Modelling of Static Synchronous Series Compensator (SSSC) to Address the Issues of AC Transmission Network

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Abstract

Simulation and modelling of Static Synchronous Series Compensator (SSSC) is portrayed for VAR compensation in Flexible Alternating Current Transmission System in this paper. MATLAB software is utilized for simulation purpose of reactive power compensation using SSSC. The AC transmission network requires VAR compensators such as SSSC which improves various other aspects of the power system as well. The SSSC controls the injecting voltage in quadrature with line current into the system. It provides voltage regulation by compensating reactive power of the system. The SSSC comprises of Voltage Source Inverter (VSI), PI controller, PWM generator and three-phase locked loop.

Keywords: *FACTS devices, Static Synchronous Series Compensator (SSSC), Transmission line, Reactive power compensation*

INTRODUCTION

The advancement of Flexible AC Transmission System is started by the Electric Power Research Institute (EPRI). In FACTS, power flow is dynamically controlled by power electronic devices. The goals of FACTS are to enhance transmission capacity of line and control the power flow on indicated paths [1, 2].

The development & commercial presence of fast power-semiconductor devices like IGBT, Gate Turn-Off thyristor (GTO) has made fast controllable reactive power sources possible. The advancement of FACTS switching technologies e.g., STATCOM, SSSC, UPFC etc. is offering considerable merits over existing techniques. The voltage source inverter (VSI) are getting acceptance as the new emerging devices. They offer far more flexible reactive power control compared to conventional reactive power compensation devices like Thyristor Switched Capacitor (TSC), Thyristor Controlled Reactor (TCR), Thyristor Controlled Series Capacitor (TCSC) and Thyristor Switched Series Capacitor (TSSC) etc. The Static Synchronous Series Compensator (SSSC) comprises of PI controller, Voltage Source Converter, IGBT or GTO thyristor switches having intrinsic turn-off capability, coupling transformer and a DC capacitor. The DC capacitor is used as energy storage system. A DC battery can also be used in lieu of DC capacitor [3].

Nowadays, the transmission lines are being heavily loaded due to increase in load demand. Reactive power compensation helps in enhancing power transfer capability of the transmission line. It can also be used for improving the voltage regulation of the power system [4].

In High Voltage transmission lines, the reactance to resistance X_L/R ratio is between ranges of 3 to 10. When capacitive compensation increases this ratio is further reduced. This will limit the active power transfer due to increase in VAR absorption, line losses and possible voltage depression [5].

SSSC has negligible output impedance at frequencies other than fundamental frequency. Therefore, the converter allows only the positive sequence component of voltage and current through it under balanced condition. There is no problem of sub-synchronous resonance (SSR) below synchronous frequency under balanced condition because of the inability of the SSSC to establish classical series resonance circuit [6]. When the system is under major disturbance or faulty condition there are large power oscillations in the system. The SSSC reduces the power oscillations of the system during faulty condition. Thus, SSSC also provides power oscillation damping under unhealthy (faulty) conditions [7]. However, the scope of this research work is limited to compensate reactive power only using SSSC under healthy and balanced conditions.

FACTS DEVICES

FACTS technology adds flexibility to the power system by using controllers which can control impedances, current, voltage, phase angle and oscillation damping. FACTS Controller can be divided into four categories:

- Series controller: In principle, all series controller inject voltage in series with the line. Variable impedance multiplied by current flow through it, represents an injected series voltage in line. This series controller could be variable impedance, such as capacitor and inductor. This only supply or consumes variable reactive power. E.g., TCSC, TSSC, SSSC etc.
- Shunt controller: They represent current source connected to shunt with the line. Shunt Controllers only generates or absorb reactive power due to the injected current in phase quadrature with line voltage. E.g., TSC, TCR, TSC-TCR, STATCOM (Static Synchronous Compensator).
- Combined series-series controller: This is a combination of co-ordinately controlled separate series-series controller on the transmission line e.g., IPFC (Interline Power Flow Controller). They control both active and reactive powers.
- Combined series-shunt controller: It is the combination of series and shunt controller. E.g., Unified Power Flow Controller (UPFC). It controls active as well as reactive power [6].

SSSC is one of the key FACTS controllers. It can be based on a voltage source converter or current-source converter. The voltage soured converter is the most preferable. The SSSC converts the input voltage (V_{dc}) into three phase output voltages with desired amplitude, frequency and phase or the output voltage of the inverter must be in synchronous operation with the system voltage under any condition. SSSC installed in transmission line for many applications such as:

- Increasing the power transmission capability
- Reactive power compensation
- Voltage regulation
- Improving the transient and steady state stability
- Damping of power oscillation
- Power factor correction [8].

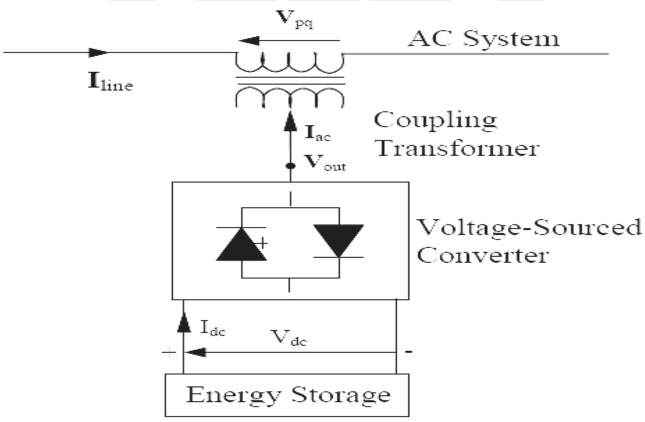

Fig. 1: *Functional model of SSSC [3]*

The Voltage Source Inverter (VSI) injects almost sinusoidal voltage at 90° with line current into the system through a coupling transformer [9]. The real power (P) and reactive power (Q) equations for a power system can be represented as follows:

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

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

The real & reactive power flow equations with SSSC are given below:

$$P = \frac{V^2 * \sin\delta}{X_{eff}} \quad ...(3)$$

$$Q = \frac{V^2 * (1 - \cos\delta)}{X_{eff}} \quad ...(4)$$

Where

$$X_{eff} = X_L \left(1 - \frac{X_q}{X_L}\right) \quad ...(5)$$

X_{eff} = Effective reactance
X_q = Compensating reactance
X_L = Inductive reactance

Inductive reactance is emulated in the system by SSSC when AC voltage leading the line current is injected. This decreases active power flow along with line current. Capacitive reactance is emulated in the system by SSSC when injected AC voltage lags the line current [8].

The compensating voltage is injected into the network from Voltage Source Inverter through a coupling transformer as shown in fig. 1. I_{dc} is dc current and V_{dc} is the DC voltage in the energy storage. I_{Line} is line current of power system. V_{pq} is the system voltage and V_{out} is the injected voltage into the coupling transformer [3].

SSSC MODELLING

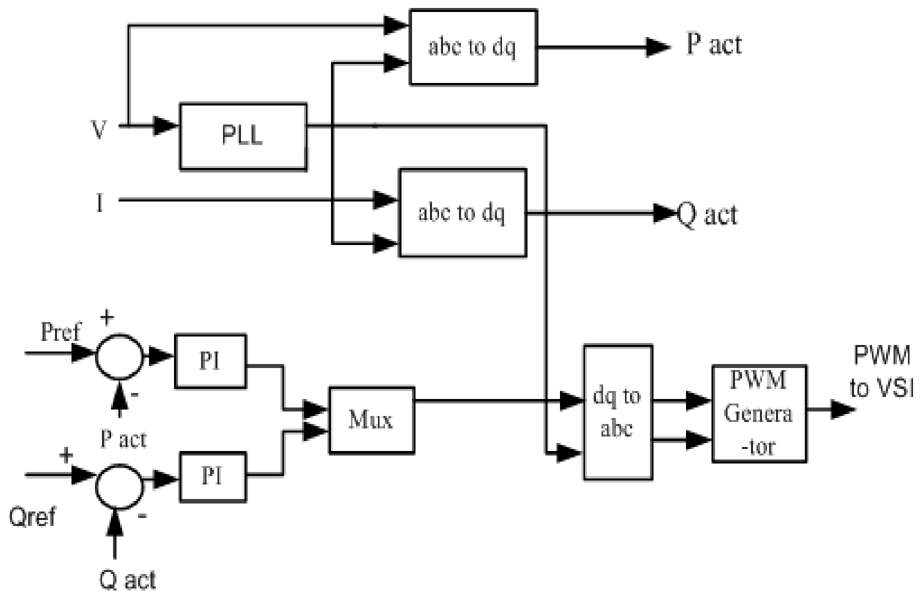

Fig. 2: *Control system of SSSC*

The dq0 technique provides details of active and reactive power flow. The quantities are represented in instantaneous dq0 form. The voltage and current are converted from abc to dq0 reference frame. The control system implementation is executed by comparing active power P_{act} in dq0 form with the provided reference active power P_{ref}. Similarly, Reactive power in dq0 form is compared with the reference reactive power as shown in fig. 2.

The errors obtained from both these comparisons are eliminated in PI controller. Then again dq0 to abc conversion is performed to provide commutation sequence to the gate pulse inputs of VSI using SPWM technique. The Three Phase Locked Loop (PLL) is used to synchronize the given sinusoidal voltage with the supply voltage [10].

SIMULATION & RESULTS

Here, the SSSC is connected in series with the system between bus 1 & 2. The SSSC controls active & reactive power at bus 2 thereby controlling the power flow & voltage regulation of the system.

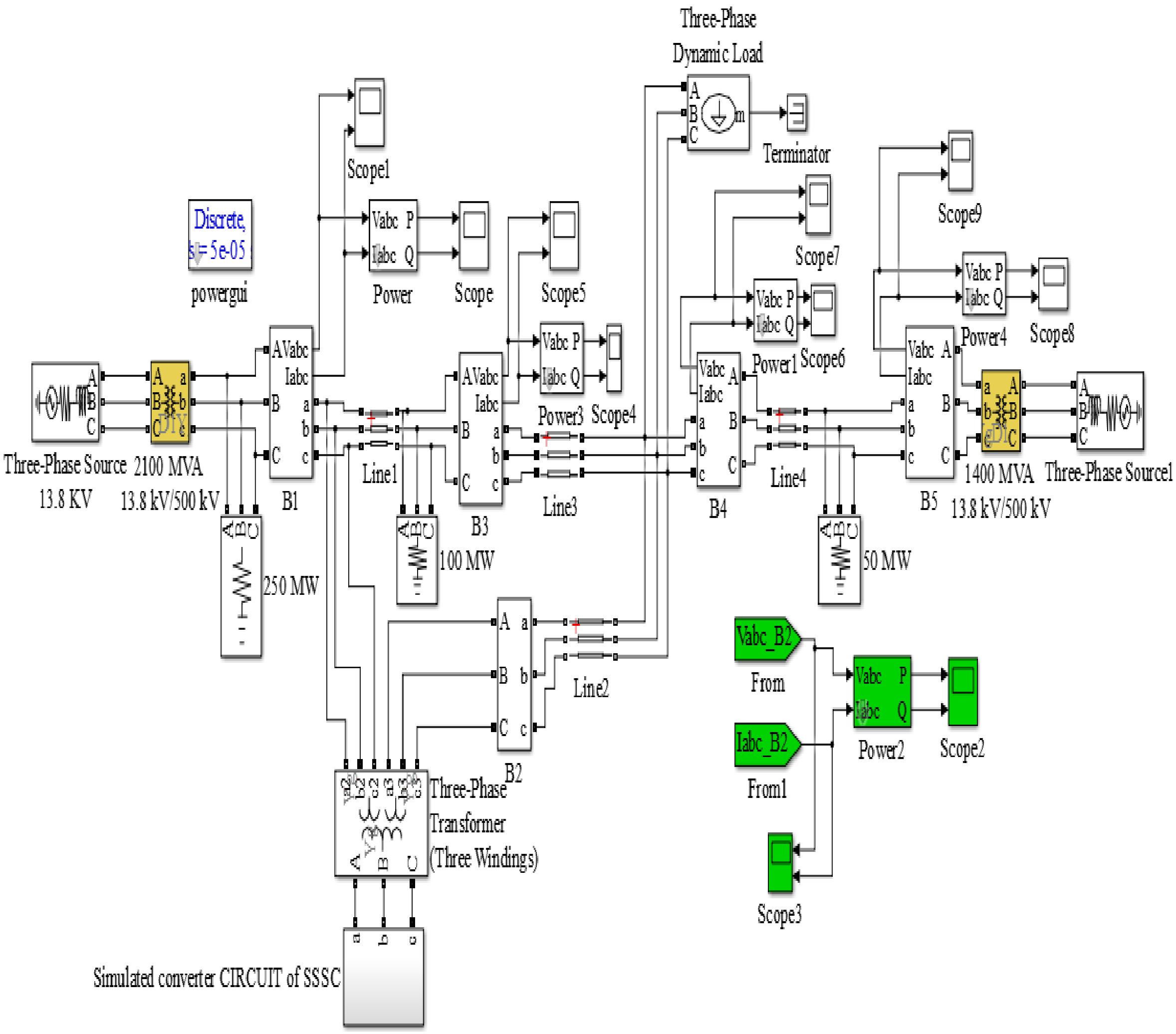

Fig. 3: *SSSC with 5-bus System*

The SSSC is disengaged from the system using a circuit breaker during time t= 0.8 to t= 1.0 second. The simulation model prepared for the proposed 5-bus power system is given below in fig. 3. The specifications of the simulation model are given in the table 1. A table 2 presents observation results of the 5-bus system without SSSC. Table 3 presents observation results of the given system with SSSC.

The compensator circuit is connected with DC voltage source. The resulting waveforms of voltage and current at bus 2 are presented in fig. 4 & 5. The results of active & reactive power at bus 2 are presented in fig. 6 & 7. The Pulse Width Modulated (PWM) signals obtained from PWM generator in the control system are given as input to the gates of VSI.

Table 1: *Specifications & Parameters of Model*

System specifications	System parameters
Generator 1	13.8 kV
Generator 2	13.8 kV
Transformer 1	2100 MVA, 13.8/ 500 kV
Transformer 2	1400 MVA, 13.8/ 500 kV
Transmission line voltage	500 kV
Dynamic load	1620 MW, 784.6 MVAR
Line length	Line 1= 110 km Line 2= 200 km Line 3= 110 km Line 4= 80 km
Coupling transformer	6.6 /48 kV, 70 MVA

Table 2: *Observations without SSSC*

Bus No.	Voltage (kV)	Current (Amp)	Active Power (MW)	Reactive Power (MVAR)
1	434.87	866.91	830	770
2	434.87	430.62	392	382
3	425.67	376.88	265	400
4	411.53	1025.30	925	863
5	424.97	1053.58	975	924

Table 3: *Observations with SSSC*

Bus No.	Voltage (kV)	Current (Amp)	Active Power (MW)	Reactive Power (MVAR)
1	441.94	862.67	900	720
2	441.94	428.5	390	420
3	431.33	387.49	260	430
4	417.19	1025.3	970	845
5	428.5	1055	1020	910

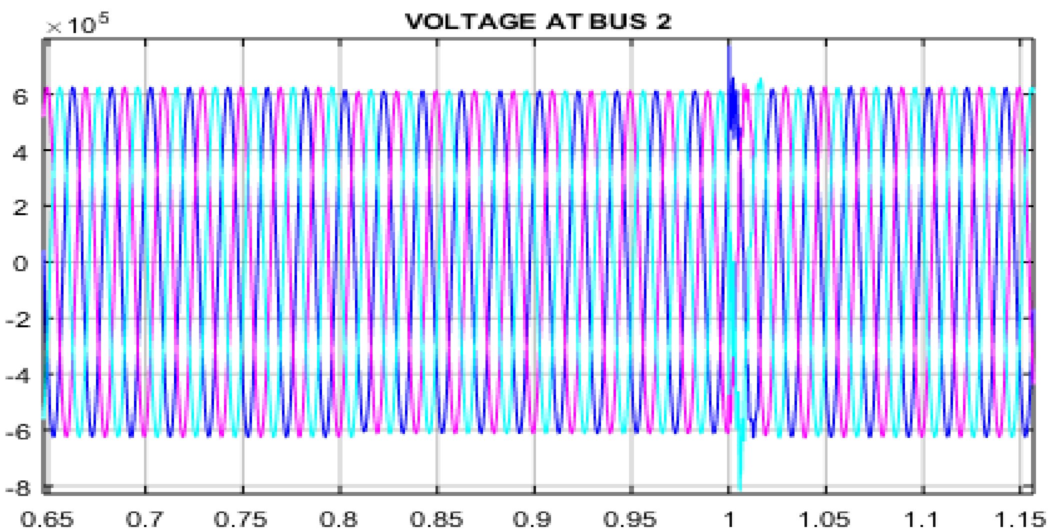

Fig. 4: *Voltage at Bus 2*

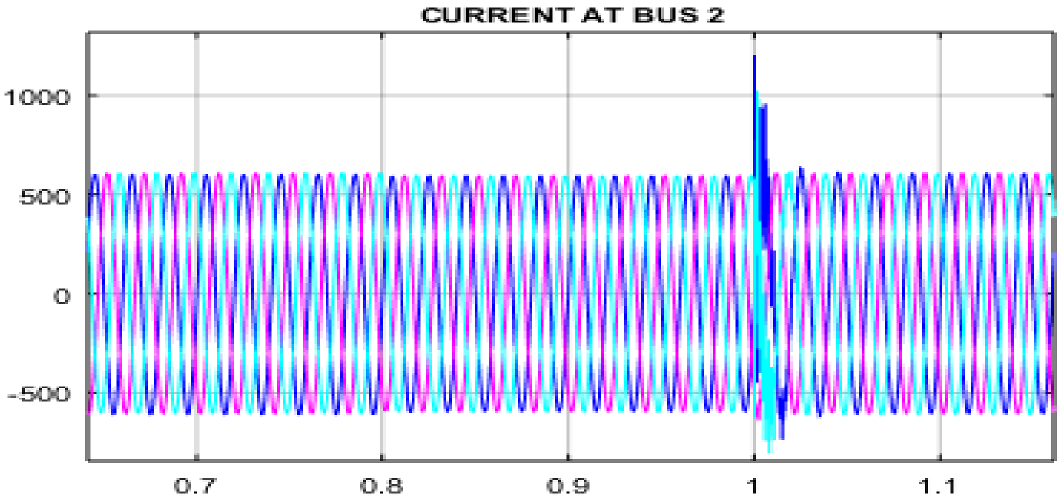

Fig. 5: *Current at Bus 2*

The SSSC injects reactive power at bus 2 in the 5-bus system. So the reactive power at bus 2 is increased from 382 MVAR to 420 MVAR. Its effect can also be observed on bus 3 where reactive power has enhanced from 400 to 430 MVAR. Due to this VAR injection, VAR at buses 1, 4 & 5 has been reduced which are near the generation buses. This event also increases the active power flow in the system at those buses. Voltage profile improvement is obtained at all the buses using SSSC.

There are considerable voltage drops at all the buses in any transmission system due to reactive drops. Therefore, the voltage regulation of the system is prime concern at all the buses. The percentage increase in the voltage levels of all the buses present their regulations respectively. The bus 2 has the most effective voltage regulation because SSSC is connected to bus 2. Bus 1 has also the same improvement in terms of voltage since SSSC is connected in series.

The settings for dynamic load are selected in such a way to obtain constant impedance type behavior. Hence, the real and reactive power fluctuations are having very small deviations in the ranges of only 5 to 10 MW in their steady state in comparison of real power flow up to 1020 MW and reactive power flow up to 910 MVAR in the system. The sudden change in reactive and active powers shown in fig. 6 & 7 at time “t = 1.0 sec” is due to the disconnection of circuit breaker.

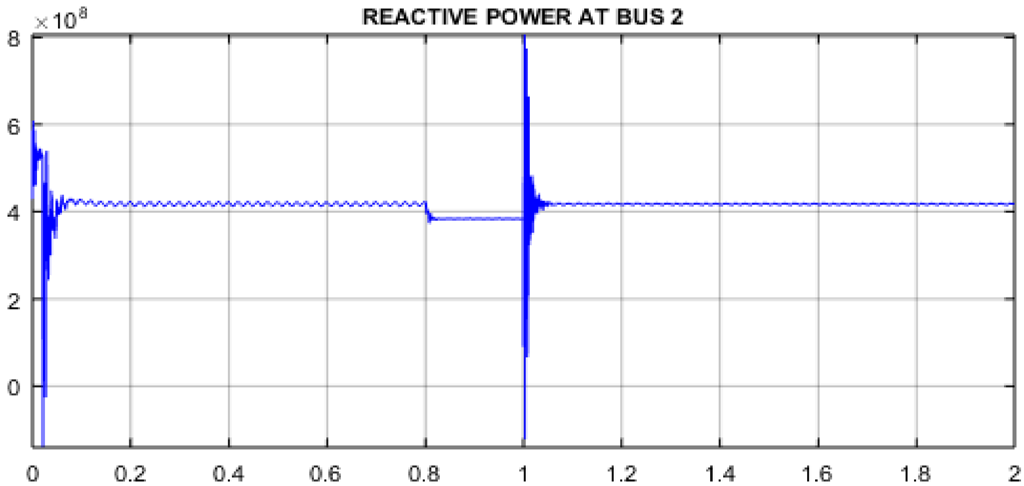

Fig. 6: *Reactive Power at Bus 2*

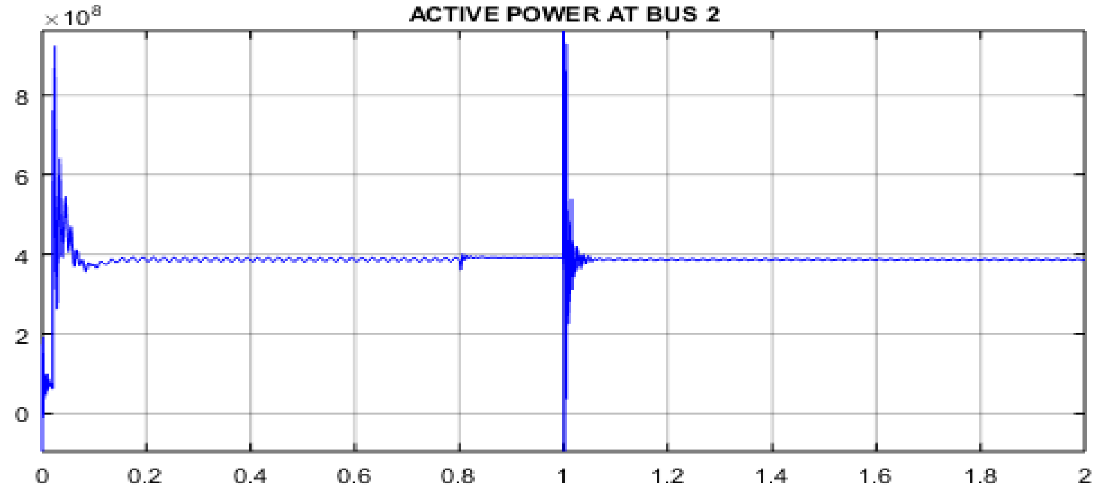

Fig. 7: *Active Power at Bus 2*

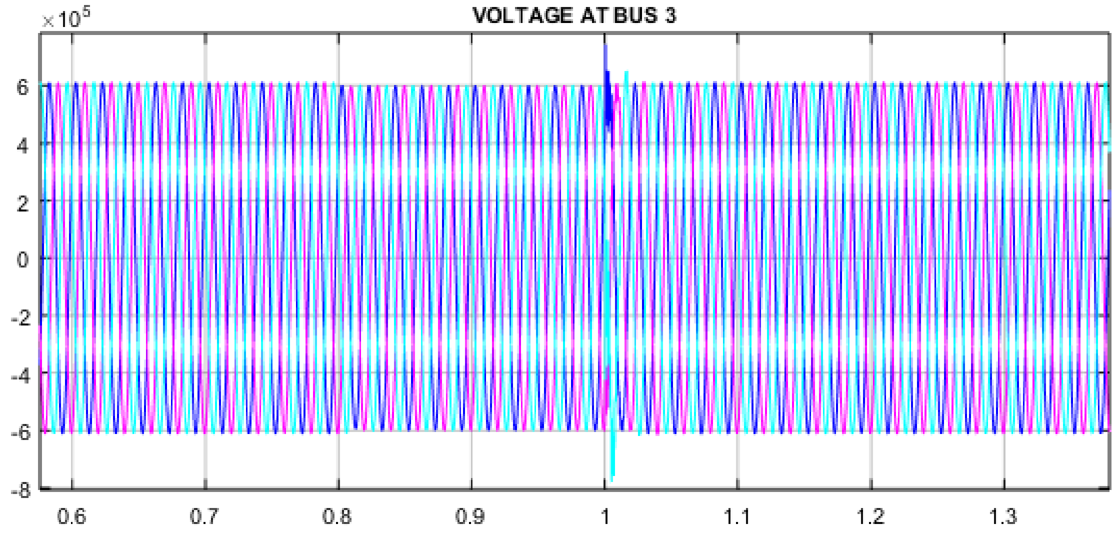

Fig. 8: *Voltage at Bus 3*

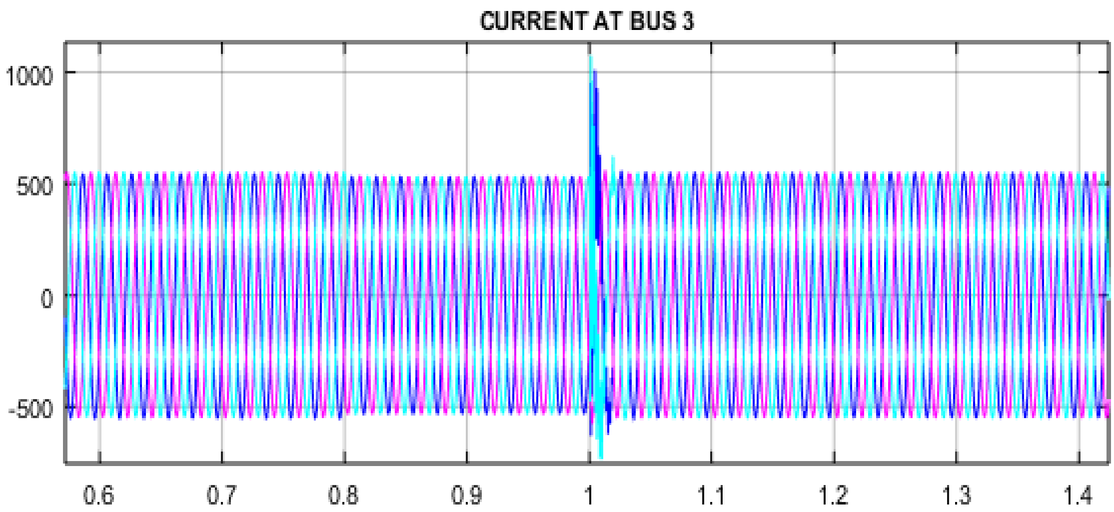

Fig. 9: *Current at Bus 3*

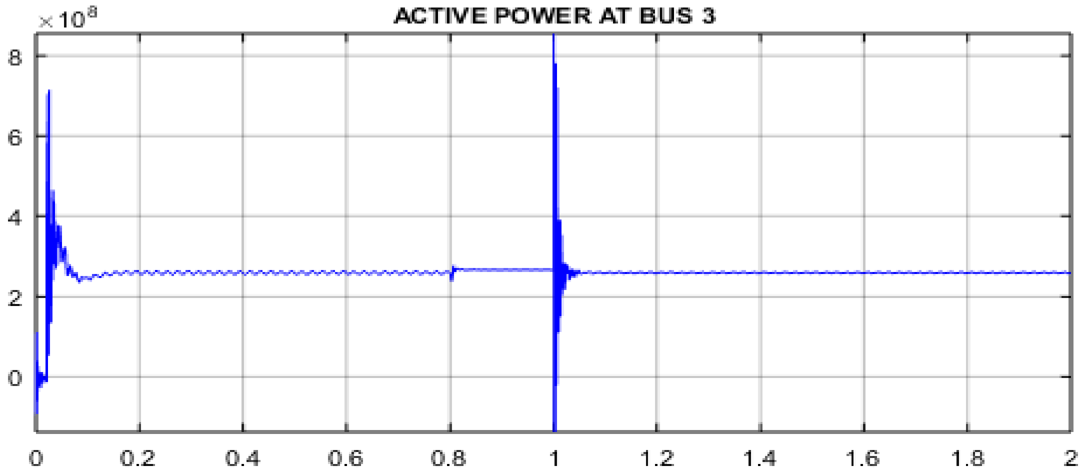

Fig. 10: *Active Power at Bus 3*

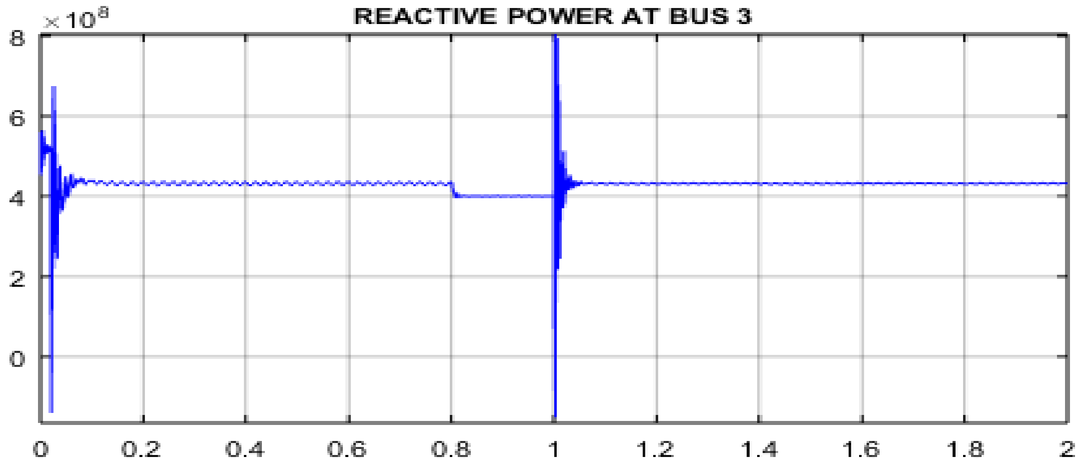

Fig. 11: *Reactive Power at Bus 3*

The voltage & current at bus 3 are shown in fig. 8 & 9 respectively. The active & reactive powers are shown in fig. 10 & 11 respectively. It is observed that the voltage regulation improvement at bus 3 is less compared to the improvement at bus 2. The perturbations in voltage, current, active and reactive powers at time “t=1.0 sec” are due to opening of circuit breaker.

CONCLUSION

The SSSC regulates the voltage profile of the power system by providing VAR compensation. The voltage increase achieved at buses 1, 2, 3, 4 and 5 are 10.85%, 10.85%, 7.61%, 6.397% and 4.70%. Thus, better voltage regulations are achieved at buses 1 and 2 than other remaining buses. The SSSC can also be utilized in multi-machine system. The future scope of research is to analyze and simulate the transient stability & damping of power system oscillations.

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