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Enhancement of Power Handling Capability by Static Synchronous Series Compensator

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ABSTRACT: A power system is becoming more complex and heavily loaded day by day. Earlier electric power systems were small and localized. Thus, Real and reactive power compensation in transmission line is essential which will improve the stability of ac system. Flexible Alternating Current Transmission System (FACTS) technology provides new opportunity to control the power and enhancing the capacity of the present as well as new lines. The Static Synchronous Series Compensator (SSSC) is newer generation of FACTS device which enables control of active and reactive power and enhancement of power transfer capability of transmission line. This paper describes theory and modelling technique of SSSC using multi level (Three) inverter with Sinusoidal Pulse Width Modulation technique and dq0 transformation using MATLAB Simulink.

KEYWORDS: FACTS, Inverter, Matlab/Simulink, Pulse width modulation, Real and Reactive power, SSSC.

I.INTRODUCTION

Electricity demand has been increased since last few decades. Today's power system is interconnected and highly complex. Electric power flow through an alternating current transmission system is the function of the line impedances, the magnitudes of sending end and receiving end voltages and phase angle between these voltages. [1] According to IEEE the FACTS can be defined as, "Alternating current transmission systems consisting of power electronics based and other controllers to enhance controllability and available power transfer capability (APTC) controllers which can provide limit on one or more AC transmission system parameters like voltage, current and powers. By using FACTS devices the line parameters can be changed and power flow along transmission lines could be controlled. The devices under the FACTS are capable of fast responses and thus could be used for multiple applications. [2-4]

II. LITERATURE SURVEY

Mr. D.M. Tagare [1] has discussed the working of Static Synchronous Series Compensator thoroughly. Flexibility through fixed series capacitor and devices based on voltage source inverter are explained. The responses of SSSC for different contingencies have been studied. N.G. Hingorani and L Gyugyi [2] have been deeply involved in pioneering work in this new FACTS technology. Hingorani pioneered the concept from EPRI and Gyugi invented several key FACTS controllers. Both the authors provides all the basic idea of FACTS to power engineers, it also differentiates the state of transmission line before and after evolution of FACTS controllers. R. Mohan Mathur and Rajiv K. Verma [3] explain the system before and after evolution of FACTS. The necessity, advantages and controller over the traditional or conventional system is proposed. Sen K.K. [4] has developed model of Static Synchronous Series Compensator (SSSC) using Electromagnetic Transient Program (ETAP) simulation package, with pulse width modulation (PWM) technique. 48 pulse PWM inverter is used for the simulation. M.H. Rashid [5] has discussed about all the basics of inverters along with controlling strategies. M. Faridi, H. Maeiat and P. Farhadi [6] has developed SSSC model equipped with a source of energy in the DC link which can supply or absorb the reactive and active power to or from the line. Simulations have been done in MATLAB/SIMULINK environment. P. Suman, N. Vijaysimha and C.B. Saravanan [7] have developed the schematic and basic controls of a reconfigurable FACTS system that can be used to realize the major voltage source converter FACTS topologies: STATCOM, SSSC and UPFC. A Digital Signal Processor (DSP) is used to implement the control system for these devices. A 24 pulse GTO converter is used for the simulation model. L. Surindam Kumar, Arindam Ghosh [8] and Fawzi A. L. Jowder [9] have discussed about modelling, control design and different modes of SSSC.

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III. THEOROTICAL CONCEPT

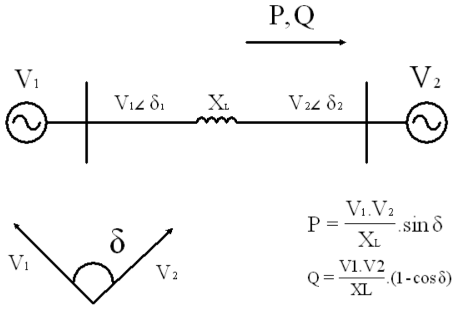

Fig. 1: Simple transmission line.

Fig. 1 shows single line diagram of simple transmission system with an inductive reactance X_L connecting in between sending end voltage $|\overline{V_1}|$ and a receiving end voltage source is $|\overline{V_2}|$ respectively. The real and reactive power flow at the receiving end voltage source is given by,

$$P = \frac{V_1 . V_2}{X_L} . \sin(\delta_1 - \delta_2) = \frac{V^2}{X_L} . \sin\delta \quad (1)$$

$$Q = \frac{V_1 . V_2}{X_L} [1 - \cos(\delta_1 - \delta_2)] = \frac{V^2}{X_L} [1 - \cos\delta] \quad (2)$$

Where V_1 and V_2 are magnitudes of sending and receiving end voltages and δ_1 and δ_2 are the phase angles of $\overline{V_1}$ and $\overline{V_2}$ respectively. For sake of simplicity, $V_1 = V_2 = V$ and $\delta_1 - \delta_2 = \delta$. A SSSC connected in series with transmission line which can emulate series compensating reactance (X_q) either inductive or capacitive in addition to inductive reactanceX_L. Thus expression for power flow is given as, [4, 8, 9]

$$P_q = \frac{V^2}{X_{eff}} . \sin\delta = \frac{V^2}{X_L\left(1 - \frac{X_q}{X_L}\right)} . \sin\delta \quad (2a)$$

$$Q_q = \frac{V^2}{X_{eff}} . (1 - \cos\delta) = \frac{V^2}{X_L\left(1 - \frac{X_q}{X_L}\right)} . (1 - \cos\delta) \quad (2b)$$

Where X_{eff} = Effective reactance of the transmission line between two ends including reactance emulated by SSSC

Fig 2 shows example of simple power transmission system with SSSC operated both in inductive and capacitive mode with related phasor diagram. From fig 2b, if line current decreases from 0% to -100% during inductive reactance compensation $\frac{-X_q}{X_L}$ increases from 0% to 100%. From fig 2c, if line current increases from 0% to 33% during capacitive reactance compensation, $\frac{X_q}{X_L}$ increases from 0% to 33%. From equations 1 and 2a, [4, 9]. The following table gives value of compensating reactance and mode of SSSC.

TABLE I
MODE OF SSSC

Value compensating reactance (X_q)	Mode of operation
Negative	Inductive mode
Positive	Capacitive mode

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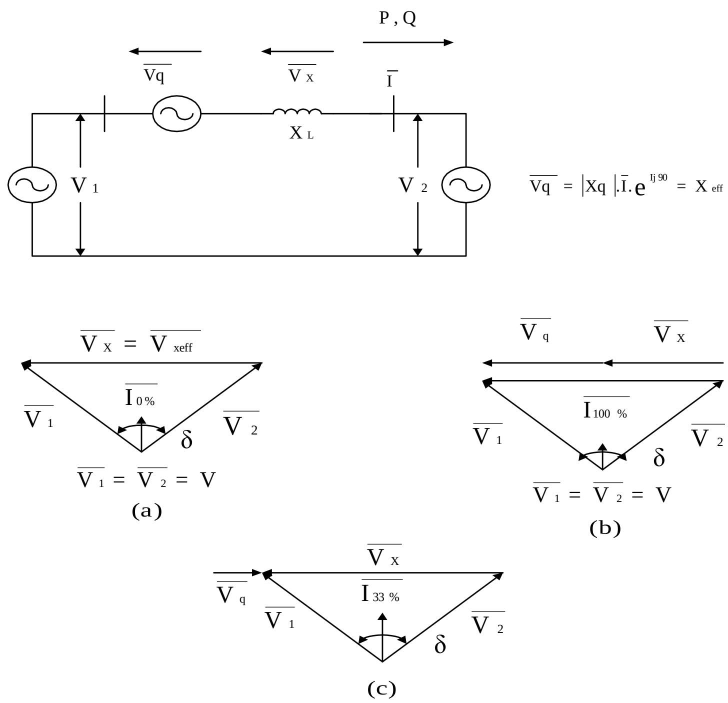

Fig. 2: Transmission line with SSSC connected in series.

(a) Normal mode of operation. (b) Inductive mode of operation. (c) Capacitive mode of operation.

$$\frac{P_q}{P} = \frac{X_L}{X_L(1-\frac{X_q}{X_L})} = \frac{1}{1-\frac{X_q}{X_L}} \quad (3)$$

$$\frac{X_{eff}}{X_L} = \frac{1}{1-\frac{X_q}{X_L}} \quad (3a)$$

IV. RESULT AND DISCUSSION

A. Two machine power systems

The test system (shown in fig. 3) consists of two machine power system which essentially consisting of two power generation plants. The specifications of model are as shown in table no. 1. The actual SSSC is connected between bus B1 and B2. (Shown in fig.4)

TABLE II
SPECIFICATION AND PARAMETERS OF MODEL

Specifications	System parameters
Generator G1 or Machine M1	2100 MVA, 13.8 kV
Generator G2 Machine M2	1400 MVA, 13.8 kV
Transformer (TR1)	2100 MVA, 13.8 kV/500 kV
Transformer (TR2)	1400 MVA, 13.8 kV/500kV
System phase to phase voltage	13.8 kV
Transmission line	500 kV
Load	2000 MW
Base Parameters	(MVA)base = 100 MVA
Line lengths	L1 = 280 km, L2 = 150 km , L3 = 150 km, L4 = 50 km

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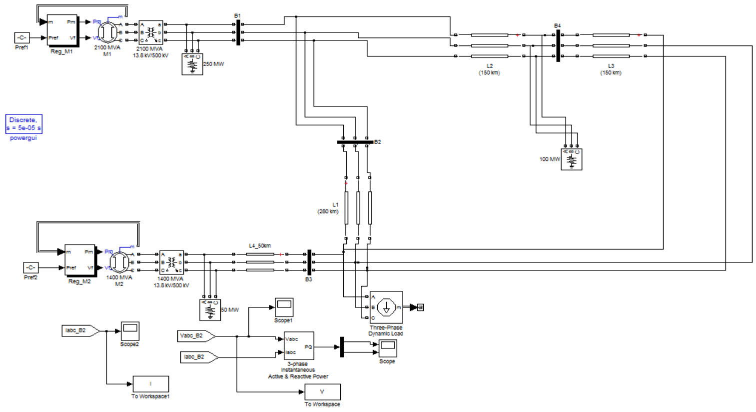

Fig. 3: Two machine power system model in MATLAB (Without SSSC and without fault).

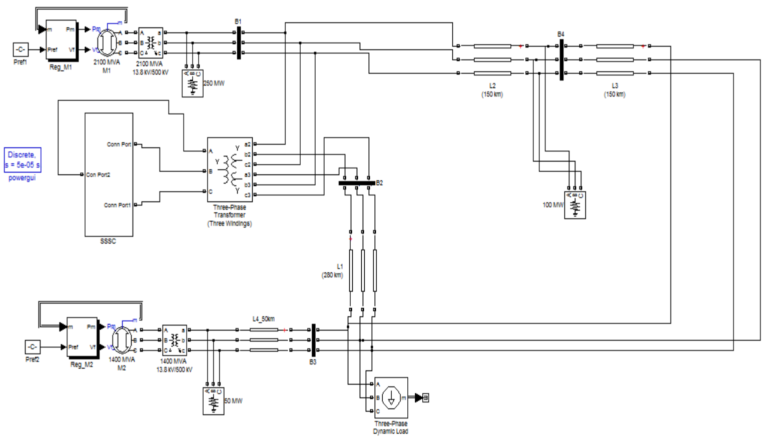

Fig. 4: Two machine power system with SSSC and without fault.

B. Control System:

In this control scheme, (Refer the fig. 5) Pref is taken as 4pu and Qref is taken as -1 pu is taken. The instantaneous power is obtained in terms of d-q quantities of voltages and currents as below,

$$P_{act} = V_d.I_d + V_q.I_q \quad (4)$$

$$Q_{act} = V_q.I_d + V_d.I_q \quad (5)$$

The voltage and current of bus-2 in dq0 references are used to find out active and reactive powers of bus-2 and are compared with the determined reference values and thus error signal is produced which is further given to the PI controllers. By adjusting parameters of the PI controllers, our goal is to achieve the zero signal error. Then, the output of the controllers are converted to the abc frame of reference and given to the SPWM. In SPWM, the reference wave is sinusoidal wave and carrier wave is triangular wave. [5, 8]

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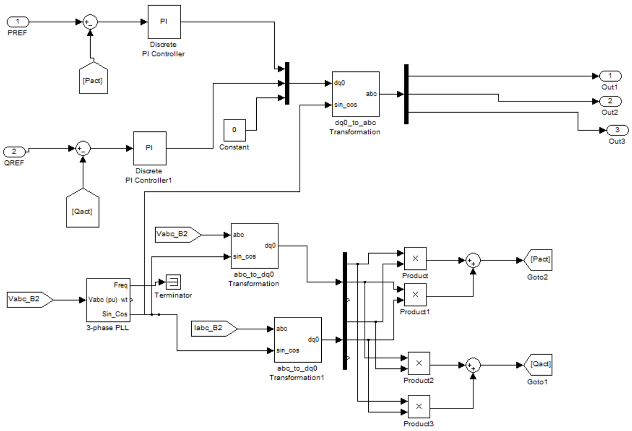

Fig. 5: Control scheme for SSSC.

C. Different cases and Results:

Two machine systems with four buses configuration have been simulated in the MATLAB / SIMULINK software. We are getting the results at bus 2 as SSSC is connected at bus 2. Results after simulation are given in following table.

TABLE II
SPECIFICATION AND PARAMETERS OF MODEL

Bus no.	Voltage	Current	Active power	Reactive power
1	1 pu	12.2 pu	33.84 pu	-3.72 Pu
2	**1 pu**	**6.40 pu**	**4.21 pu**	**1.798 Pu**
3	1 pu	10.2 pu	13.05 pu	-23.27 pu
4	1 pu	5 pu	19.69 pu	-8.417 pu

Case I: Bus 2 parameters without SSSC without fault:

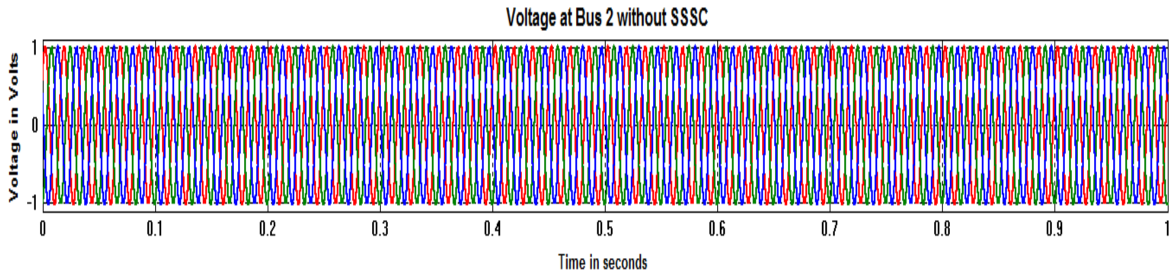

Fig.6: Voltage waveform without SSSC.

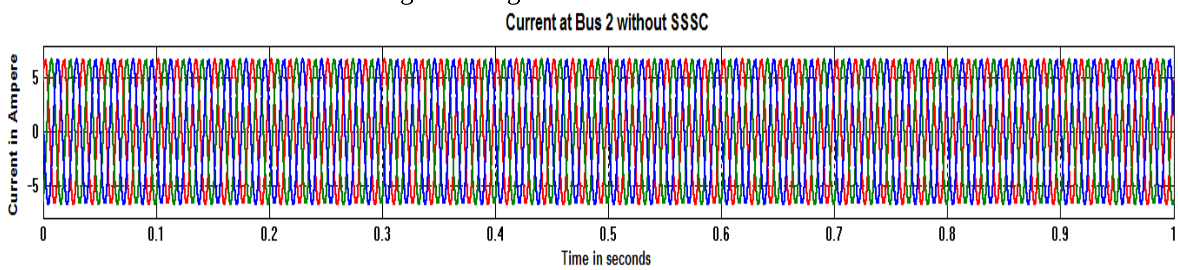

Fig.7: Current waveform without SSSC.

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Fig. 6 and 7 shows Voltage and current waveforms without connection of SSSC and without occurrence of fault on transmission line. All the three phases of voltages and currents are shown clearly. Both current and voltages are expressed in terms of per unit quantities.

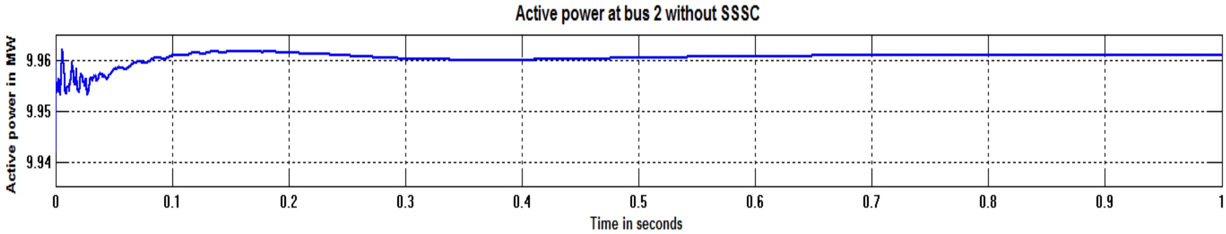

Fig. 8 Active power at Bus-2 without SSSC.

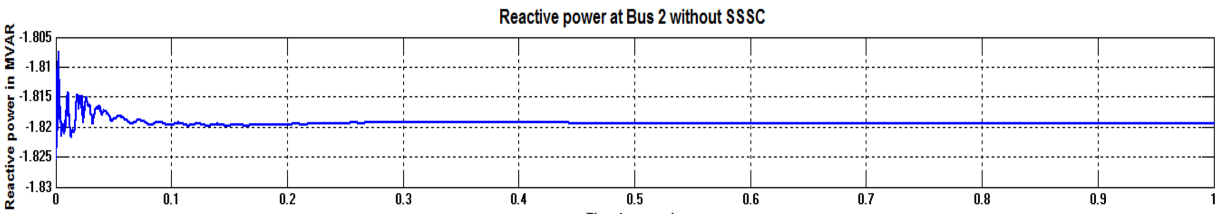

Fig.9: Reactive power at Bus-2 without SSSC.

Fig.8 and 9 shows the active and reactive power at bus 2 oscillates due to presence of large loads in the system. This condition continues till the 0.9 to 1.0 cycles. There are various stabilizing devices such as governor, PSS that can be used for damping out oscillations. Amplitude of oscillation is more in case of active power than reactive power. Voltage and current waveforms are shown in fig. 6 and 7 which are relatively same as that of sinusoidal waveforms. The voltage amplitude is near to 1 pu and current amplitude is near about 6.40 pu.

Case II: Bus-2 parameters with SSSC without fault:

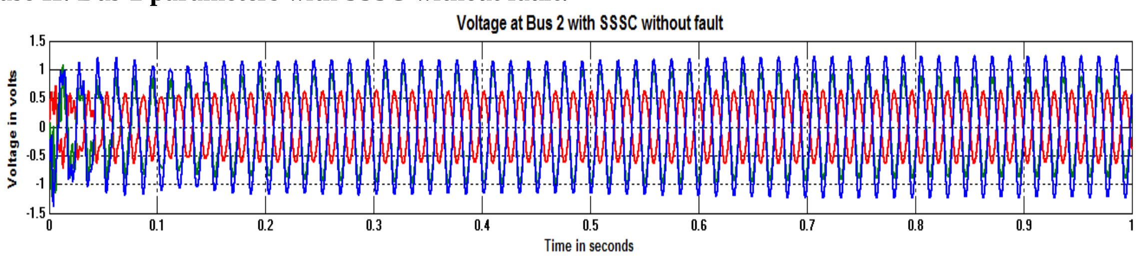

Fig.10: Voltage at bus -2 when SSSC is connected.

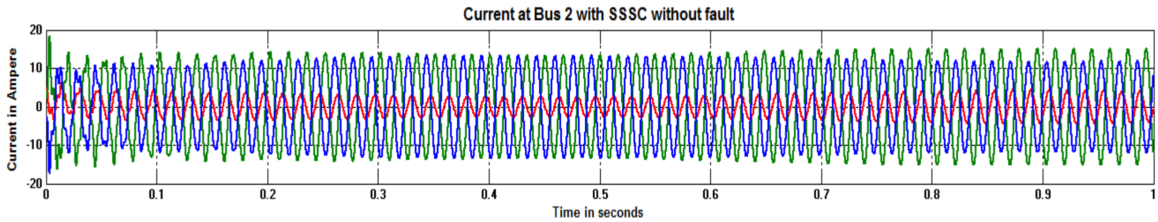

Fig.11: Current at bus -2 when SSSC is connected.

Fig. 10 and 11 shows Voltage and current waveform at bus 2 when SSSC is connected to the system.

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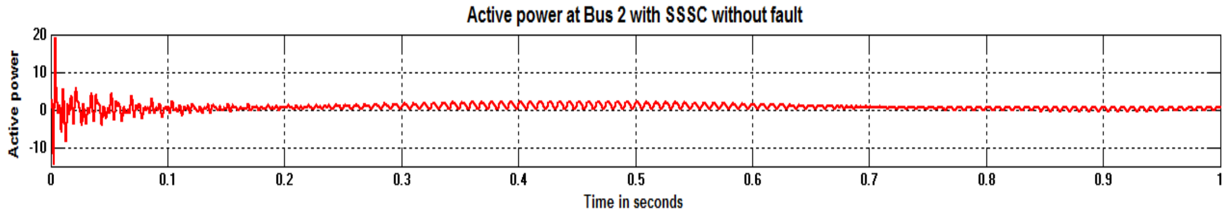

Fig.12: Active power at bus -2 when SSSC is connected.

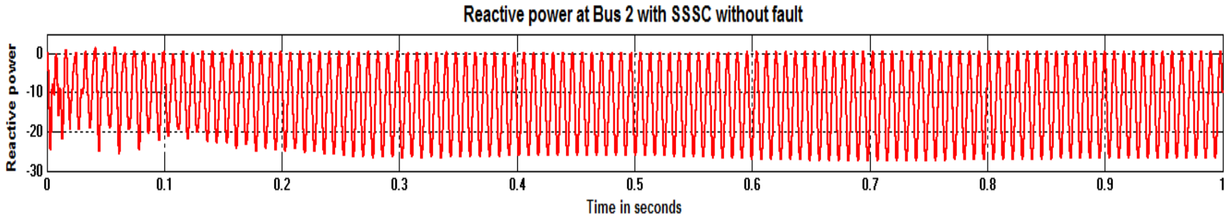

Fig.13: Reactive power at bus -2 when SSSC is connected.

Fig. 12 and 13 shows active and reactive power at bus 2 when SSSC is connected. Whenever SSSC is connected to the system, active power damping time will get reduced than that of the mode without SSSC. In case of without SSSC damping time was near about 1 cycle or sec. whereas in case of SSSC mode, time is 0.8 to 0.85 cycles. After connecting SSSC, controlling the power flow at bus-2, we want to keep the constant voltage 1 pu.

Case III: Bus-2 parameters without SSSC with fault:

Here, three phase fault is occurring at bus and system performance is checked without SSSC. Ground resistance used is 1.66 ohm and transition time is [0.15 0.2]

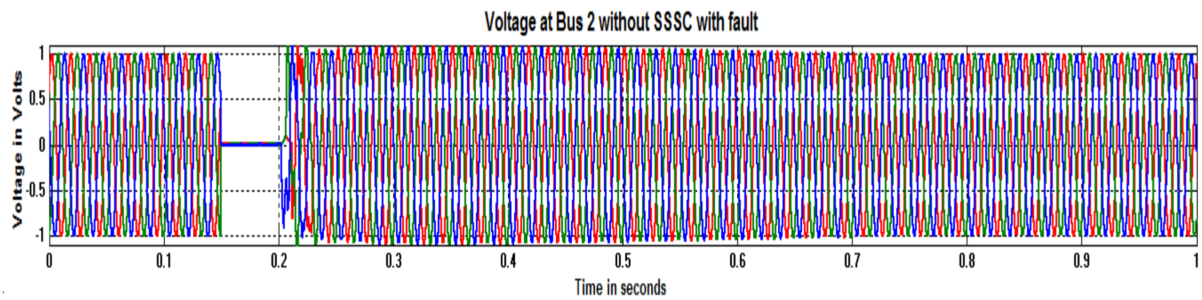

Fig.14: Voltage at bus 2 without SSSC with fault.

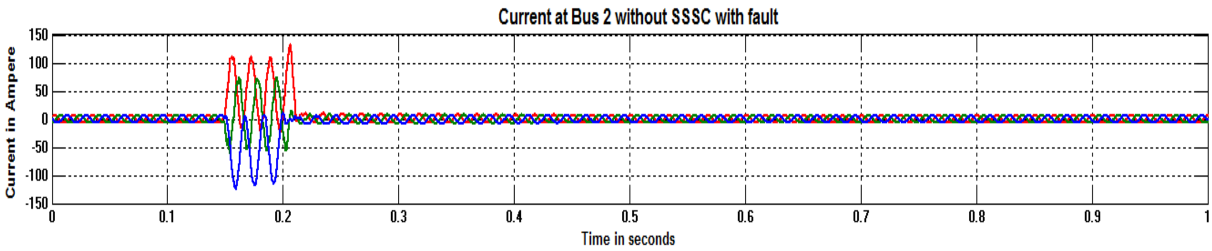

Fig.15: Current at bus 2 without SSSC with fault.

Fig. 14 and 15 shows voltage and current at bus 2 without SSSC but with fault. Three phase fault has been occurred on transmission system. Fault can make disturbances in the system for a greater time. Fault occurs at 0.15 to 0.2 cycles.

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The voltage reduces to zero during fault period and at the same time magnitude of current is high as compared to healthy condition.

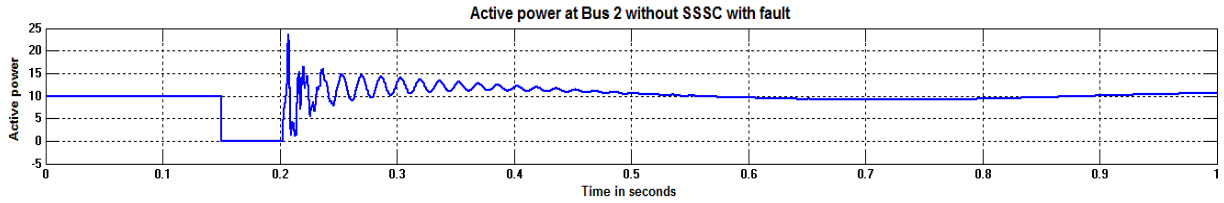

Fig.16: Active power at bus 2 without SSSC with fault.

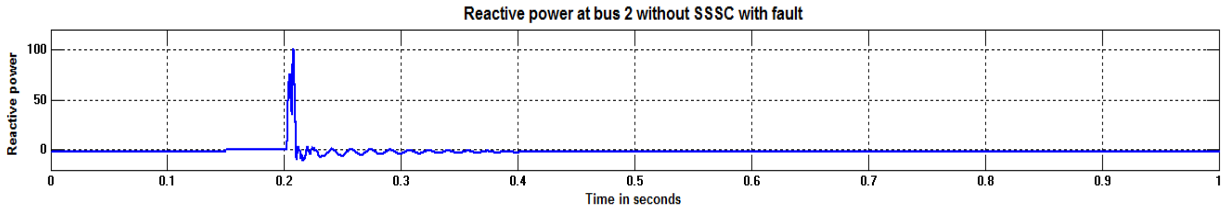

Fig.17: Reactive power at bus 2 without SSSC with fault.

From fig. 16 and 17, during the period of occurrence of fault, active power drastically reduces to zero. Fault is cleared at 0.2 seconds. As soon as the fault is clear, Active power starts increasing and it damp out nearly 0.9 to 1.0 cycles. While during fault, reactive power increases and as fault is cleared it reduces to zero or even at negative value. The time required to damp out the oscillation is near about 0.4 to 0.5 seconds.

Case IV: Bus-2 parameters with SSSC with fault:

In this case, three phase fault occurs on the line. Transition time is [0.15 0.2] and system performance is checked in the presence of SSSC.

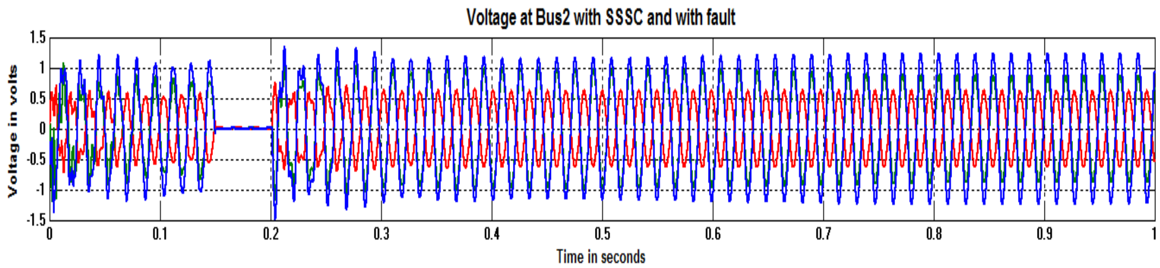

Fig.18: Voltage at bus-2 with SSSC and with fault.

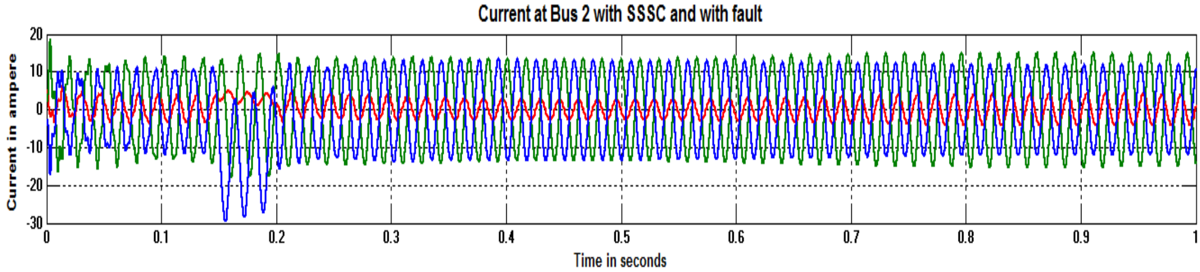

Fig.19: Current at bus-2 with SSSC and with fault.

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Fig.18 and 19 shows voltage and current of bus 2 when SSSC in connected and three phase fault occurs on the transmission line. Transition time for the fault is [0.15 0.2]. During fault period, voltage waveform drastically reduces to zero while current waveform increases.

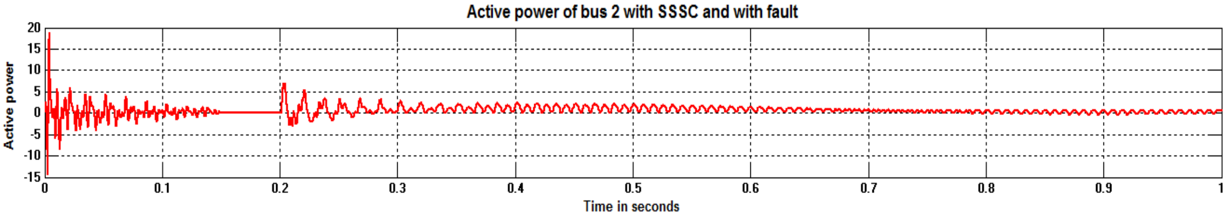

Fig.20: Active power at bus-2 with SSSC and with fault.

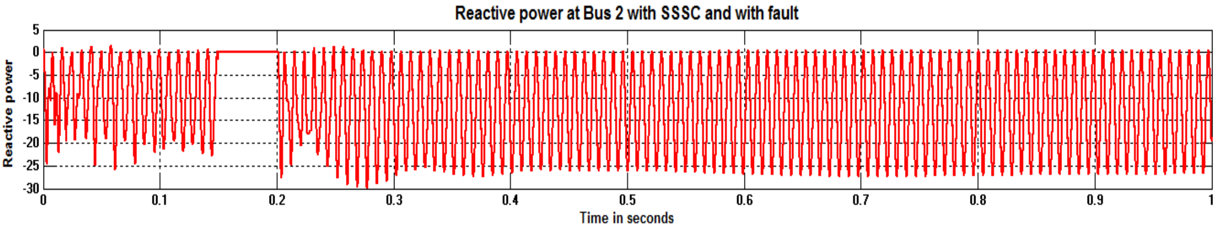

Fig.21: Reactive power at bus-2 with SSSC and with fault.

Fig. 20 and 21 shows Active and reactive power at bus 2 with SSSC and with fault. As the fault occurs between 0.15 to 0.2 seconds, the active power reduces to zero for that period. As fault is cleared at 0.2 seconds, active power begins to increase. The oscillations get damp out nearly at 0.8 to 0.85 seconds whereas in case reactive power, power reduces to zero during fault period and after clearing the fault it becomes negative and even increases towards negative side.

V. CONCLUSION

The onset of series connected FACTS controller like SSSC has made it possible not only to regulate power flow in critical lines. SSSC has reactive voltage control which can inject controllable reactive voltage in quadrature with the line current, emulating either inductive or capacitive reactance in series with transmission line. In this paper, the operation of SSSC model is verified by connecting it in series with the transmission line. SSSC has been studied on two machine power system and connected at bus-2. Thus from this paper, SSSC can be effectively used to damp out power oscillations on power transmission system with and without fault. It can also able to control power flow at particular or desired point. The application of the SSSC can be expanded in future for complex and multi-machine system to mitigate the problem of power oscillation in power systems.

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BIOGRAPHY

Chaitanya Deshpande received his BE degree in Electrical Engineering from Savitribai Phule University (formerly Pune University) - India in 2013, and is currently pursuing his ME in Electrical Power Systems from Savitribai Phule University (formerly Pune University) – India. Upon completing his graduation he joined the Department of Electrical Engineering at Zeal institute's, Dnyanganga college of Engineering and Research as Lecturer in 2014. His field of interest includes HVDC - FACTS, Power Systems and Power Quality,

Mrs. Sangeeta Jain (Kotecha) received her BE degree in Electrical Engineering from Government college of Engineering (NIT), Raipur, India in 1996. She has completed ME in Electrical Power systems from Savitribai Phule University (formerly Pune University) – India in 2009. She has total teaching experience of 12 years. Currently she is working in Department of Electrical Engineering at Zeal institute's Dnyanganga college of Engineering and Research as Assistant professor. Her field of interest includes HVDC - FACTS, Power Systems and Power Quality,