Modelling and Analysis of Static Synchronous Series Compensator (SSSC) for Reactive Power Compensation and Voltage Regulation

[1]Ruchirkumar Mehta, [2]A. R. Patel, [3]Dr. N. G. Mishra
[1]PG student, [2] Asst. Professor, [3]Professor
[1]Electrical Engineering Department,
[1]Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar, India

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Abstract: Nowadays, power system is heavily loaded as the power demand is rapidly increasing. Therefore, the problem of power transfer capability and voltage drop at the receiving end stations arise in AC power system. For sustaining this trend, the need is to compensate reactive power to eliminate the problems of voltage drop. The Static Synchronous Series Compensator (SSSC) is a FACTS device which performs to compensate the reactive power and improves the voltage profile of the power system. SSSC injects compensating voltage into the power system that is in quadrature with the line current of the system. The SSSC injects this compensating voltage into the system from Voltage Source Inverter (VSI) through a coupling transformer. This paper presents modelling and performance analysis of SSSC to address the issues of reactive power compensation and voltage regulation of transmission networks. The simulation has been executed using MATLAB software. In the proposed method, the SSSC injects compensating voltage at bus no. 2 in a 4 bus system.

***Index Terms*- Static Synchronous Series Compensator (SSSC), Reactive Power Compensation, Voltage Profile Improvement, Compensating Voltage, Circuit Breaker (CB).**

I. INTRODUCTION

The Static Synchronous Series Compensator (SSSC) is a static device which provides faster operation than other static switching devices. High Voltage Alternating Current (HVAC) transmission system requires devices to provide reactive power compensation and voltage regulation to the system e.g. SSSC. The SSSC can control both the active and reactive power flow control when a DC battery is used instead of a DC capacitor on the DC side of the three-phase voltage source inverter [1]. The SSSC can operate in both the inductive and capacitive regions. The range for capacitive region is up to -1.0 p.u. and the range for inductive region is up to +1.0 p.u. for the reactive power compensation [2]. The SSSC is a FACTS (Flexible Alternating Current Transmission System) device that can perform either capacitive or inductive compensation as per the operators' command and system requirement. The capacitive compensation reduces the reactive power demand from the generation sources and supplies the reactive power to the power system [3]. The inductive compensation increases the reactive power demand from the generation sources and absorbs reactive power from the system. Thus reducing the voltage at various buses of the power system [4].

Whenever the reactive power compensation is required, the voltages at all the buses in the system get increased from their previous values. Thus the voltage drop at these buses is significantly reduced. The voltage profile of the system is enhanced by providing capacitive compensation. The SSSC not only provides reactive power compensation but also improves the system stability. PI controller adjusts the control parameters of the power system [5]. The main objective of this paper is to obtain reactive power compensation along with voltage profile improvement in the 4 bus power system.

II. PRINCIPLE OF SSSC

The SSSC acts as a synchronous voltage source instead of just a series capacitor insertion. It provides reactive power compensation to the power system by injecting a three-phase AC compensating voltage which is at 90° with the line current. The SSSC injects the compensating voltage in series with the system as shown in fig. 1 & 2 [6].

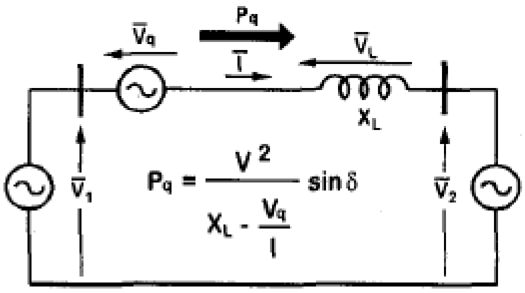

Fig. 1. Basic two machine system for SSSC [2]

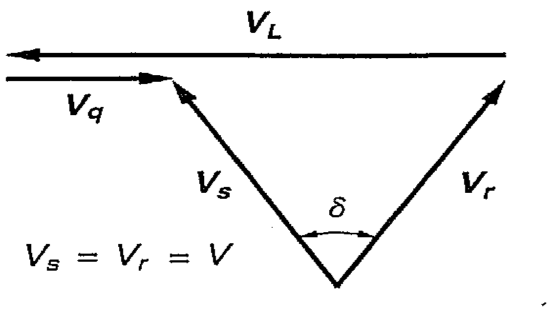

Fig. 2. Phasor diagram of system including SSSC [2]

The compensating voltage leads or lags the line current as it operates in the inductive or capacitive region respectively. The rating of SSSC is the product of the compensating voltage V_q and line current [7].

The power system has real and reactive power flow without SSSC which can be represented by following equations:

$$P=\frac{V_S*V_R*\sin\delta}{X_L}=\frac{V^2*\sin\delta}{X_L} \qquad \ldots(1)$$

$$Q=\frac{V_S*V_R*(1-\cos\delta)}{X_L}=\frac{V^2*(1-\cos\delta)}{X_L} \qquad \ldots(2)$$

X_{eff} is the effective reactance of the system including the injected reactance in the transmission line. Injected reactance X_q is negative for inductive compensation and X_q is positive for capacitive compensation [8].

The real and reactive power flow in the power system with SSSC has following equations:

$$P_q=\frac{V^2*\sin\delta}{X_{eff}}=\frac{V^2*\sin\delta}{X_L\left(1-\frac{X_q}{X_L}\right)} \qquad \ldots(3)$$

$$Q_q=\frac{V^2*(1-\cos\delta)}{X_{eff}}=\frac{V^2*(1-\cos\delta)}{X_L\left(1-\frac{X_q}{X_L}\right)} \qquad \ldots(4)$$

Where $V_S=V_R=V$ (Assumed). $\delta=\delta_S-\delta_R$.

III. CONTROL STRATEGY FOR SSSC

The voltage and current from bus 2 are given as input in the control system. The voltage input is provided to the three-phase locked loop where the system frequency is matched with internal oscillator frequency and the phase difference is made zero between both of them. This voltage and current are transformed from abc to dq0 [9].

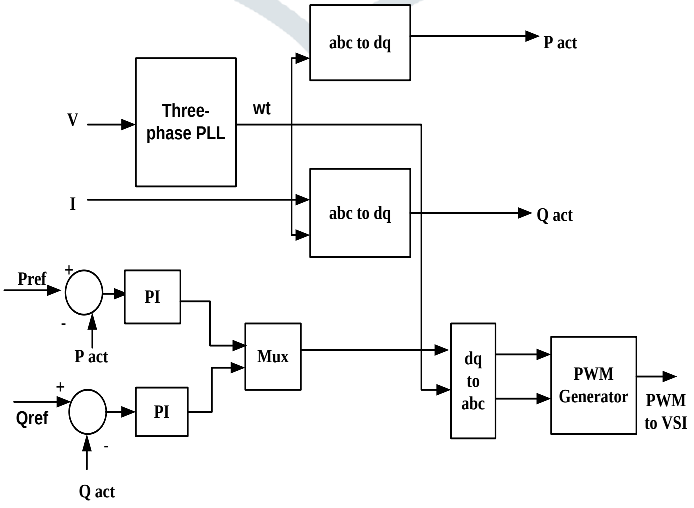

Fig. 3. Control strategy of SSSC

Actual real and reactive powers are obtained in dq0 using the following equations:

$$P = V_d * I_d + V_q * I_q \qquad \ldots(5)$$

$$Q = V_q * I_d + V_d * I_q \qquad \ldots(6)$$

These actual active and reactive powers (P_{act} and Q_{act}) are then compared with reference values P_{ref} and Q_{ref} respectively as shown in fig. 3. These errors are provided as input to PI controller which eliminates the steady state error. Now, dq0 to abc transformation is executed which is given as input to the pulse width modulator (PWM). These PWM produces pulses which are provided as gate signals to the Voltage Source Inverter (VSI). This VSI produces compensating voltage which is injected into the system through a coupling transformer as shown in fig. 4 [10].

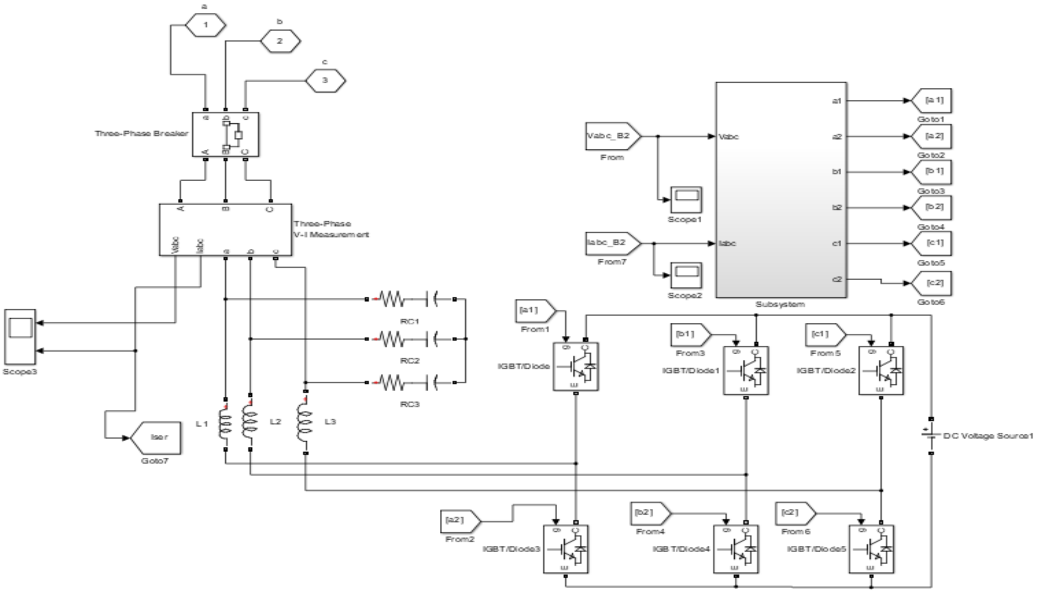

Fig. 4. Simulated converter circuit of SSSC

IV. SIMULATION & RESULTS

Both generators 1 & 2 generate 13.8 kV. The power transformers TR1 and TR2 step up the voltages from 13.8 kV to 500 kV which is the line voltage. The transmission line length from bus B1 to bus B3 is (L1) =150 km. Bus B4 is 150 km away from B3 i.e. (L3) =150 km. The transmission line length from bus B2 to bus B4 is (L2) =280 km and line length from bus B4 to generator G2 is (L4) =50 km. The proposed simulation model of this power system with and without SSSC is shown in fig. 5 and 6. As shown from fig. 7, the voltage level is compensated from 438.4 kV (R.M.S.) to 446.89 kV (R.M.S.) at bus 2 by using SSSC for reactive power compensation. Similarly, the voltage levels at other buses are increased. The voltage at the bus B4 near the receiving end station is also increased from 405.1 kV to 410.12 kV. Figure 8 presents current at bus 2 in presence & absence of SSSC respectively.

Circuit breaker (CB) is closed during starting time as shown in fig. 9. So SSSC is operating till time t=0.8 seconds. CB is open from t=0.8 to t=1.0 sec. Therefore, SSSC is not operating during this period. Then at time t=1.0 sec, CB is closed again that makes SSSC come into operation once again.

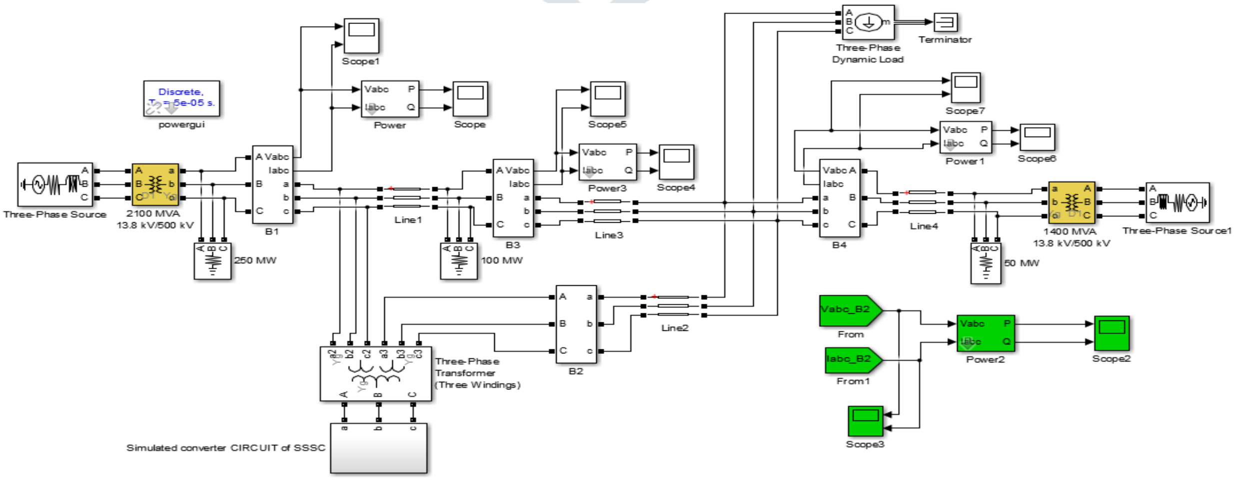

Fig. 5. 4-bus system with SSSC

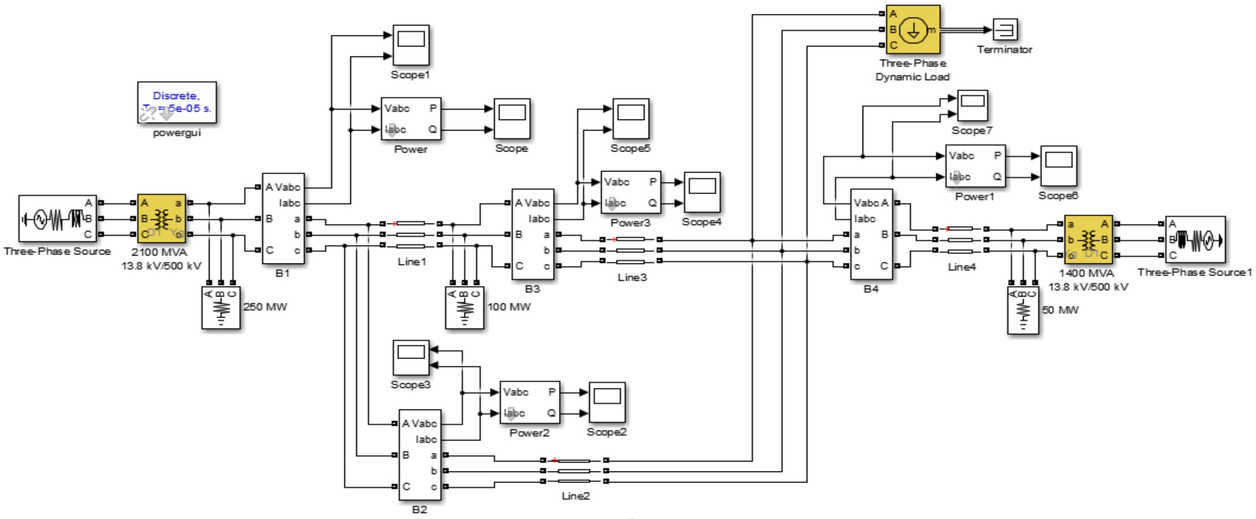

Fig. 6. 4-bus system without SSSC

The specifications & system parameters of SSSC are shown in the table 1:

Table 1 System parameters & specifications

Specifications	**System parameters**
Generator G1	13.8 kV
Generator G2	13.8 kV
Transformer TR1	2100 MVA, 13.8 kV/ 500 kV
Transformer TR2	1400 MVA, 13.8 kV/ 500 kV
Transmission line voltage	500 kV
Dynamic Load	1800 MW, 871.78 MVAR
Coupling transformer	70 MVA, 6.6 kV/ 48 kV
Line length	L1= 150 km, L2=280 km, L3= 150 km, L4= 50 km

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The results for system without SSSC are depicted in the table 2 below:

Table 2 Simulation results for system without SSSC

Bus no.	Voltage (kV)- R.M.S.	Current (Amp)- R.M.S.	Active power (MW)	Reactive power (MVAR)
1	438.4	848.53	848	734
2	438.4	415.7	400	371
3	427	388.9	257	425
4	405.1	1195	1120	932

Table 3 provides injected compensating voltage V_q & reactive power injection into the power system. The SSSC injects reactive power in the system through bus 2. Therefore, reactive power at bus 2 gets increased. Figure 9 represents active power at bus 2. Figure 10 represents reactive power at bus 2.

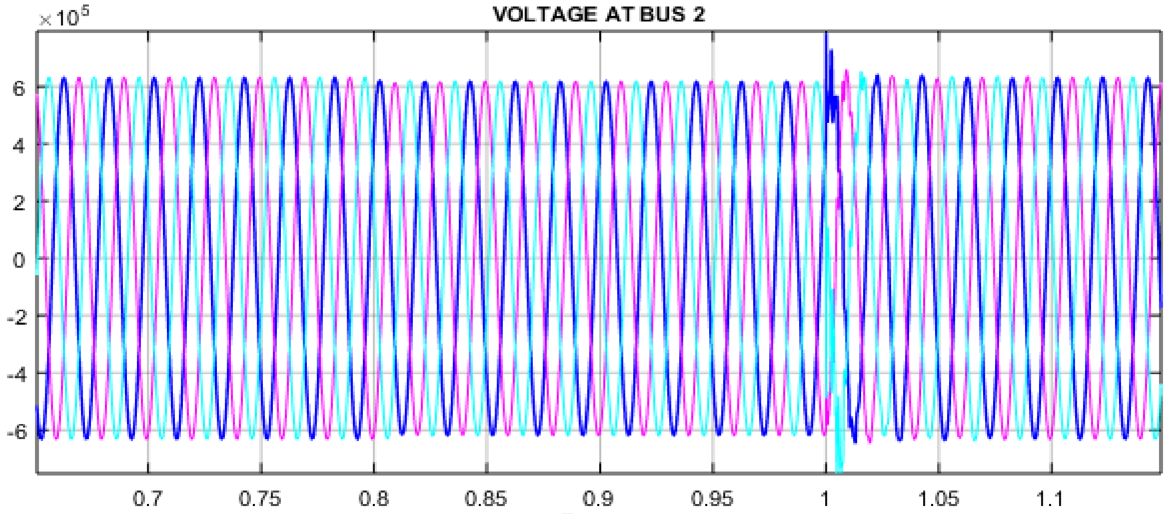

Fig. 7. Voltage at bus 2

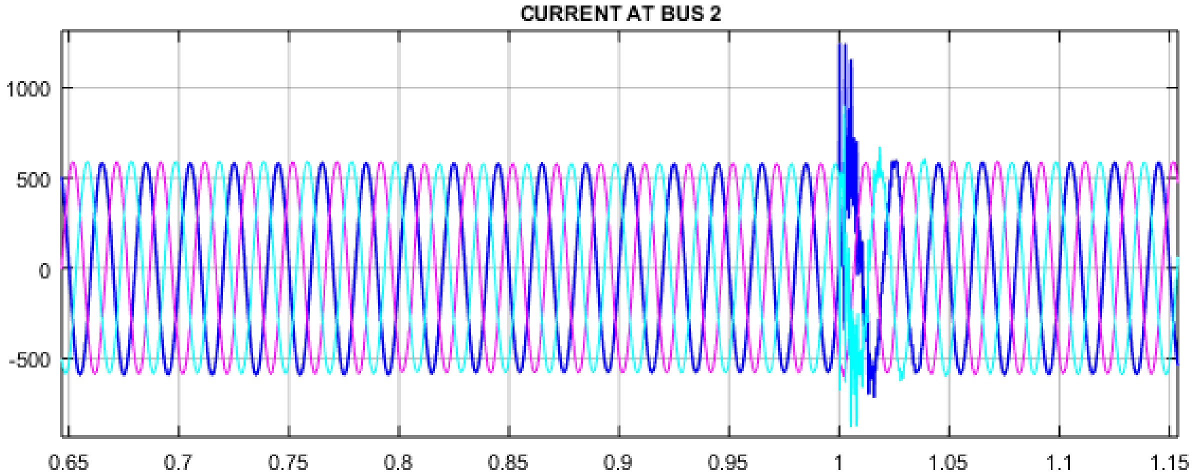

Fig. 8. Current at bus 2

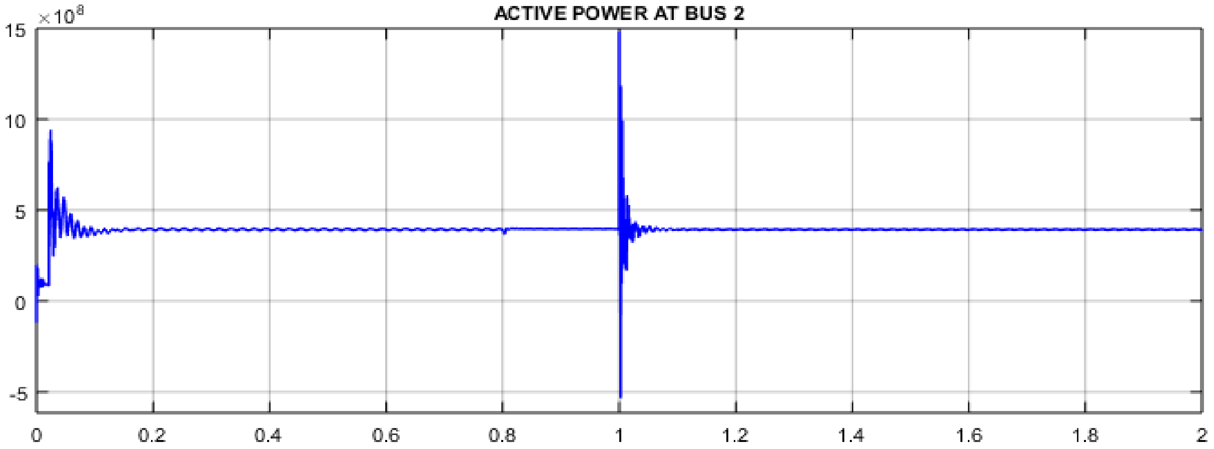

Fig. 9. Active power at bus 2

The active power is maintained at 400 MW using the DC battery. The increase in VAR absorption from 371 MVAR to 400 MVAR at bus 2 reduces the demand of reactive power from the generation stations which reduce the reactive power at buses 1 & 4. The injected compensating voltage is 35.35 kV (R.M.S.). Therefore, the active power at buses 1 & 4 are significantly increased as seen from table 3.

The power transfer from bus B4 is very high compared to other buses as it is closest to the dynamic load. The dynamic load is 1800 MW, 871.78 MVAR. It is connected in parallel to line 2 and line 3 connected in parallel in the HVAC transmission line.

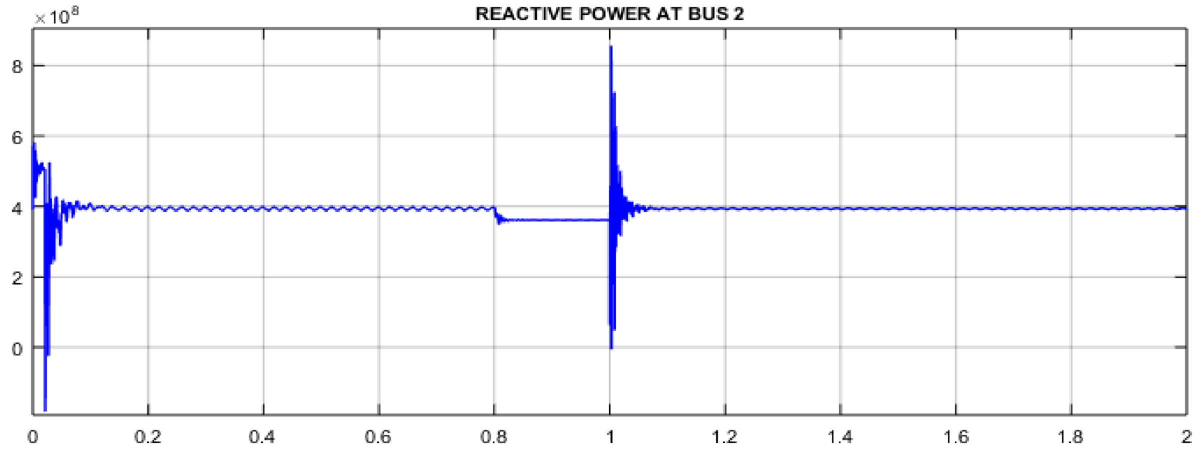

Fig. 10. Reactive power at bus 2

Table 3 Simulation results for system with SSSC

Bus no.	Voltage (kV)- R.M.S.	Current (Amp)- R.M.S.	Active power (MW)	Reactive power (MVAR)
1	446.89	848.53	920	680
2	446.89	410.12	400	400
3	431.33	397.4	251	450
4	410.12	1195	1160	910

V. CONCLUSION

The results justify that voltage regulation is obtained and there is improvement in voltage profile at all the buses. The series compensation provided for voltages at buses 1, 2, 3 & 4 is attained as 13.78%, 13.78%, 5.93% & 5.29% respectively. Thus, reactive power compensation and voltage regulation both are attained using SSSC in the power system. The SSSC controls the power flow in the system effectively. The VAR absorption at buses 1 & 4 is reduced & real power transfer is increased.

REFERENCES

[1] L. Gyugyi, A. A. Edris, and M. Eremia, "Static Synchronous Series Compensator (SSSC)," *Advanced Solutions in Power Systems: HVDC, FACTS, and Artificial Intelligence: HVDC, FACTS, and Artificial Intelligence*, pp. 527-557.

[2] L. Gyugyi, C. D. Schauder, and K. K. Sen, "Static synchronous series compensator: a solid-state approach to the series compensation of transmission lines," *IEEE Transactions on power delivery*, vol. 12, pp. 406-417, 1997.

[3] K. Padiyar, "FACTS Controlling in power Transmission system and distribution," *New Age International Publishers*, 2008.

[4] M. Faridi, H. Maeiiat, M. Karimi, P. Farhadi, and H. Mosleh, "Power system stability enhancement using static synchronous series compensator (SSSC)," in *Computer Research and Development (ICCRD), 2011 3rd International Conference on*, 2011, pp. 387-391.

[5] H. Taheri, S. Shahabi, S. Taheri, and A. Gholami, "Application of synchronous static series compensator (SSSC) on enhancement of voltage stability and power oscillation damping," in *EUROCON 2009, EUROCON'09. IEEE*, 2009, pp. 533-539.

[6] L. Gyugyi, "Dynamic compensation of AC transmission lines by solid-state synchronous voltage sources," *IEEE Transactions on Power Delivery*, vol. 9, pp. 904-911, 1994.

[7] K. K. Sen, "SSSC-static synchronous series compensator: theory, modeling, and application," *IEEE Transactions on power delivery*, vol. 13, pp. 241-246, 1998.

[8] I. Zhang, M. Crow, Z. Yang, and S. Chen, "The steady state characteristics of an SSSC integrated with energy storage," in *Power Engineering Society Winter Meeting, 2001. IEEE*, 2001, pp. 1311-1316.

[9] M. El-Moursi and A. Sharaf, "Novel controllers for the 48-pulse VSC STATCOM and SSSC for voltage regulation and reactive power compensation," *IEEE Transactions on Power systems*, vol. 20, pp. 1985-1997, 2005.

[10] P. Nagar and S. Mittal, "Reactive Power Compensation by Static Synchronous Series Compensator," in *Micro-Electronics and Telecommunication Engineering (ICMETE), 2016 International Conference on*, 2016, pp. 301-304.