

Power System Stability Enhancement Using Static Synchronous Series Compensator (SSSC)

B. M. Naveen Kumar Reddy¹, Mr. G. V. Rajashekar², Dr. Himani Goyal³

¹M. Tech (PE), Dept. Of EEE, Aurora's Engineering College, Bhongir, A.P

²Associate Professor, Aurora's Engg. College, Bhongir, A.P

³Professor & HOD Dept. of EEE, Aurora Engg. College, Bhongir, A.P

Abstract: This paper investigates the problem of controlling and modulating power flow in a transmission line using a Synchronous Static Series Compensator (SSSC). The studies, which include detailed PWM techniques controlled for SSSC, are conducted and the control circuits are presented. In this study, a static synchronous series compensator (SSSC) is used to investigate the effect of this device in controlling active and reactive powers as well as damping power system oscillations in transient mode. The SSSC equipped with a source of energy in the DC link can supply or absorb the reactive and active power to or from the line.

Simulations have been done in MATLAB/SIMULINK environment. Simulation results obtained for selected bus-2 in two machine power system shows the efficacy of this compensator as one of the FACTS devices member in controlling power flows, achieving the desired value for active and reactive powers, and damping oscillations appropriately.

Keywords: static synchronous series compensator (SSSC), FACTS, Two machine power system, active and reactive powers.

I. INTRODUCTION

Nowadays, the need for flexible and fast power flow control in the transmission system is anticipated to increase in the future in view of utility deregulation and power wheeling requirement. The utilities need to operate their power transmission system much more effectively, increasing their utilization degree. Reducing the effective reactance of lines by series compensation is a direct approach to increase transmission capability. However, power transfer capability of long transmission lines is limited by stability considerations. Because of the power electronic switching capabilities in terms of control and high speed, more advantages have been done in FACTS devices areas and presence of these devices in transient stability during transient faults resulting in improvement in power system stability [1].

This paper investigates the static synchronous series compensator (SSSC) FACTS controller performance in terms of stability improvements. A Static Synchronous Series Compensator (SSSC) is a member of FACTS family which is connected in series with a power system. It consists of a solid state voltage source converter (VSC) which generates a controllable alternating current voltage at fundamental frequency. When the injected voltage is kept in quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line [2,3]. While the primary purpose of a SSSC is to control power flow in steady state, it can also improve transient stability of a power system.

II. SSSC CONFIGURATION

The basic scheme of the SSSC is shown in Fig. 1. The compensator is equipped with a source of energy, which helps in supplying or absorbing active power to or from the transmission line along with the control of reactive power flow.

As the name suggests, SSSC is a series compensator. It is connected in series with the transmission line. Three phase series transformers are used to connect the compensator in series with the power system.

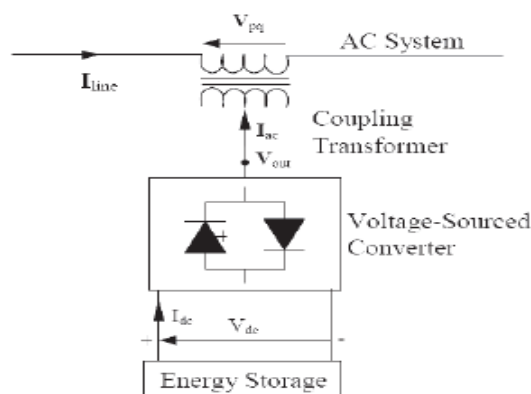


Figure 1. Static synchronous series capacitor

III. BASIC OPERATING PRINCIPLES OF THE SSSC

Fig.1 shows a functional model of the SSSC where the dc capacitor has been replaced by an energy storage device such as a high energy battery installation to allow active as well as reactive power exchanges with the ac system. The SSSC's output voltage and phase angle can be varied in a controlled manner to influence power flows in a transmission line. The phase displacement of the inserted voltage V_{pq} , with respect to the transmission line current I , determines the exchange of real and reactive power with the ac system.

Fig. 2 shows the SSSC operation in four quadrants, again assuming an energy storage device connected at the SSSC's input terminals. The line current phasor I_{line} is used as a reference phasor while the injected SSSC voltage phasor is allowed to rotate around the center of the circle defined by the maximum inserted voltage V_{pq}^{max} .

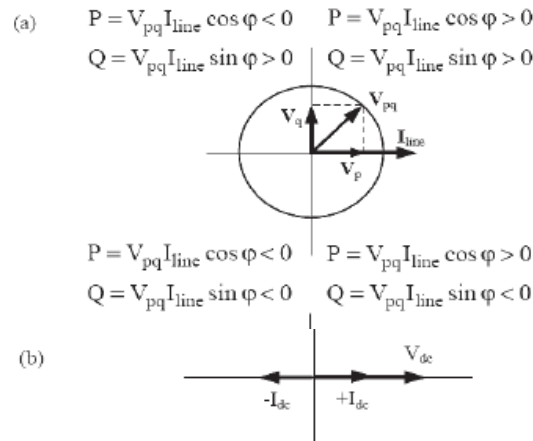


Fig 2. SSSC phasor diagram

Theoretically, SSSC operation in each of the four quadrants is possible, Theoretically, SSSC operation in each of the four quadrants is possible, but there are some limitations to the injected SSSC voltage due to operating constraints of practical power system. In capacitive mode, the injected SSSC voltage is made to lag the transmission line current by 90° ; in this case, the SSSC operation is similar to the operation of a series capacitor with variable capacitance kX_c , i.e., $V_{pq} = -j k X_c I_{line}$, where k is a variable. By this action, the total transmission line reactance is reduced while the voltage across the impedance is increased, leading to increase in the line currents and transmitted power. This action is illustrated in Fig. 3. It is also possible to reverse the injected SSSC voltage by 180° , i.e., $V_{pq} = j k X_c I_{line}$ causing an increase in the transmission line reactance, which results in a decrease of the line current and transmitted power. While this equation for V_{pq} shows changes in the phasor magnitude and phase angle, it can be somewhat misleading, since it shows that the series injected voltage magnitude is directly proportional to the line current magnitude. In reality, this is not true; the inserted voltage magnitude is set by the SSSC control and is independent of the network impedance and, consequently, line current changes. It is assumed that the SSSC losses are zero and, therefore, the series injected voltage is in perfect quadrature with the line current, leading or lagging.

IV. CONTROL SYSTEM OF SSSC

SSSC is similar to the variable reactance because the injected voltage and current to the circuit by this device are changing depend upon to the system conditions and the loads entering/getting out. For responding to the dynamic and transient changes created in system, SSSC utilizes the series converter as shown in Fig. 3.

One side of the converter is connected to the AC system and the other side is connected to a capacitor and battery which in the system we assume DC source as battery. If a dynamic change in system will be occurred, SSSC circuit works such that according to the control circuit in Fig. 4 the energy of battery will be converted to the ac form by converter and then injecting this voltage to the circuit the changes will be damped appropriately.

To control the active and reactive powers of bus-2, the control circuit as shown in Fig. 3 is utilized. For controlling the powers, first, sampling from the voltage and current is One side of the converter is connected to the AC system and the other side is connected to a capacitor and battery which in the system we assume DC source as battery. If a dynamic change in system will be occurred, SSSC circuit works such that according to the control circuit in Fig. 4 the energy of battery will be converted to the ac form by converter and then injecting this voltage to the circuit the changes will be damped appropriately.

To control the active and reactive powers of bus-2, the control circuit as shown in Fig. 3 is utilized. For controlling the powers, first, sampling from the voltage and current is done and transformed to the dq0 values. Active and reactive powers of bus-2 are calculated using their voltage and current in dq0 references and compared with the determined reference and the produced error signal is given to the PI controllers. Adjusting parameters of the PI controllers, we are trying to achieve the zero signal error such that powers can follow the reference powers precisely. Then, the output of the controllers are transformed to the abc reference and given to the PWM.

V. TWO MACHINE POWER SYSTEM MODELINGSING

The dynamic performance of SSSC is presented by real time voltage and current waveforms. Using MATLAB software the system shown in Fig. 5 has been obtained. In the simulation one SSSC has been utilized to control the power flow in the 500 KV transmission systems. This system which has been made in ring mode consisting of 4 buses (B1 to B4) connected to each other through three phase transmission lines L1, L2-1, L2-2 and L3 with the length of 280, 150, 150 and 5 km respectively. System has been supplied by two power plants with the phase-to-phase voltage equal to 13.8 kv.

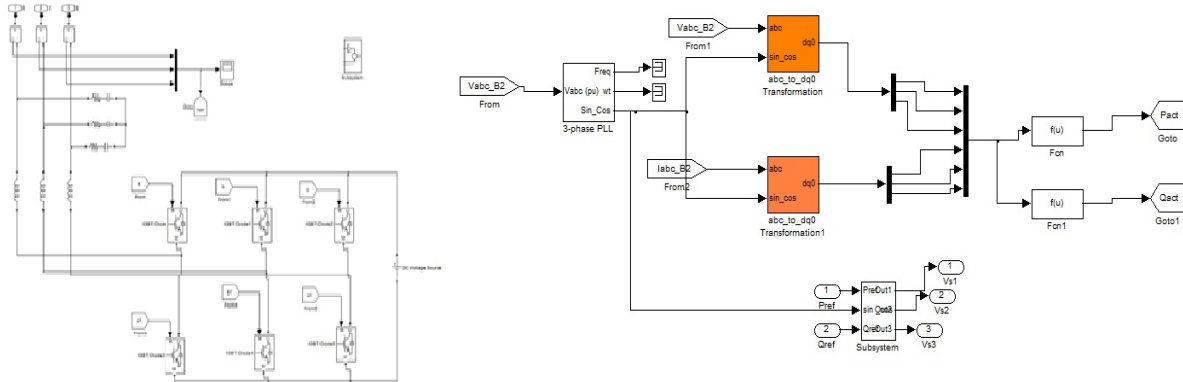
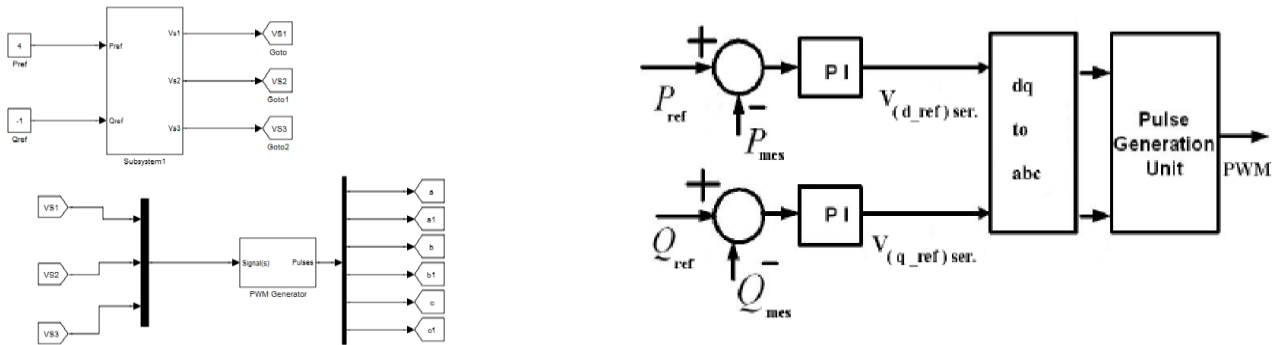


Figure 3. The converter of SSSC



a) Simulated control signal generation using pwm generator circuit

b) Single line diagram

Figure 4. The control circuit of SSSC

Active and reactive powers injected by power plants 1 and 2 to the power system are presented in per unit by using base parameters $S_b = 100\text{MVA}$ and $V_b = 500\text{KV}$, which active and reactive powers of power plants 1 and 2 are $(24-j3.8)$ and $(15.6-j0.5)$ in per unit, respectively.

VI. Simulation Results With MATLAB/SIMULINK

First, power system with two machines and four buses has been simulated in MATLAB environment, and then powers and voltages in all buses have been obtained. The results have been given in Table. Using obtained results bus-2 has been selected as a candidate bus to which the SSSC be installed. Therefore, the simulation results have been focused on bus-2.

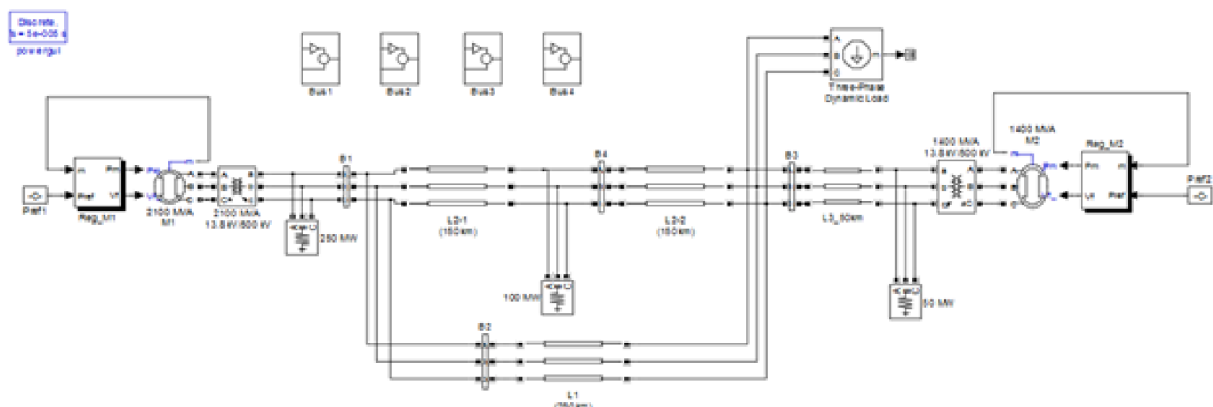


Figure 5. The configuration of two machine power system

TABLE I. OBTAINED RESULT FROM THE SIMULATIONS

Bus No.	Voltage	Current	Active Power	Reactive Power
1	1 pu	13.5 pu	20.06 pu	-3.77 pu
2	1 pu	6.7 pu	9.96 pu	1.82 pu
3	1 pu	10 pu	14.84 pu	-0.49 pu
4	1 pu	5.55 pu	8.45 pu	-0.59 pu

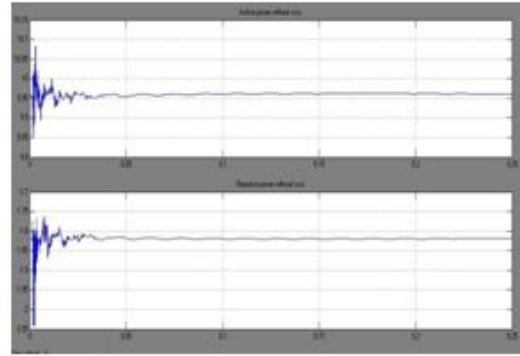


Figure 6. Active and reactive powers of bus-2 without the installation of SSSC

VII. CASE STUDIES

A. Bus-2 parameters without SSSC

Changes in current, voltage, active and reactive powers of bus-2 have been obtained in real time. According to the Figure. 6, at first, due to the large loads of the system active power of bus-2 got oscillations which keep continuing for 3 seconds. However, the controlling systems in power plants 1 and 2 such as governor, PSS and other stabilizing devices are used for damping these oscillations. As shown in Figure. 6, because of the abovementioned reasons reactive power of bus-2 got oscillations at first and then will be damped properly. Oscillations amplitude for active power is more than reactive power, and this is because the ohmic parts of loads of system are much more.

According to Figure. 7, after transient mode created at first in system, voltage and current waveforms of bus-2 got closer to sinusoidal waveforms. Voltage amplitude is 1 per unit, but, despite the drawn currents by loads in system, current amplitude is 6.7 pu.

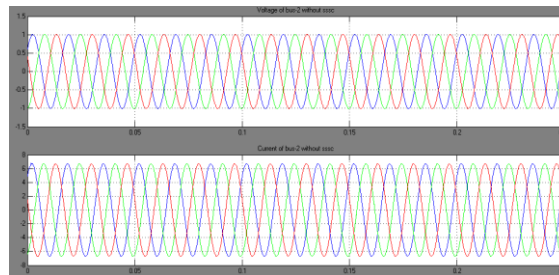


Figure. 7 Voltages and Currents of bus-2 without the installation of SSSC

B. Bus-2 parameters with SSSC

As shown in Figure.8, SSSC has been placed between bus-1 and bus-2 and the aim is achieving the following active and reactive powers:

$$P_{ref} = 4 \text{ pu} ; \quad Q_{ref} = -1 \text{ pu}$$

The main role of SSSC is controlling the active and reactive powers; beside these SSSC could fairly improve the transient oscillations of system.

After the installation of SSSC, besides controlling the power flow in bus-2 we want to keep constant the voltage value in 1 per unit, hence the power flow is done in the presence of SSSC and the simulation results are as follows.

According to the Fig. 9, by installing the SSSC, active power damping time will be less than the mode without SSSC and it will be damped faster. Also as shown in Fig. 9, reactive power damping time will be decreased and system will follow the references value with acceptable error.

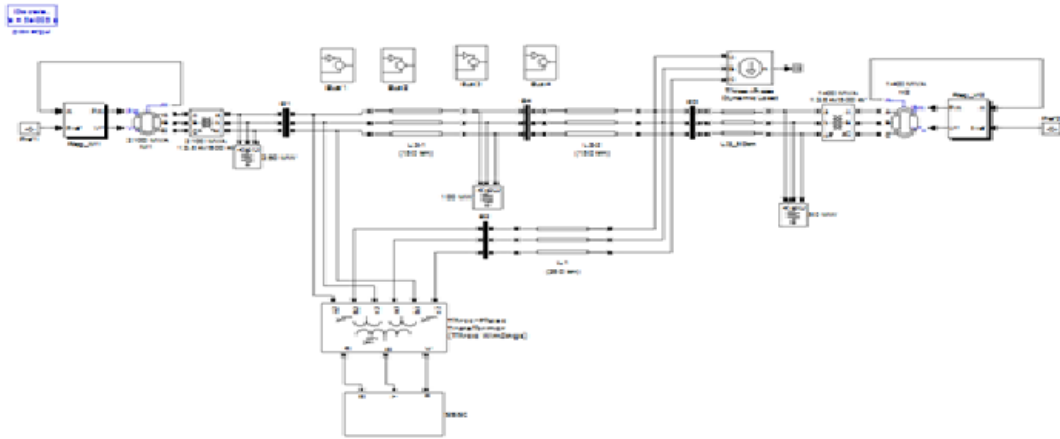


Figure 8. Two machines system with SSSC

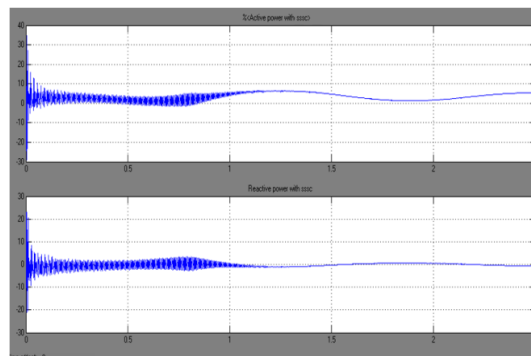


Figure 9. Active and reactive power of bus-2 in the presence of SSSC

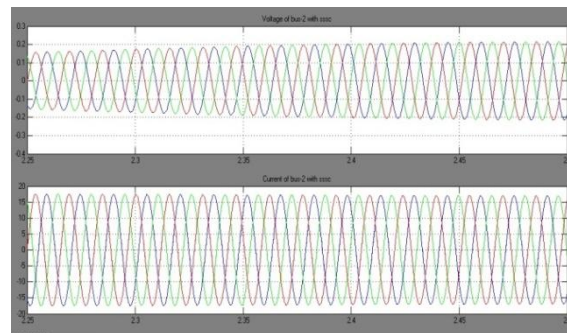


Figure. 10, Voltage and currents of bus-2 in the presence of SSSC

As shown in Fig. 10, Current of bus-2 in the presence of SSSC after transient mode will be in the form of sinusoidal form.

C. Bus-2 parameters with a fault without SSSC

In this section a three phase fault is applied to the power system, and observing the system performance without using SSSC.

Here, as shown in figure. 11, circuitual arrangement having three phase faults is modeled using MATLAB/SIMULINK software. Figure 12 shows the active and reactive powers of bus-2

Figure 13 shows the voltage and currents of bus-2 for the system shown above. In this chapter, we conclude that the applied fault make disturbances in the system for a long time.

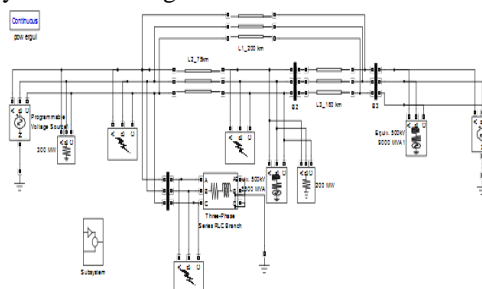


Figure. 11, Two machine system with a fault without SSSC

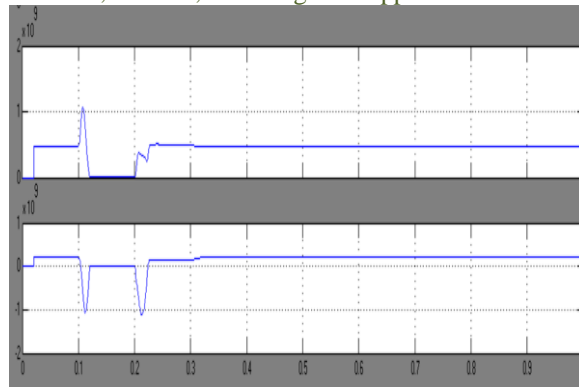


Figure. 12. Active and reactive powers of bus-2 with a fault without applying SSSC

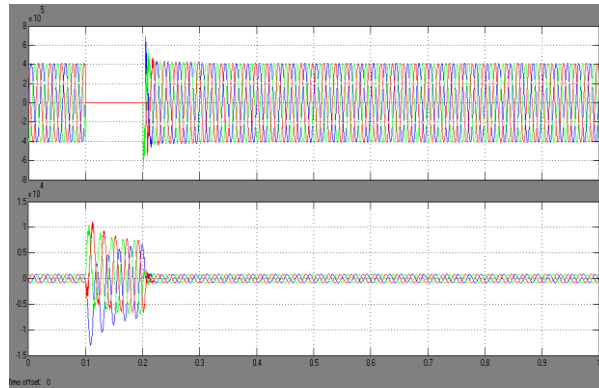


Figure. 13. Voltage and currents of bus-2 with a fault without applying SSSC

D. Bus-2 parameters with a fault with SSSC

To further test the proposed SSSC controller, a three phase fault is applied at Bus 2. also, in this simulation the transition times is set as follows: [0 1 1.5 2]; In Fig. 14, the simulation result shows that the power oscillation on the L1 line following the three-phase fault. Moreover the performed simulation indicates that the SSSC compensator is a very effective tool to damp power oscillation.

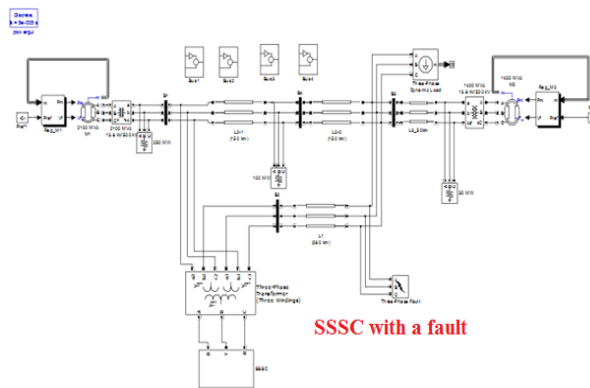


Figure. 14, Two machine system with a fault with SSSC

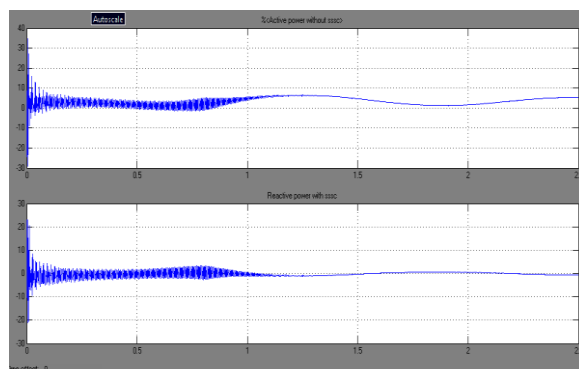


Figure. 15. Active and reactive powers with fault and with SSSC

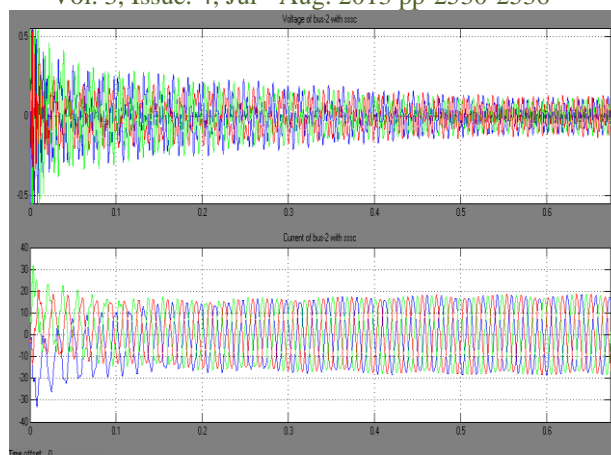


Figure. 16. Voltage and currents of bus 2 with fault and with SSSC

VIII. CONCLUSION

It has been found that the SSSC is capable of controlling the flow of power at a desired point on the transmission line. It is also observed that the SSSC injects a fast changing voltage in series with the line irrespective of the magnitude and phase of the line current.

This paper, the SSSC is used to damp power oscillation on a power grid following a three-phase fault. Based on obtained simulation results the performance of the SSSC has been examined in a simple two-machine system simply on the selected bus-2, and applications of the SSSC will be extended in future to a complex and multi machine system to investigate the problems related to the various modes of power oscillation in the power systems.

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BIOGRAPHY



B.M. Naveen Kumar Reddy has received his B.Tech degree from Sindhura Engineering College, Ramagundam. He is post graduated in M.Tech(P.E) stream from Department of Electrical and Electronics Engineering from Aurora's Engg. College, Bhongir. Presently he is working as an Assistant professor in Vidya Bharathi Institute of Technology, Hyderabad.