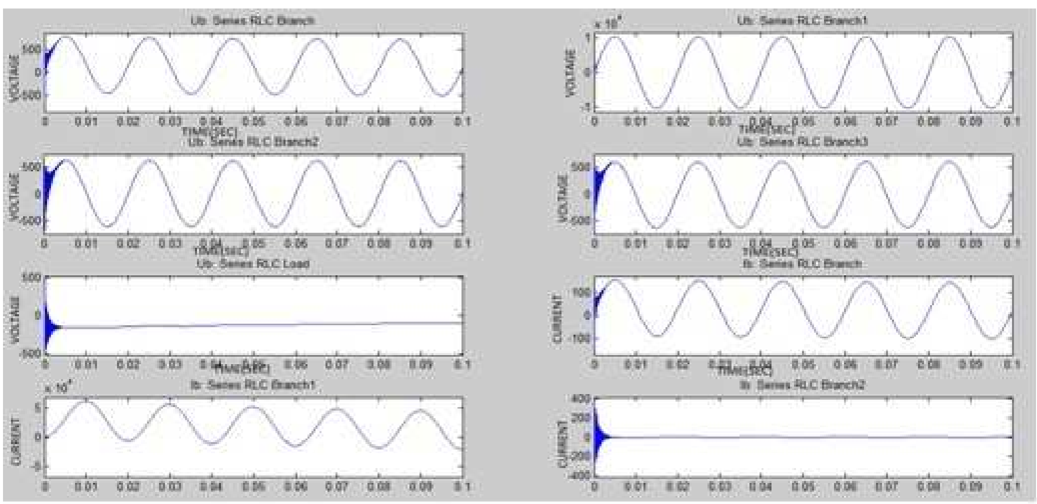

Figure 13: Voltage/Current Profile of Transmission Line with TCSC

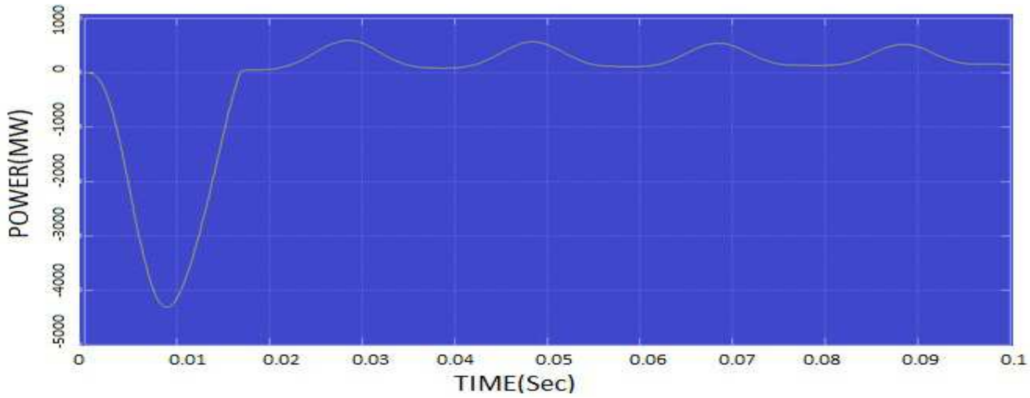

Figure 14: Active Power of Transmission Line TCSC

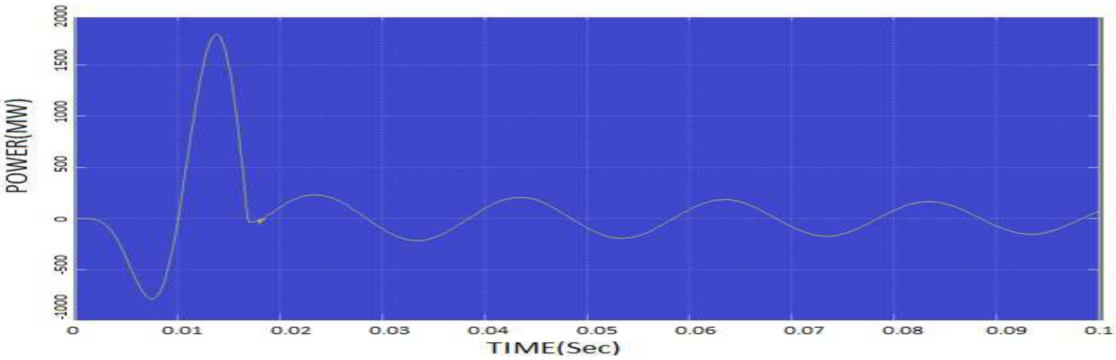

Figure 15: Reactive Power of Transmission Line with TCSC

Variation of Power Flow with Change of Capacitance

Table 2

S.No.	Capacitance	Active Power(Mw)	Reactive Power (Mvar)
1	20	341	127.7
2	30	341.3	128
3	40	341	127.7
4	50	340.4	127.37
5	100	338.7	125
6	200	330	117
7	300	320	107
8	500	298	85

From the above table it is seen that both active and reactive power increases with the increase in capacitance value up to 30µF. Beyond this value both real and reactive power starts decreasing. So the better compensation is obtained at a capacitor value of 30µF.

CONCLUSIONS

MATLAB/SIMULINK environment is used for the comparative study using 11kv simple transmission line. This paper presents comparative study of performance analysis of STATCOM, and TCSC devices in graphical form. Real and Reactive power flow profile are seen to improve with all the compensating devices. Results show that in case of compensation, reactive power flow improves proportionally with value of capacitance (1000µF here), in case of STATCOM compensation a capacitor rating 100µF yield best result. For TCSC compensation with a fixed inductance of

100mH and capacitance value of 30μF gives best result. Both active and reactive power increases with the increase in capacitance value up to 30μF. Beyond this value both real and reactive power starts decreasing. So the better compensation is obtained at a capacitor value of 30μf.

Comparison of Power Flow among FACTS Controller

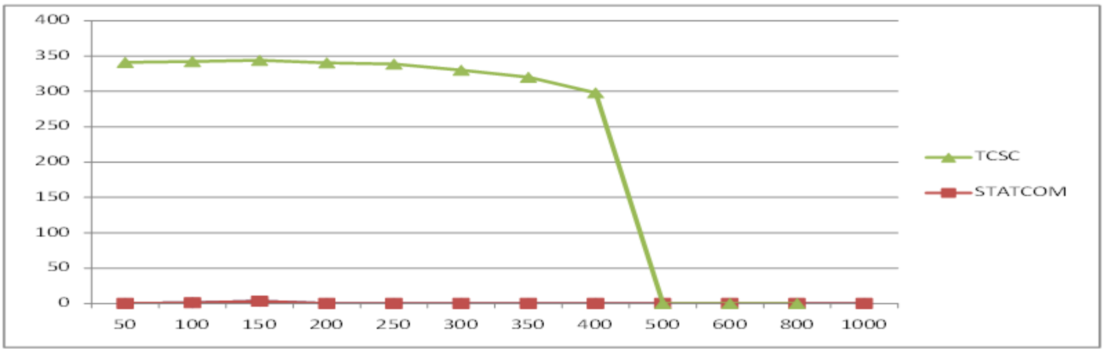

Figure 16: Variation of Power Flow among Above FACTS Devices with Change in Capacitance (20-1000μF)

REFERENCES

1. N. G Hingorani & Laszlo G yugyi, "Understanding FACTS: Concepts and technology of flexible AC transmission System",
2. Zarate-Minano, R., T. Van Custsem, F., Milano, A.J. Conejo, 2010. Securing transient stability using time Domain simulations within an optimal power flow. IEEE Trans. Power Sys. 5: 243-253. DOI: 10.1109/TPWRS.2009.203069
3. M.P.Donsion, J.A. Guemes, J.M. Rodriguez, "Power Quality Benefits of Utilizing FACTS Devices in Electrical power System", IEEE 2007, 26-29.
4. CIGRE, "FACTS Overview", IEEE Power Engineering Society, 95 TP 108, April 1995
5. S.K. Sethy and J.K. Moharana, "Modeling, Design and Simulation of Current and Voltage Linear Controller of a STATCOM for Reactive Power Compensation", NSPEES-12, Sept.29-30, GIET, BBSR, pp-37-44, 2012.
6. P.S. sensarma, K.R. Padiyar and V. Ramnarayanan, "Analysis and Performance Evaluation of a Distribution STATCOM for Compensating Voltage Fluctuations", IEEE Transaction on Power Delivery, Vol.16, No.2, pp.259- 264, April 2012
7. S. Buso, L. Malesani and P. Mattavelli, "Comparison of Current Control Techniques for Active Filter Application"IEEETrans.Industrial Electronics, Vol.45, No.5, pp.722-729, October 1998.
8. R.M. Mathur and R.K. Varma, "Thyristor based FACTS Controllers for Electrical Transmission Systems", IEEE Power Engineering Society, Sponsored, Wiley Interscience, 2002.
9. A. Kazemi, V. Vahidinasab and A. Mosallanejad, Nov 28-29, 2006," study of STATCOM and UPFC controllers for voltage stability Evaluated by Saddle-Node Bifurcation Analysis", First International Power and Energy Conference PE Con/IEEE, Putrajaya, Malaysia.
10. ArthitSode-yome, Nadara jk Mithilananthan and Kwang Y. Lee, 2005, "Static voltage stability Margin Enhancement Using STATCOM, TCSC, and SSSC", IEEE/PES Transmission and Distribution conference and Exhibition, Asia and Pacific, Dalian chine.

11. American Journal of Applied Sciences 7 (12): 1558-1561, 2010 Mitigation Voltage Sag in Power System by Static Synchronous Compensator Prechanon Kumkratug Division of Electrical.

12. D. Murali, Dr. M. Rajaram & N. Reka, "Comparison of FACTS Devices for Power System Stability Enhancement", International Journal of Computer Applications, Volume8-No.4, October 2010.

13. Bindeshwar singh, K. S. Verma, Deependra Singh, C.N. Singh, Archana singh, Ekta Agarwal, Rahul Dixit, Baljiv Tyagi "Introduction of FACTS controllers, a critica review", International Journal of reviews in computing, Vol 8, 31st December 2011.

14. S. Sankar, S. Balaji & S. Arul, "Simulation and Comparison of Various FACTS Devices in Power System", International Journal of Engineering Science and Technology, Vol.2 (4), 2010, 538-547.