Active Reactive Power Flow Control Using Static Synchronous Series Compensator (SSSC)

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 Abstract: *In present scenario, the performance of power systems decreases with the size, the loading and the complexity of the system networks. This is related to problems with power oscillations, large power flow and voltage instability with inadequate control, so the power flow control plays a major role in power systems. In this paper SSSC series FACTS device are regulates system voltage by absorbing or generating reactive power and the control of active, reactive power flow and voltage well as damping power system oscillations in long transmission line. In this paper results of SSSC series FACT device compared with the STATCOM shunt FACT device and Simulation studies were carried out in the MATLAB simulation environment to observe the compensation achieved by the SSSC device. The system parameters such as voltage, current, active power and reactive power transmissions are observed when the SSSC, STATCOM device is connected to the power system. For the simulation purpose, the model of two-area four-machine 11-bus system with SSSC and STATCOM device is developed in MATLAB/SIMULINK using Simpower System (SPS) blockset.*
Keywords: *FACT Device, SSSC, STATCOM, Power Oscillation Damping (POD) controller, Test system model, MATLAB/SIMULINK, Modelling of SSSC, STATCOM*

I. INTRODUCTION

For efficient and reliable operation of power system, the voltage and reactive power control must be properly done to make voltage at all the buses within the acceptable limits [1]-[2]. Facts devices provide voltage support at critical buses in the system (shunt connected controllers) and regulate power flow in critical lines (with series connected controllers) [3]. The need for these power flow controllers capable of increasing transmission capability and controlling power flows is increasing [4]. FACTS devices can regulate the active and reactive power control as well as adaptive to voltage magnitude control simultaneously by their fast control characteristics and their continuous compensating capability and so reduce flow of heavily loaded lines and maintain voltages in desired level [5].

II. SSSC (STATIC SYNCHRONOUS SERIES COMPENSATOR)

Static synchronous series compensator (SSSC) is one of the important members of FACTS family which can be installed in series in the transmission lines. SSSC is very effective in controlling power flow in a transmission line with the capability to change its reactance characteristic from capacitive to inductive [6]. Among all FACTS devices, static synchronous series compensators (SSSC) plays much more important role in reactive power compensation and voltage support because of its attractive steady state performance and operating characteristics [7]-[8]. The SSSC using a voltage source converter to inject a controllable voltage in quadrature with the line current of a power network is able to rapidly provide both capacitive and inductive impedance compensation independent of the power line current[9]-[14]. The SSSC injects a voltage Vs in series with the transmission line where it is connected [15].
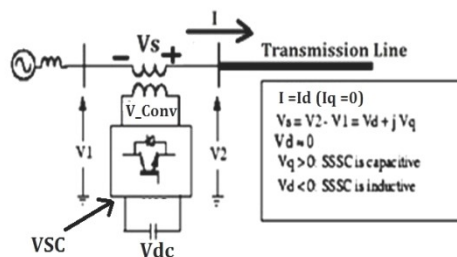

Fig. 1. Single line diagram of SSSC Configuration [15].

III.   STATCOM (STATIC SYNCHRONOUS COMPENSATOR)

Static synchronous Compensator (STATCOM) is member of FACTS family that is connected in shunt with the system [16],[17]. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive) [15]. The variation of reactive power is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V2 from a DC voltage source. The principle of operation of the STATCOM is explained on the figure below showing the active and reactive power transfer between a source V1 and a source V2. In this figure 2, V1 represents the system voltage to be controlled and V2 is the voltage generated by the VSC [15].
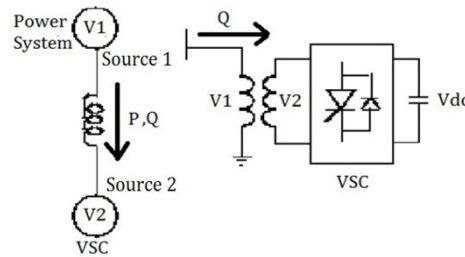
Fig. 2. STATCOM configuration connected with system bus [15].

$$P = (V1 V2) \, Sin\delta / X \qquad (1)$$

$$Q = V1(V1 - V2 \, Cos\delta) / X \qquad (2)$$

Where, V1,V2 = Line to line voltage of sources 1 and source 2
X = reactance of interconnected transformer and filters
δ = phase angle of V1 with respect to V2

In steady state operation, the voltage V2 generated by the VSC is in phase with V1 (δ=0), so that only reactive power is flowing (P=0). If V2 is lower than V1, Q is flowing from V1 to V2 (STATCOM is absorbing reactive power). On the reverse, if V2 is higher than V1, Q is flowing from V2 to V1 (STATCOM is generating reactive power). The amount of reactive power is given by [15]

$$Q = V1(V1 - V2) / X \qquad (3)$$

To improve the voltage stability and the damping of oscillations in power systems, supplementary control techniques can be applied to existing devices. These supplementary actions are referred to as voltage stability and power oscillation damping (POD) control. In this work, voltage stability and POD control has been applied to Static synchronous series compensator (SSSC) [18]. To improve the voltage stability and the damping of oscillations in power systems, supplementary control laws can be applied to existing devices. These supplementary actions are referred to as voltage stability and power oscillation damping (POD) control. In this work, voltage stability and POD control has been applied to Static synchronous series compensator (SSSC).The SSSC using a voltage source converter to inject a controllable voltage in quadrature with the line current of a power network is able to rapidly provide both capacitive and inductive impedance compensation independent of the power line current [19]-[21].

IV. 11 BUS TEST SYSTEM MODEL WITH STATCOM

A multi machine power system with 11 bus two area test system, Area-1 and Area-2 system is used to access the effectiveness of STATCOM model developed. Figure 3 shown the proposed single line diagram of 11 bus power system with installed STATCOM shunt FACT device at bus 8 has been considered.
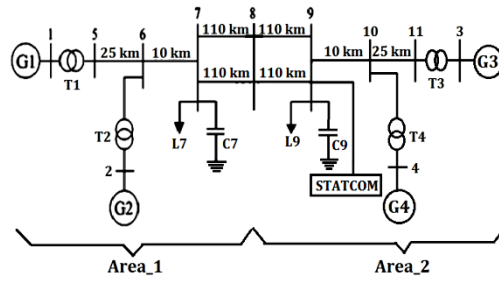
Fig. 3. Two-area power system with shunt FACT device STATCOM.

V. SIMULATION MODELLING OF 11 BUS TEST SYSTEM WITH STATCOM

All the relevant parameters are given in Appendix. The source voltages of 13.8kV are connected by a 290km transmission line through three-phase step-up transformers. The system consists of two output voltage of transformer is 500KV equivalents, respectively 1000MVA and 4200MVA in each area, connected by a 290km transmission line. The loads in each area having 30KW are so chosen that the real power flow on the transmission line from area 1 to 2. The STATCOM used for this model is a phasor model. The load centre of approximately 60KW is modelled where the active & reactive power absorbed by the load is a function of the system voltage. The STATCOM model is operate at Voltage regulation mode only at this mode the reference value of STATCOM voltage is set at 1pu, when VAR generation mode is disable then the reference value of reactive power will be zero is shown in figure 4.
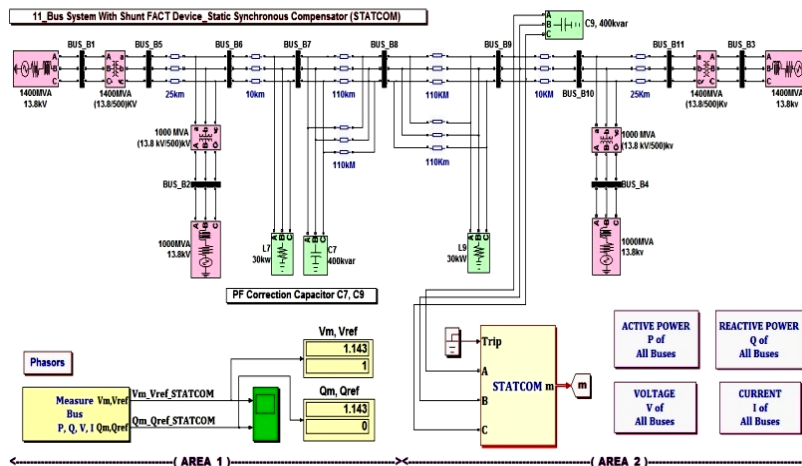

Fig. 4. Simulink model of 11 bus power system with STATCOM at bus 8 (For Voltage regulation mode only).

VI. SIMULATION MODELLING RESULTS OF STATCOM

The STATCOM internal control parameter is shown in figure 5. The reference value is representing by magenta trace and measured value represent by yellow trace is shown in figure 6, figure 7. In this paper the STATCOM is operated in voltage regulation mode only and obtained all the data in this mode is shown in following figures.
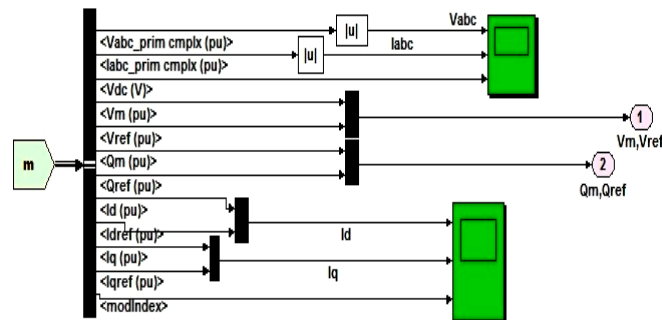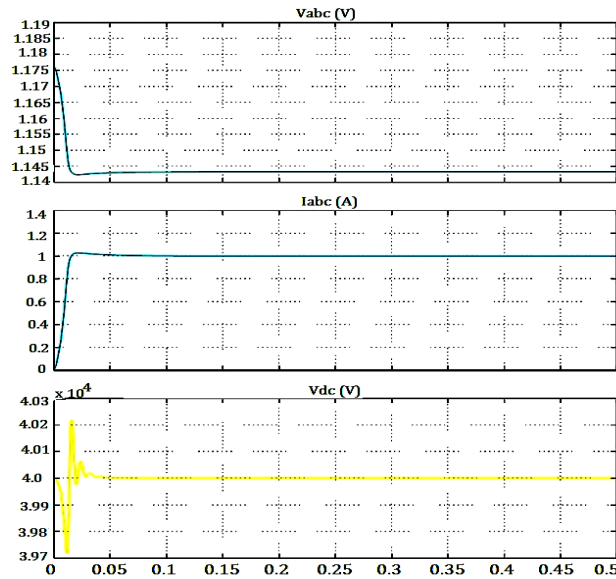

Fig. 5. STATCOM control parameter block.

Fig. 6. Graphically represented STATCOM control parameter Vabc, Iabc, Vdc
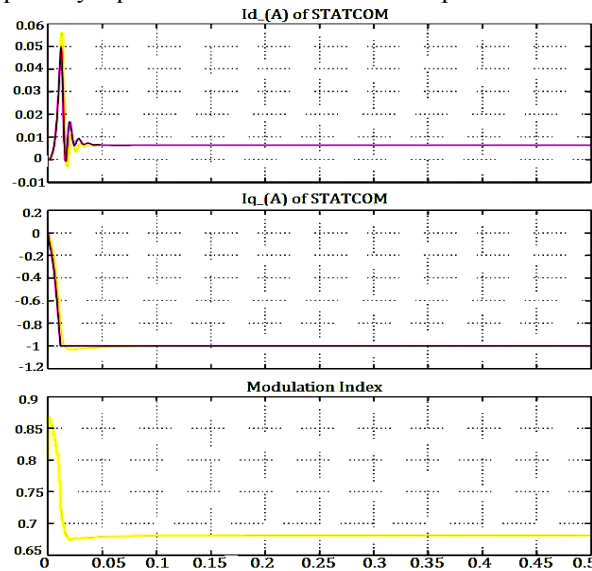

Fig. 7. Graphically represented STATCOM control parameter Id, Iq, Modulation Index.

The STATCOM shunt FACT device installed in two area 11 bus system to find out the active, reactive power flow in all the buses, the power at bus B1,B2, B3, B4, B5, B6, B7, B8, B9, B10, B11 is calculated, the variations in total active, reactive power will be shown in figure 8, figure 9, figure 10 and figure 11.
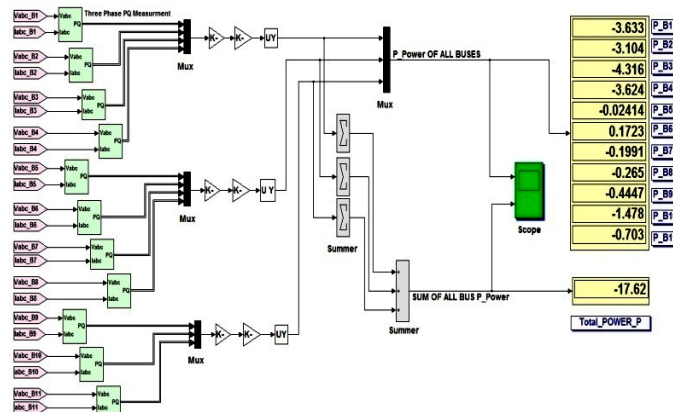

Fig. 8. Control parameter blocks for Active power (P) of all buses and sum of total power at buses.
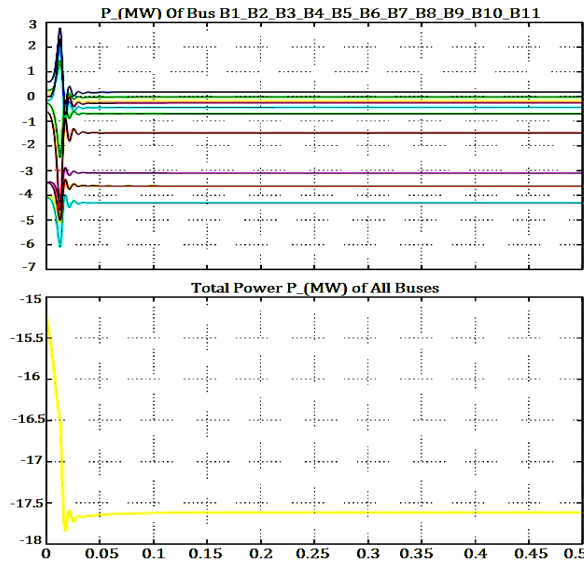
Fig. 9. Graphically represent the Active power (P) of all buses and sum of total power at buses.
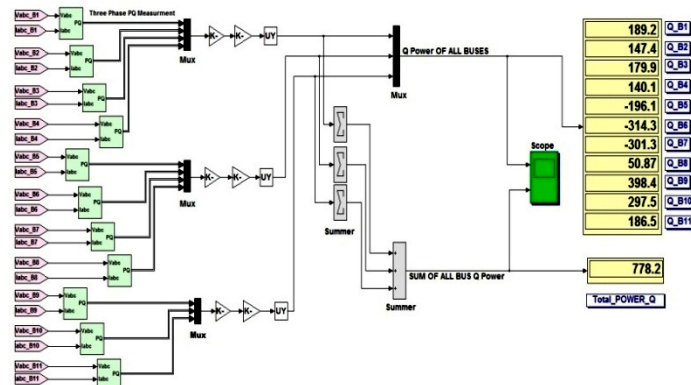

Fig. 10. Blocks of Control parameter for reactive power (Q) of all buses and sum of total power at buses.
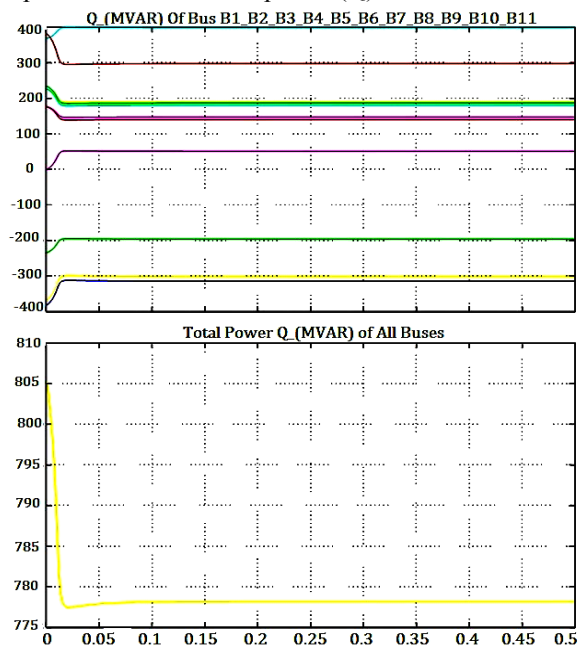

Fig. 11. Graphically represent the reactive power (Q) of all buses and sum of total power at buses.
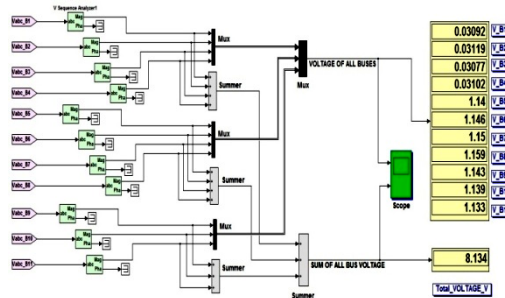
Fig. 12. Blocks represent the voltage control by STATCOM Shunt FACT device at different buses and sum of total voltage.
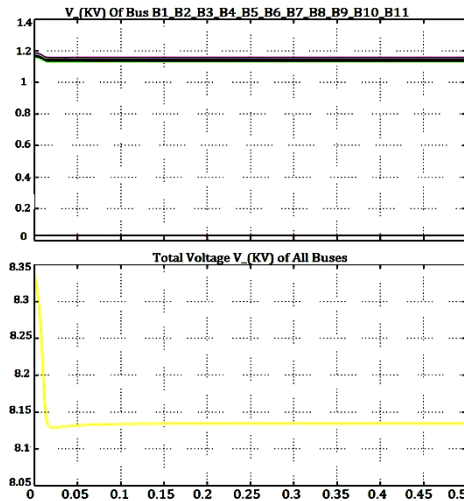

Fig. 13. Graphically represent the bus voltage control by STATCOM Shunt FACT device at different buses and sum of total bus voltage.
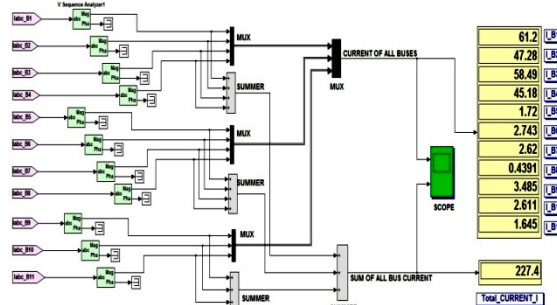

Fig. 14. Blocks represent the Current control by STATCOM Shunt FACT device at different buses and sum of total Current.
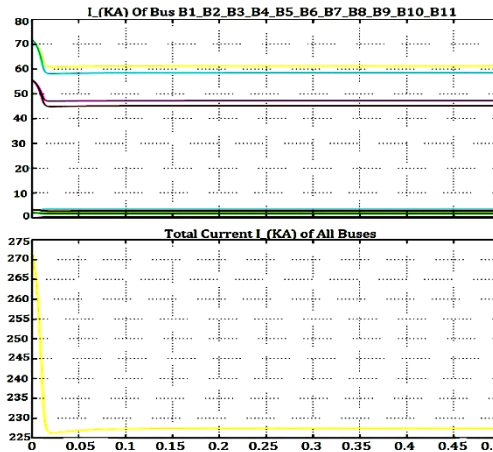

Fig. 15. Graphically represent the bus current control by STATCOM Shunt FACT device at differenct buses and sum of total current.

VII. TWO AREA 11 BUS TEST SYSTEM MODEL WITH SSSC

A multi machine power system with two-area 11-bus test system model, Area-1 and Area-2 system is used to access the effectiveness of SSSC model developed. Figure 16 show the proposed single line diagram of 11 bus power system with installed SSSC Fact device has been considered. The SSSC Series Fact device is connected between the bus 9 and bus 10. The G1, G2, G3, G4 represent the generators and T1, T2, T3, T4 represent the transformers. The power flow in the 290km transmission systems is split-up in to two segments having a length of 110km, 25km and 10km respectively in both areas.
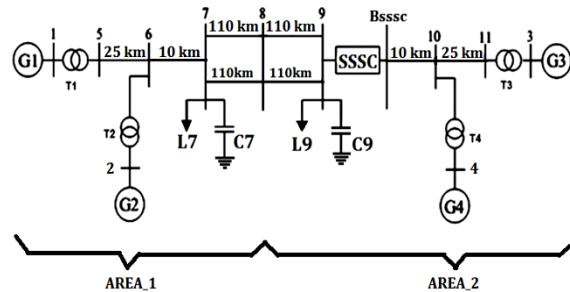
Fig. 16. Two-area power systems with series FACT device SSSC.

VIII. SIMULATION MODELLING OF 11 BUS TEST SYSTEM WITH SSSC

All the relevant parameters are given in Appendix. The source voltages of 13.8kV are connected by a 290km transmission line through three-phase step-up transformers. The system consists of two output voltage of transformer is 500KV equivalents, respectively 1000MVA and 4200MVA in each area, connected by a 290km transmission line. The loads in each area having 30KW are so chosen that the real power flow on the transmission line from area 1 to 2. The SSSC used for this model is a phasor model. The load centre of approximately 60KW is modelled where the active & reactive power absorbed by the load is a function of the system voltage. The POD controller is used to reduce the oscillations in the system when it is ON and generate the Vref signal to operate the SSSC is shown in figure 17. All the data of SSSC is calculated at ON status of POD controller. The SSSC is initially regulate from t = 0sec to 2sec after that at t = 2sec to t = 6sec SSSC operate in inductive mode and absorb the power is shown in figure 19, at t = 6sec to t = 10sec SSSC operate in capacitive mode and supplies the power flow is shown in figure 21.
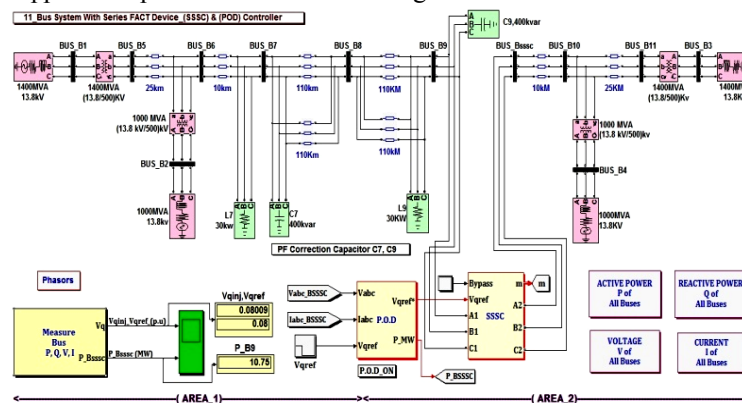
Fig. 17. Simulink model of 11 bus power system with SSSC at bus 8. (POD status-ON)

IX. SIMULATION MODELLING RESULTS OF SSSC

The SSSC series FACT device having a internal control block parameter is shown in figure 18. The quadrature voltage Vqinj injected with reference to reference quadrature voltage of SSSC is Vqref. Initially SSSC regulated from t=0s to 2s, Vqref is set to -0.08 pu (SSSC inductive); then at t=6s,Vqref is set to 0.08 pu (SSSC capacitive). The graphically represented the modulation index and quadrature voltages of SSSC are shown in figure 19.
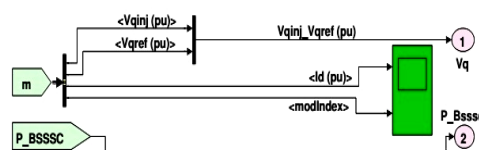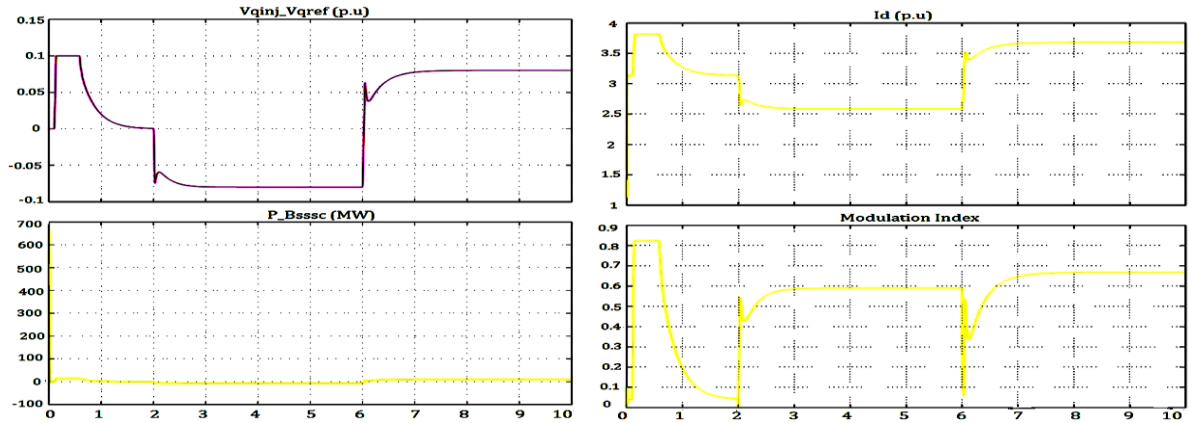
Fig. 18. SSSC control parameter.

Fig. 19. Graphically represented SSSC control parameter.

The SSSC series FACT device installed in 11 bus system to control the active power flow in all the buses, the power at bus B1,B2, B3, B4, B5, B6, B7, B8, B9, B10, B11 and Bsssc, is calculated and total power will be improved by SSSC is 62.02MW is show in figure 20 and figure 21.

Fig. 20. Block of Control parameter for Active power (P) of all buses and sum of total power at buses.
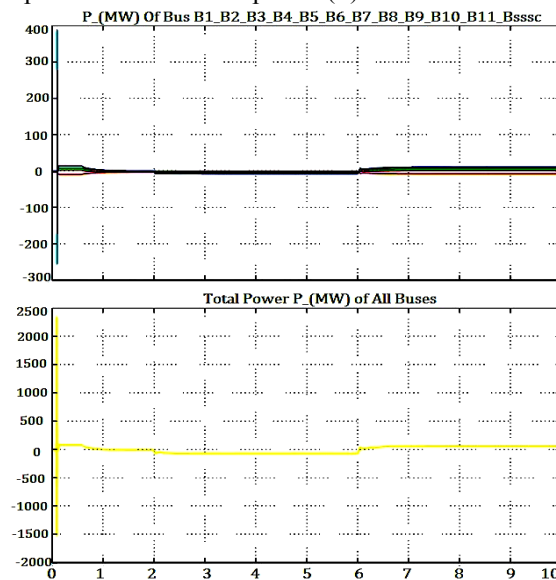
Fig. 21. Graphically represent the Active power (P) of all buses and sum of total power at buses.

The Reactive power flow control by SSSC at all the buses, the total power will be improved by SSSC 1723MVA in capacitive mode is shown in figure 22 and figure 23. (Block representation and graphical output)
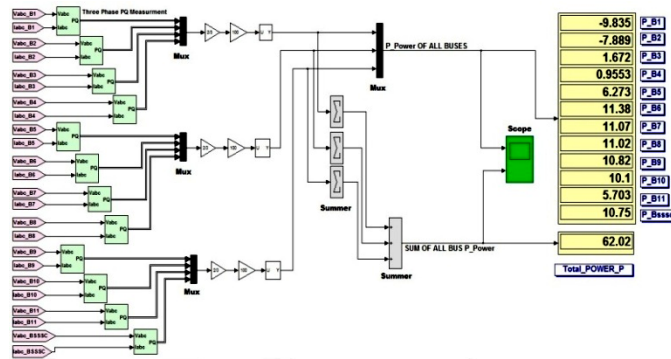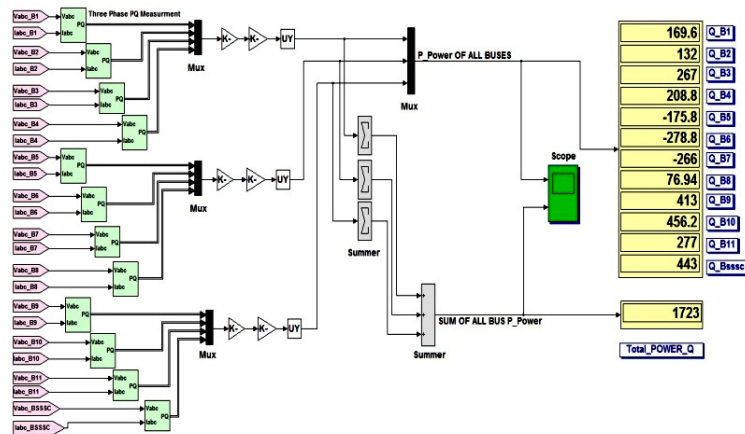
Fig. 22. Blocks of Control parameter for reactive power (Q) of all buses and sum of total power at buses.
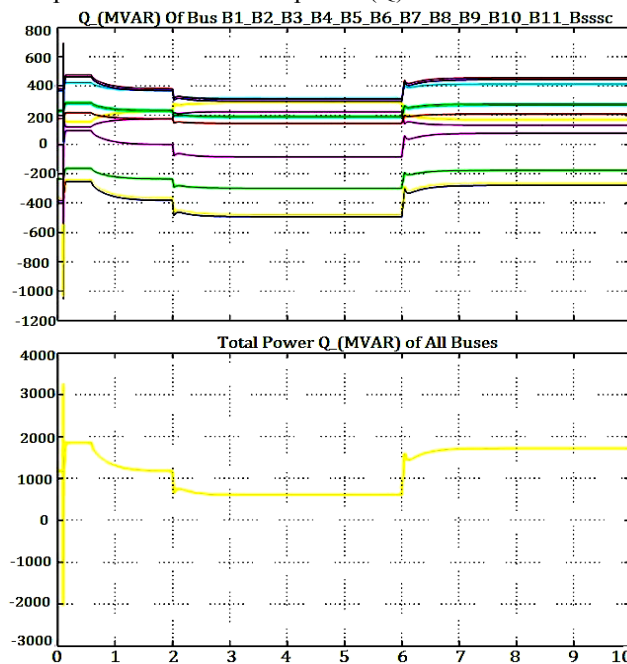
Fig. 23. Graphically represent the reactive power (Q) of all buses and sum of total power at buses.
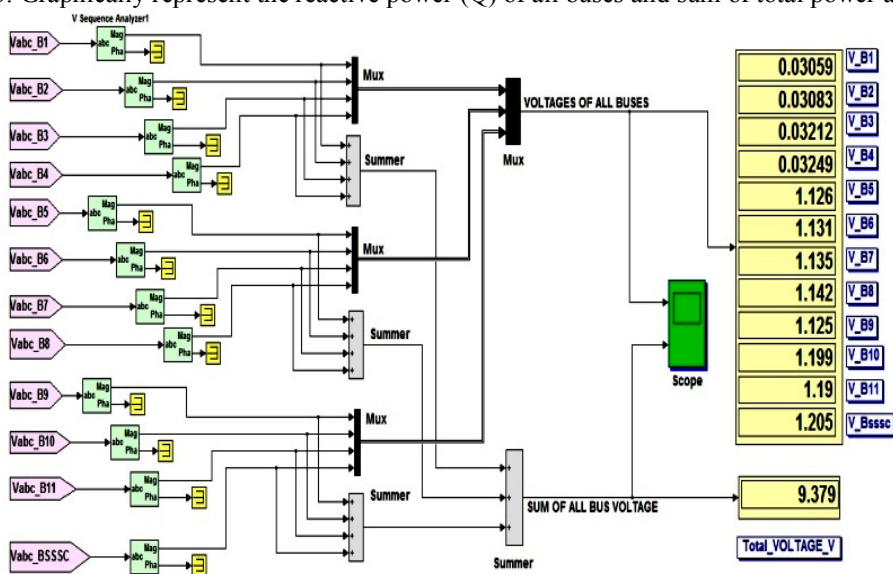
Fig. 24. Blocks represent the voltage control by SSSC Series FACT device at different buses and sum of total voltage.
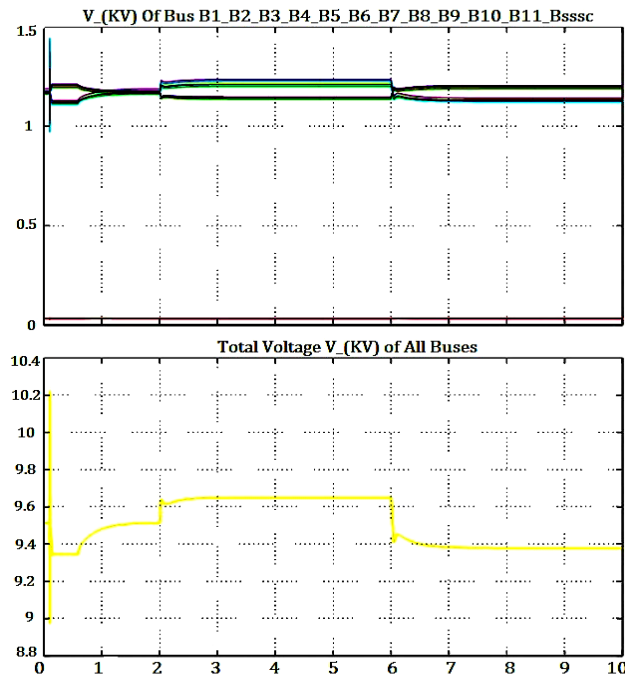
Fig. 25. Graphically represent the bus voltage control by SSSC Series FACT device at different buses and sum of total voltage.
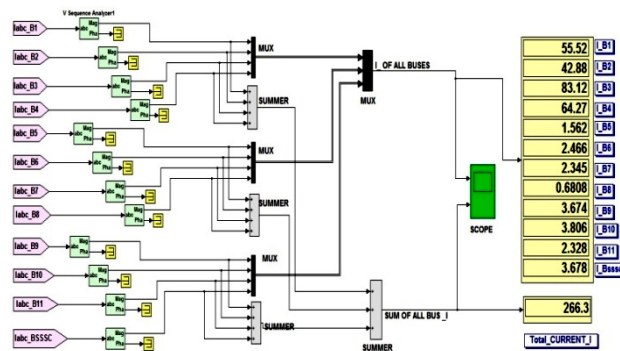
Fig. 26. Blocks represent the Current control by SSSC Series FACT device at different buses and sum of total current.

Fig. 27. Graphically represent the bus current control by SSSC Series FACT device at different buses and sum of total current.

X. SUMMARY OF SIMULATED RESULTS

The performance of the series, shunt FACT Devices (SSSC and STATCOM) model are compared and analyzed, by analyzing series connected SSSC can better improved the power that is active, reactive power flow control and voltage is improved in the two area power system network, the total bus power is P = 62.02MW, Q 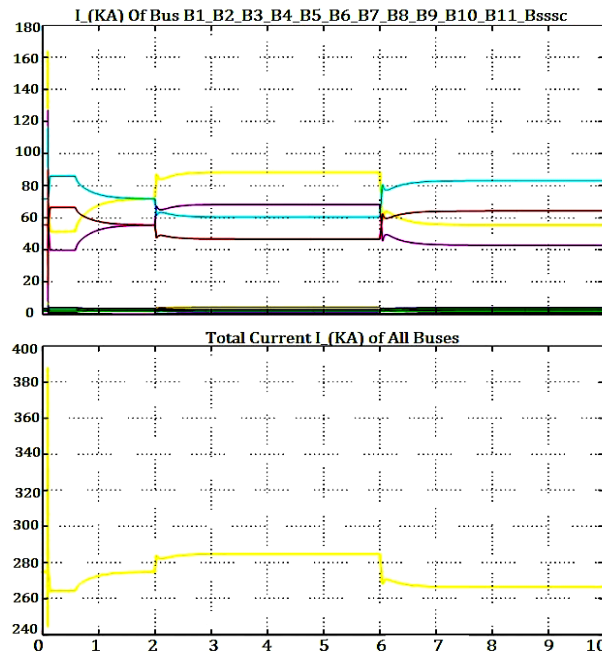=1722.94MVA and V = 9.37KV as compared to shunt connected STATCOM, the total bus power is P = -17.61MW, Q =778.17MVA and V = 8.133KV. All the SSSC connected system data obtained at POD status ON condition and STATCOM connected system data obtain for voltage regulation mode only. According to the result it was observed that the SSSC are more effective in power system to power flow control and voltage improvement, all the bus data of P,Q,V and I is shown in table 1.

Table 1 Comparison between STATCOM and SSSC for P, Q, V and I.

	STATCOM	SSSC	STATCOM	SSSC	STATCOM	SSSC	STATCOM	SSSC
BUSES	P (MW)	P (MW)	Q (MVAR)	Q (MVAR)	V (KV)	V (KV)	I (KA)	I (KA)
B1	-3.633	-9.835	189.2	169.6	0.03092	0.03059	61.2	55.52
B2	-3.104	-7.889	147.4	132	0.03119	0.03083	47.28	42.88
B3	-4.316	1.672	179.9	267	0.03077	0.03212	58.49	83.12
B4	-3.624	0.9553	140.1	208.8	0.03102	0.03249	45.18	64.27
B5	-0.02414	6.273	-196.1	-175.8	1.14	1.126	1.72	1.562
B6	0.1723	11.38	-314.3	-278.8	1.146	1.131	2.743	2.466
B7	-0.1991	11.07	-301.3	-266	1.15	1.135	2.62	2.345
B8	-0.265	11.02	50.87	76.94	1.159	1.142	0.4391	0.6808
B9	-0.4447	10.82	398.4	413	1.143	1.125	3.485	3.674
B10	-1.478	10.1	297.5	456.2	1.139	1.199	2.611	3.806
B11	-0.703	5.703	186.5	277	1.133	1.19	1.645	2.328
Bsssc	NC	10.75	NC	443	NC	1.205	NC	3.678
TOTAL	-17.6186	62.0193	778.17	1722.94	8.1339	9.37903	227.413	266.33

STATCOM - Data	
Vm	1.143
Vref	1
Qm	1.143
Qref	0

SSSC - Data	
Vinj	0.08009
Vref	0.08
P_B9	10.75

XI. Appendix

A complete list of parameters used appears in the default options of Simpower Systems toolbox of MATLAB in the above block diagram model. All data are in p.u. unless specified otherwise.

S.No	Name	Parameter
1	3-ø Source	V (KV) = 13.8e3, f (Hz) = 60, MVA = 1400e6, X/R = 8 V (KV) = 13.8e3, f (Hz) = 60, MVA = 1000e6, X/R = 8
2	3-ø Transformer	Pn (MVA) = 1400e6, f (Hz) = 60, V1 Ph-Ph (Vrms) (KV) = 13.8e3 R1(pu) = 0.002, L1(pu) = 0.08, V2 Ph-Ph (Vrms) (KV) = 500e3, R2(pu) = = 0.002, L2(pu) = 0.08, Rm (pu) = 500, Lm (pu) = 500 Pn (MVA) = 1000e6, f (Hz) = 60, V1 Ph-Ph (Vrms) (KV) = 13.8e3 R1(pu) = 0.002, L1(pu) = 0.08, V2 Ph-Ph (Vrms) (KV) = 500e3, R2(pu) = = 0.002, L2(pu) = 0.08, Rm (pu) = 500, Lm (pu) = 500
3	Distributed Parameter Line	Km = 10 & 25, f (Hz) = 60, R1 = 0.1153, R0 = 0.3963, L1 = 1.048e-3, L0 = 2.730e-3, C1 = 11.33e-9, C0 = 5.338e-9 Km = 110, f (Hz) = 60, R1 = 0.01273, R0 = 0.3864, L1 = 0.9337e-3, L0 = 4.1264e-3, C1 = 12.74e-9, C0 = 7.751e-9.
4	3-ø Load (R Load)	Vn (Vrms) (KV) = 500e3, f (Hz) = 60, P (KW) = 30e3
5	3-ø (C Bank)	Vn (Vrms) (KV) = 500e3, f (Hz) = 60, Qc = 400e3.
6	SSSC (Power Data)	Vrms L-L (Kv) = 500e3, f (Hz) = 60, Snom (MVA) = 100e6, R(pu) = 0.16/30, L(pu) = 0.16, Vdc(Kv) = 40e3, C (μF) = 375e-6
7	SSSC (Control Parameter)	Vqref (pu/s) = 3, Injected v gains (Kp =0.03/8, Ki =1.5/8), Vdc Gains (Kp =0.1e-3, Ki =20e-3)
8	POD_Status ON/OFF (For ON)	Gain = 0.09, Lowpass time constant = 100e-3, Wash-out time constant = 1, Lead-lag time constants (Tnum = 1, Tden = 0.1), Output limits (pu) (min =-0.1, max = 0.1), Initial input = 6.64.
9	Timer (For POD)	Time (S) = [0, 2, 6], Amplitude = [0, -0.08, 0.08]/7
10	Timer (For SSSC By Pass)	Time (S) = [0, 0.1], Amplitude = [1, 0]
11	STATCOM (Power Data)	Vrms L-L (Kv) = 500e3, f (Hz) = 60, MVA = 100e6, R(pu) = 0.22/30, L(pu) = 0.22, Vdc (Kv) = 40e3, C (μF) = 750e-6/2.
12	STATCOM (Control Parameter)	Vref (pu) = 1, Vref (pu/s) = 1, Droop (pu) = 0.03, Vac Gains (Kp =5 Ki =1000), Vdc Gains (Kp =0.1e-3, Ki =20e-3), I Regulators Gain (Kp =0.3, Ki =10, Kf = 0.22)

XII.   CONCLUSION

In this paper, present a detailed analysis of SSSC series and STATCOM shunt FACT devices and gives a concise idea and focusing on the best device for active, reactive power flow and voltage control in power system. A systematic procedure for modeling and simulink of SSSC and STATCOM device used for improvement on active, reactive power flow control was investigated in a two-area four-machine 11-bus test system model. A simulation result were obtained in the environment of MATLAB/SIMULINK model of a two-area system with SSSC and STATCOM FACT device, when SSSC and STATCOM device are placed at the area-2 of the transmission line. The simulation results reveal that the SSSC device with power oscillation damping (POD) controller are more effective and betterly improve the active, reactive power flow and voltage control in a power system as compared to STATCOM device.

Acknowledgements

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