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Stability Enhancement of Multi Machine system with FACTS device SSSC using Fuzzy logic

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Abstract

Continuous demand in electric power system network has caused the system to be heavily loaded leading to voltage instability. Under heavy loaded conditions there may be insufficient reactive power causing the voltages to drop. This drop may lead to drops in voltage at various buses. The result would be the occurrence of voltage collapse which leads to total blackout of the whole system. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system stability control problems. 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 for IEEE 4 bus system. The Fuzzy controller is used to tune the circuit and to provide the zero signal error. The best Non-linear system performance is seen and however PID controller couldn't do this sometimes. It was observed that using fuzzy controller, authors could achieve their goals i.e; oscillations damping, fast response and finally stabilizing power system.

Keywords*:* Static synchronous series compensator, FACTS, two machine system, Fuzzy controller, active and reactive powers.

Introduction

In recent years, greater demands have been placed on the Transmission network and the increase in demands will rise because of the increasing number of non utility generators and heightened competition among utilities themselves. Increasing demands, lack of long-term planning, and the need to provide open access electricity market for Generating Companies and utility customers, all of them have created tendencies toward less security and reduced quality of supply. The power systems of today, by and large, are mechanically controlled[1].

There is a widespread use of microelectronics, computers and high-speed communications for control and protection of present transmission systems; however, when operating signals are sent to the power circuits, where the final power control action is taken, the switching devices are mechanical and there is little high-speed control. Another problem with mechanical devices is that control cannot be initiated frequently, because these mechanical devices tend to wear out very quickly compared to static devices. In effect, from the point of view of both dynamic and steady-state operation, the system is really uncontrolled. Power system planners, Operators, and engineers have learned to live with this limitation by using a variety of ingenious techniques to make system work effectively, but at a price of providing greater operating margins and redundancies. These represent an asset that can be effectively utilized with prudent use of FACTS technology on a selective, as needed.

The FACTS devices (Flexible AC Transmission Systems) could be a means to carry out this function without the drawbacks of the electromechanical devices such as slowness and wear. FACTS can improve the stability of network, such as the transient and the small signal stability, and can reduce the flow of heavily loaded lines and support voltages by controlling their parameters including series impedance, shunt impedance, current, voltage and phase angle. Controlling the power flows in the network leads to reduce the flow of heavily loaded lines, increased system load ability, less system loss and improved security of the system.

The static synchronous series compensator (SSSC) FACTS controller is used to prove its performance in terms of stability improvement[2]. 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. 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. Here Fuzzy controller is used to control the parameters of power system[3].

SSSC Configuration: Figure-1 shows a single line diagram of a simple transmission line with an inductive reactance, XL, connecting a sending end voltage source, V_s, and a receiving-end voltage source, V_r respectively[2]. The real and reactive power (P and Q) flow at the receiving end voltage source are given by the expressions

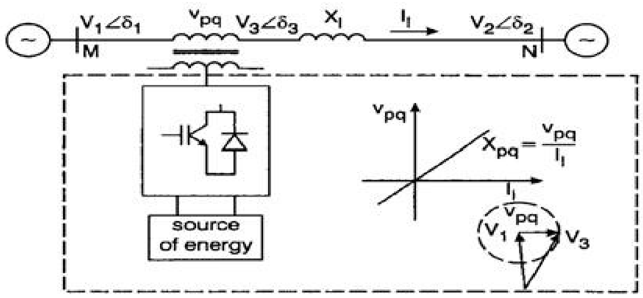

Figure-1
Static synchronous series capacitor

$$P = \frac{V_s V_r}{X_L}\sin(\delta_s - \delta_r) = \frac{V^2}{X_L}\sin\delta \quad (1)$$

$$Q = \frac{V_s V_r}{X_L}(1 - \cos(\delta_s - \delta_r)) = \frac{V^2}{X_L}(1 - \cos\delta) \quad (2)$$

Where V_s and V_r are the magnitudes and δ_s and δ_r are the phase angles of the voltage sources V_s and V_r respectively.

For simplicity, the voltage magnitudes are chosen such those $V_s = V_r = V$ and the difference between the phase angle is

$$\delta = \delta_s - \delta_r \quad (3)$$

A SSSC, limited by its voltage and current ratings, is capable of emulating a compensating reactance X_q (both inductive and capacitive) in series with the transmission line inductive reactance X_L. Therefore, the expressions for power flow given in equation (1 and 2) becomes

$$P_q = \frac{V^2}{X_{eff}}\sin\delta = \frac{V^2}{X_L(1 - X_q/X_L)}\sin\delta \quad (4)$$

$$Q_q = \frac{V^2}{X_{eff}}(1 - \cos\delta) = \frac{V^2}{X_L(1 - X_q/X_L)}(1 - \cos\delta) \quad (5)$$

Where X_{eff} is the effective reactance of the transmission line between its two ends, including the emulated variable reactance inserted by the injected voltage source of the Static Synchronous Series Compensator (SSSC). The compensating reactance X_C is defined to be negative when the SSSC is operated in an inductive mode and positive when the SSSC is operated in a capacitive mode.

Two Machine Power System Modelling

Without SSSC: The dynamic performance of SSSC is presented by real time voltage and current waveforms. Using MATLAB software the system shown in Figure- 3, has been obtained[4]. In the simulation, 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 (Bl 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.

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=100MVA and V_b=500KV, which active and reactive powers of power plants 1 and 2 are (24-j3.8) and (15.6-jO.5) in per unit, respectively.

With SSSC: 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 Figure- 10, 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 Figure-10, reactive power damping time will be decreased and system will follow the references value with acceptable error. In figure-10 on X-axis a time in seconds and on Y-axis Active and Reactive powers in Per unit (pu) is taken.

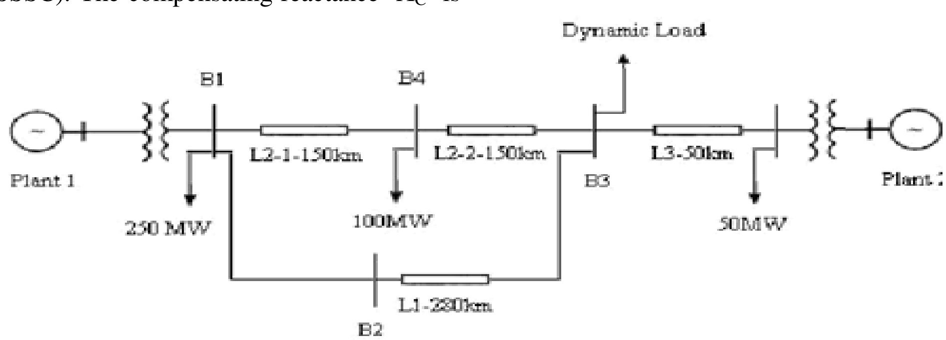

Figure-2
Line diagram of Two Machine System without SSSC

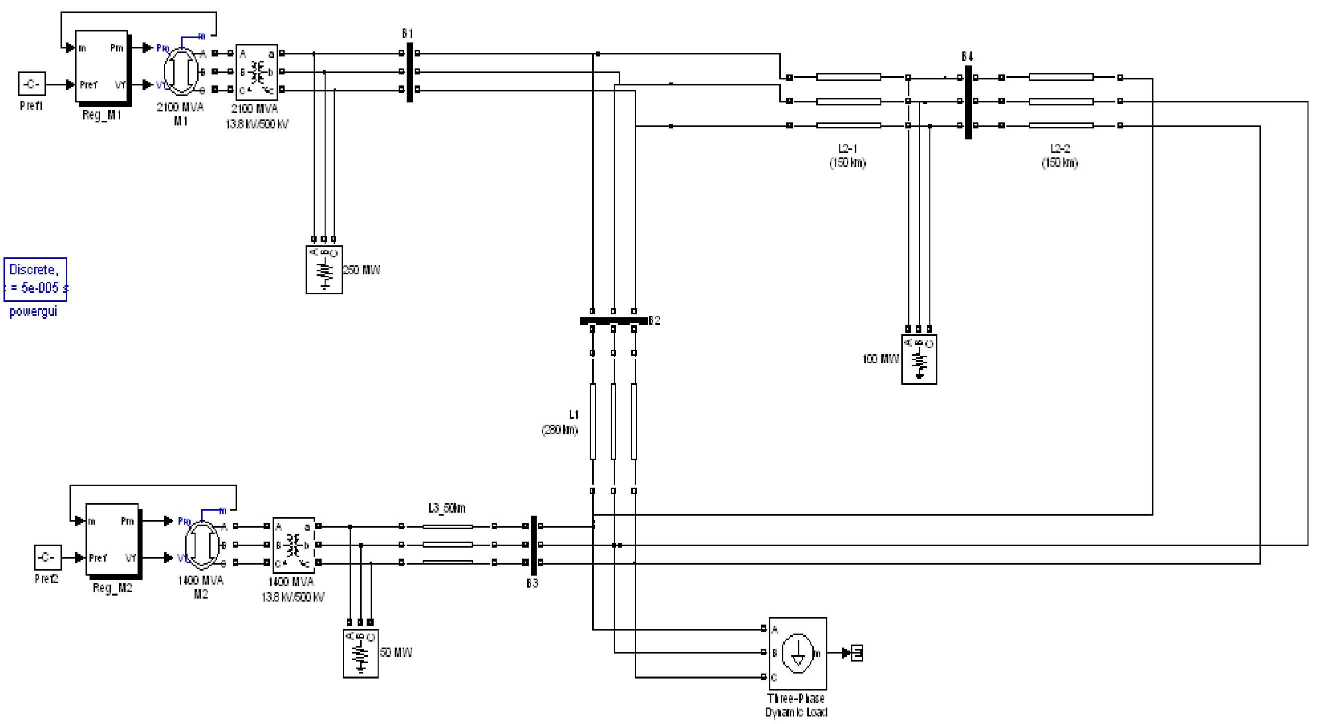

Figure-3
Two Machine System without SSSC

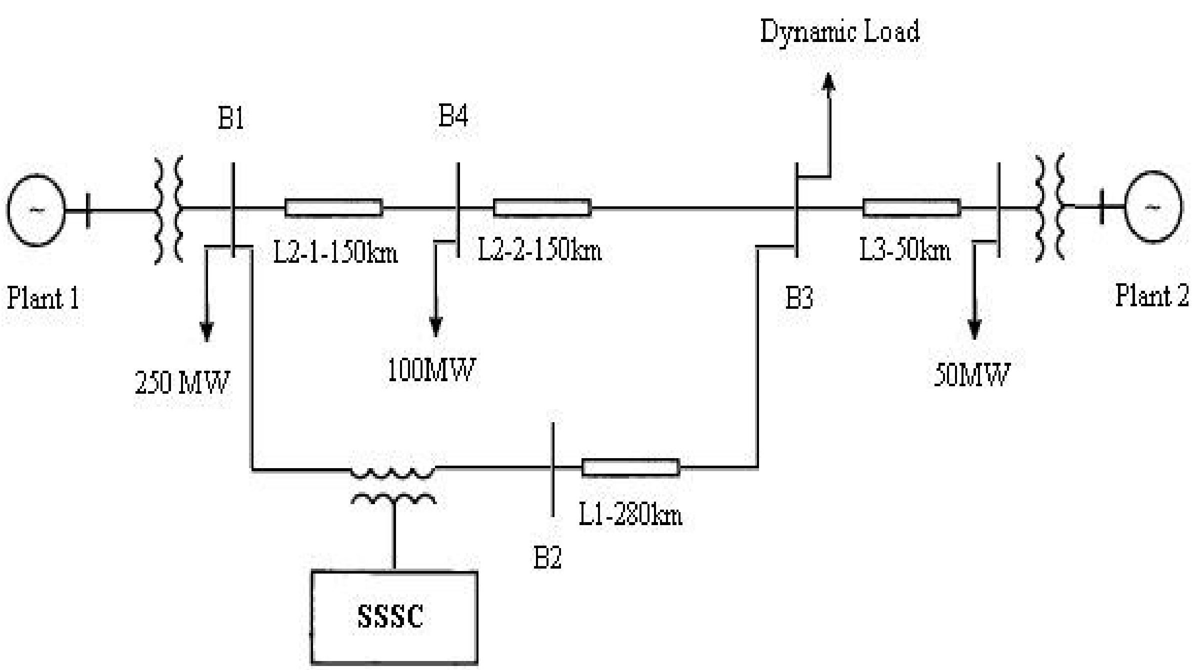

Figure-4
Line diagram of Two Machine System with SSSC

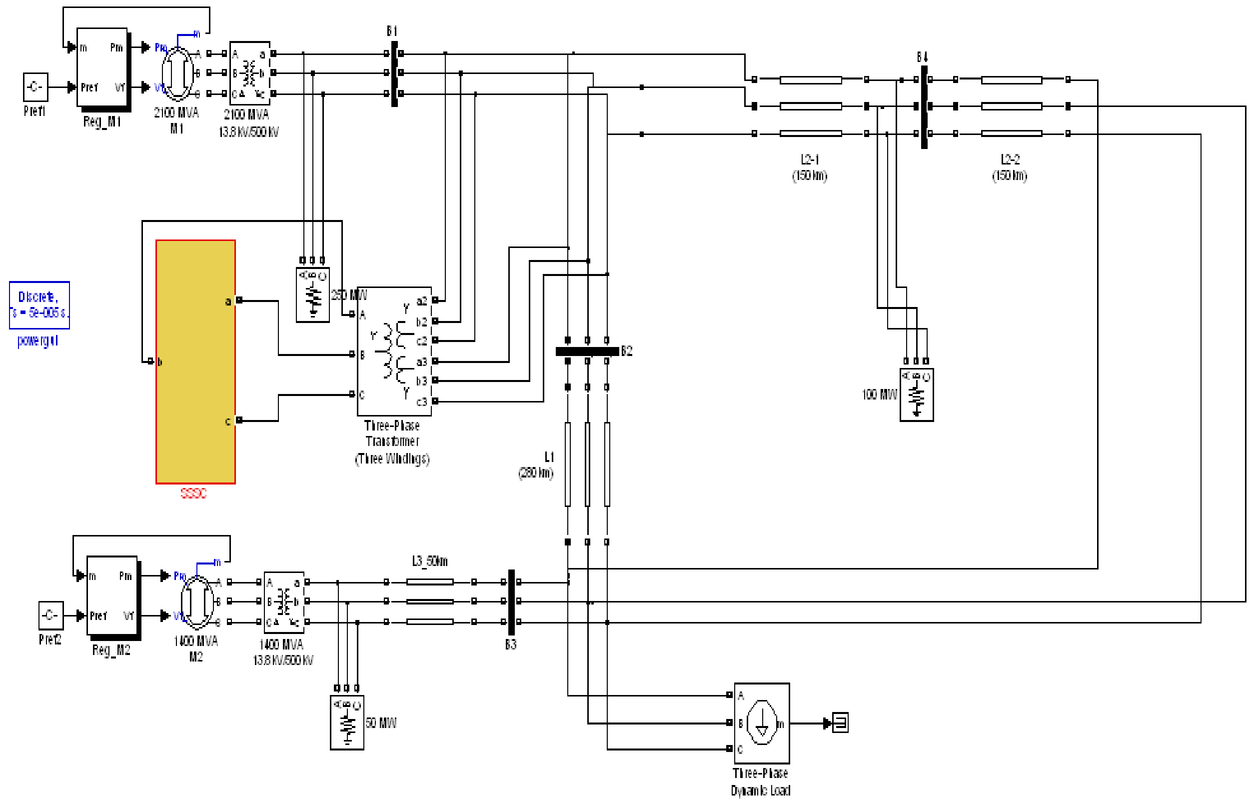

Figure-5
Two Machine Systems with SSSC

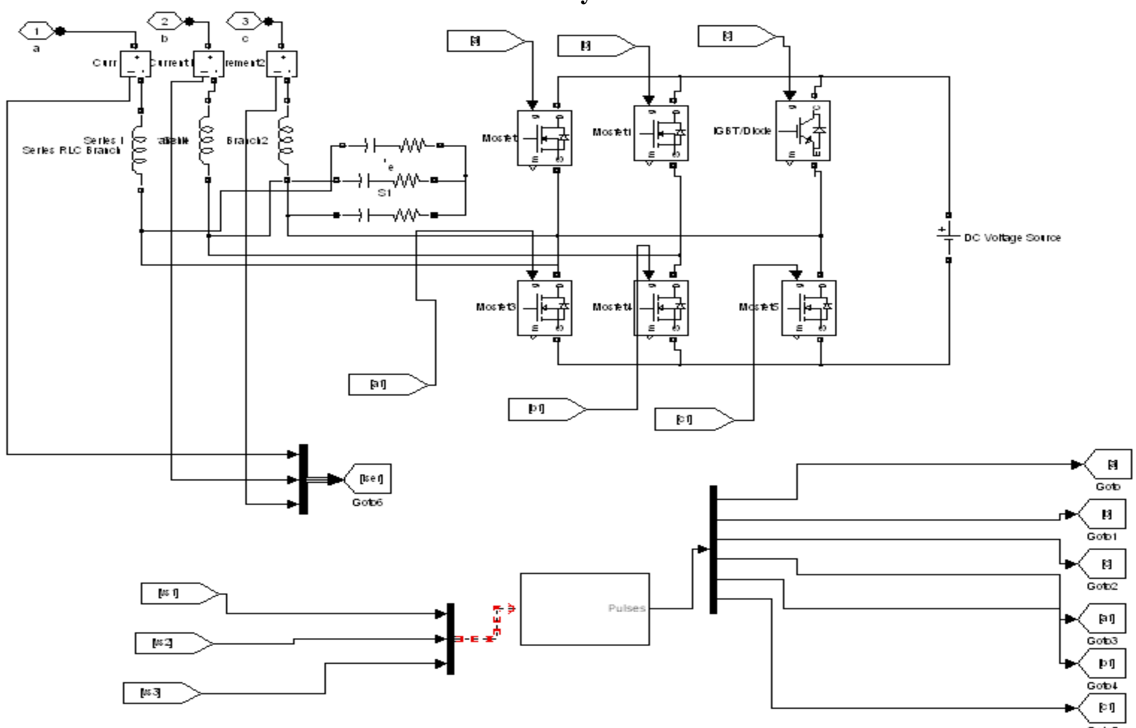

Figure-6
Control circuit with SSSC

Simulation Results and Discussions

Without SSSC: 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-1. 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.

Changes in current, voltage, active and reactive powers of bus-2 have been obtained in real time. According to figure-8, 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 8, because of the above mentioned 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. In figure-8 on X-axis Time in seconds and on Y-axis Active and Reactive powers in Per unit (pu) is taken.

According to figure-9, 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 7.8 pu. In figure-9 on X-axis Time in seconds and on Y-axis Voltage and Current in per unit (pu) is taken.

With SSSC: SSSC is controlling the active and reactive powers; beside these SSSC could fairly improve the transient oscillations of system[6].

SSSC with Fuzzy Logic: SSSC is employed with fuzzy controller, the simulation results shows that this controller gives best non-linear system performance. Fuzzy controller can achieve oscillation damping, fast response and finally stabilizing power system[7].

After the installation of SSSC with fuzzy logic, 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 figure-11, by installing the SSSC with fuzzy logic, active power damping time will be less than the mode without SSSC and it will be damped much faster. Also as shown in figure-12, reactive power damping time will be decreased and system will follow the references value with acceptable error. In figure-12 on X-axis A Time in seconds and on Y-axis Active and Reactive powers in Per unit (pu) is taken.

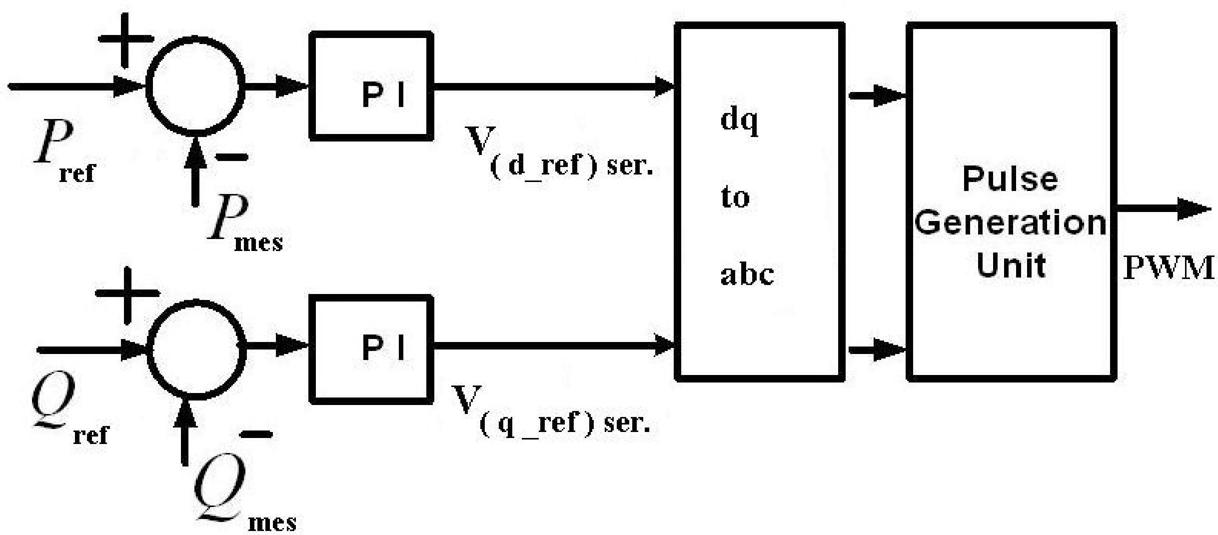

Figure-7
Line diagram of Control circuit of SSSC

Table-1
Simulation results without SSSC

Bus no	Voltage	Current	Active power	Reactive power
1.	1 pu	13.5 pu	20.06 pu	-3.769 pu
2.	1 pu	7.8 pu	9.96 pu	-1.82 pu
3.	1 pu	10 pu	14.85 pu	-0.48 pu
4.	1 pu	5.55 pu	8.45 pu	-0.59 pu

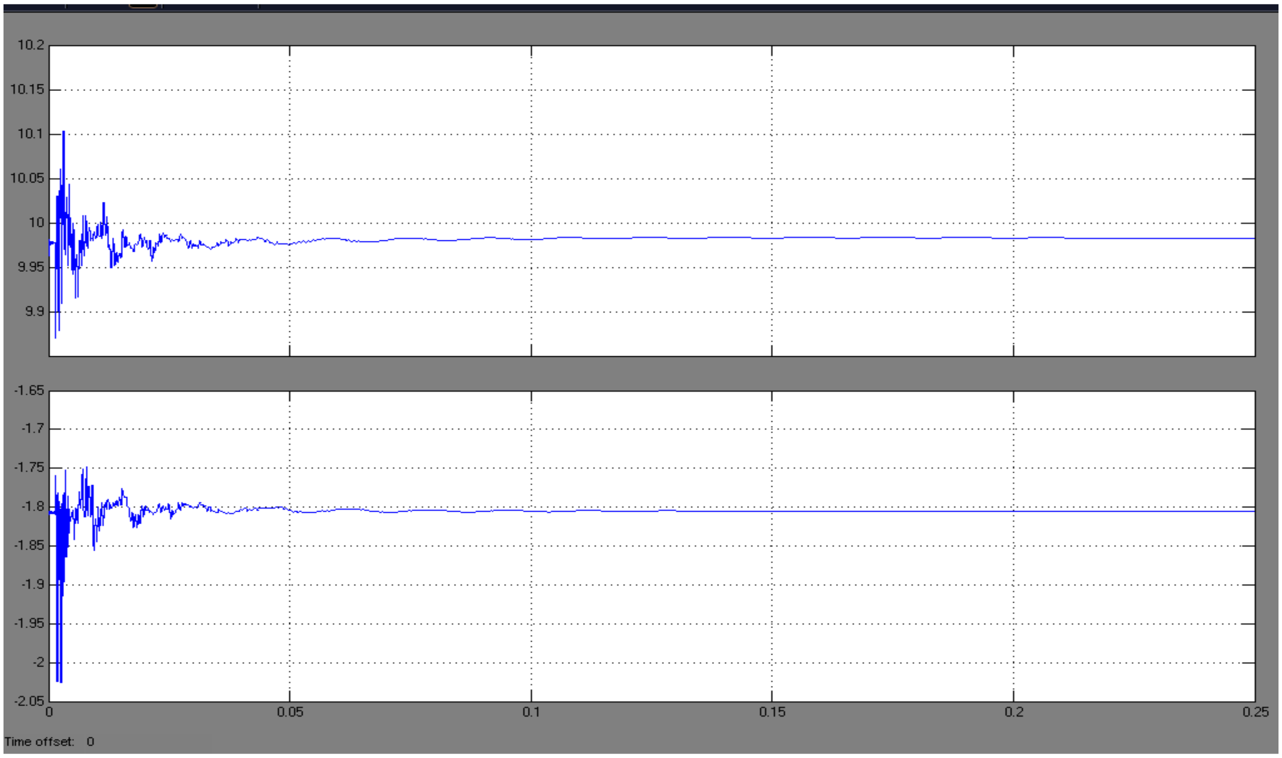

Figure-8
Active and Reactive power without SSSC of Bus-2

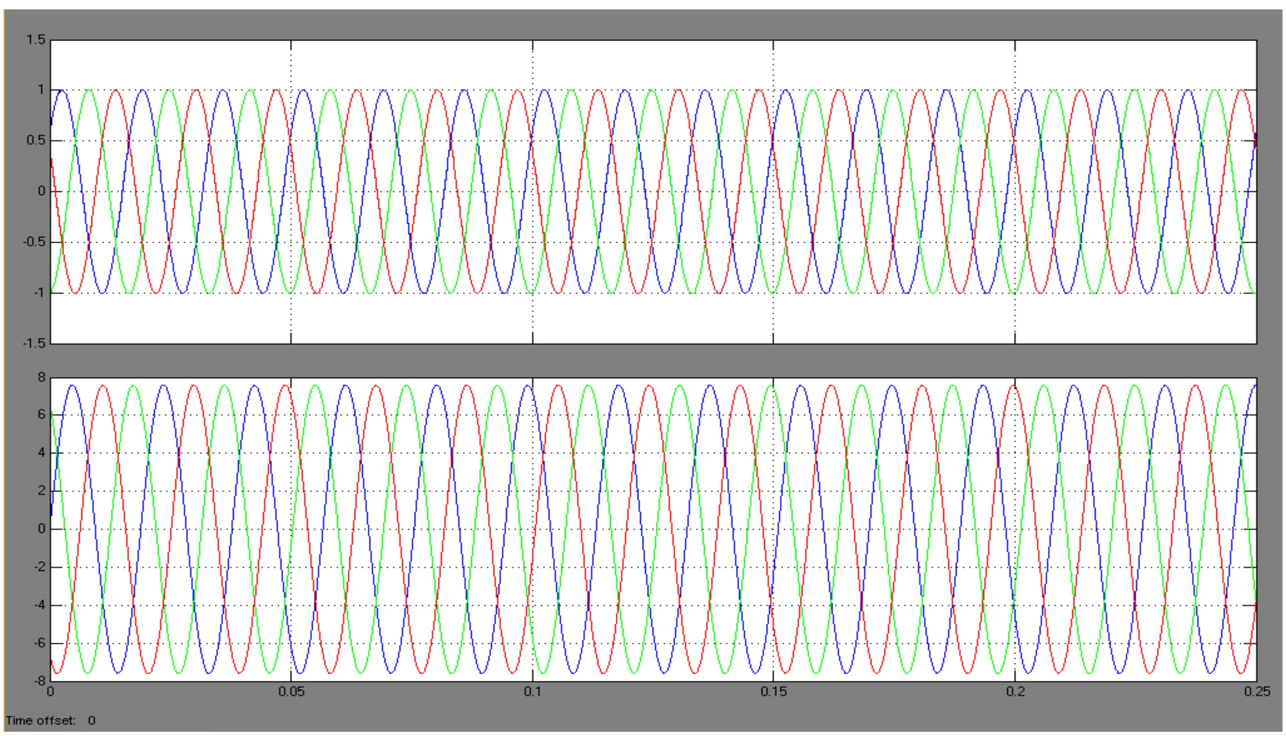

Figure-9
Voltage and Current of Bus-2 without SSSC

Table-2
Obtained results after simulation with sssc

Bus no	Voltage	Current	Active power	Reactive power
1.	1 pu	13.5 pu	20 pu	-4.74 pu
2.	1 pu	7.8 pu	11.26 pu	-1.84 pu
3.	1 pu	10 pu	14.82 pu	-0.24 pu
4.	1 pu	4.6 pu	7.09 pu	-0.24 pu

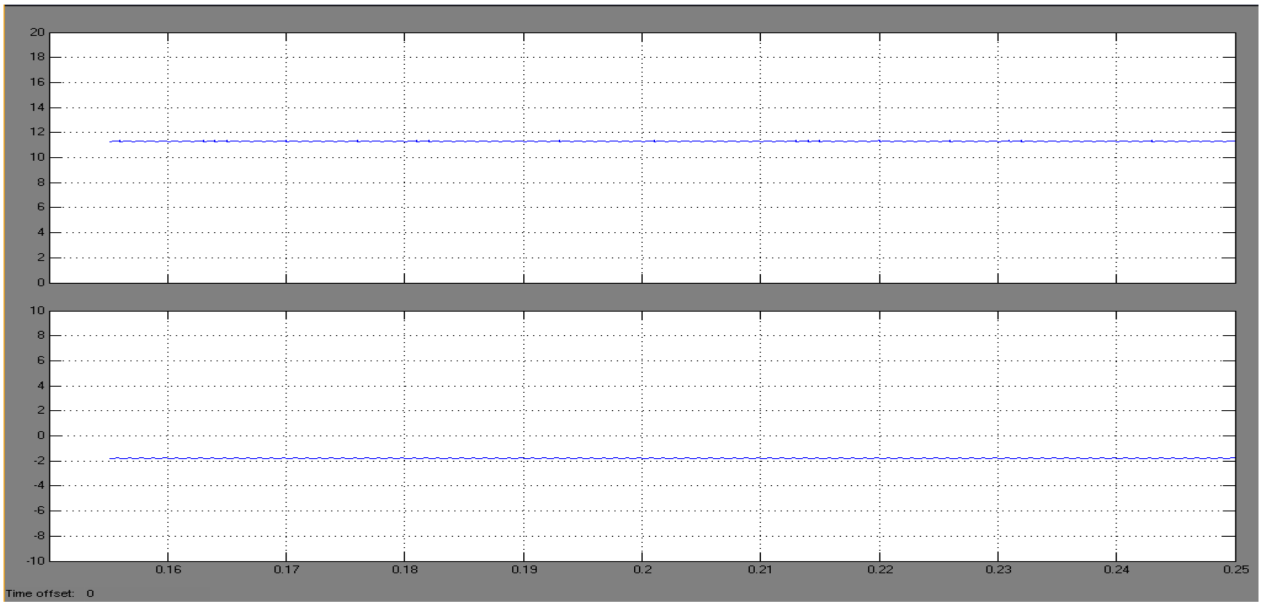

Figure-10
Active and Reactive power with SSSC of Bus-2

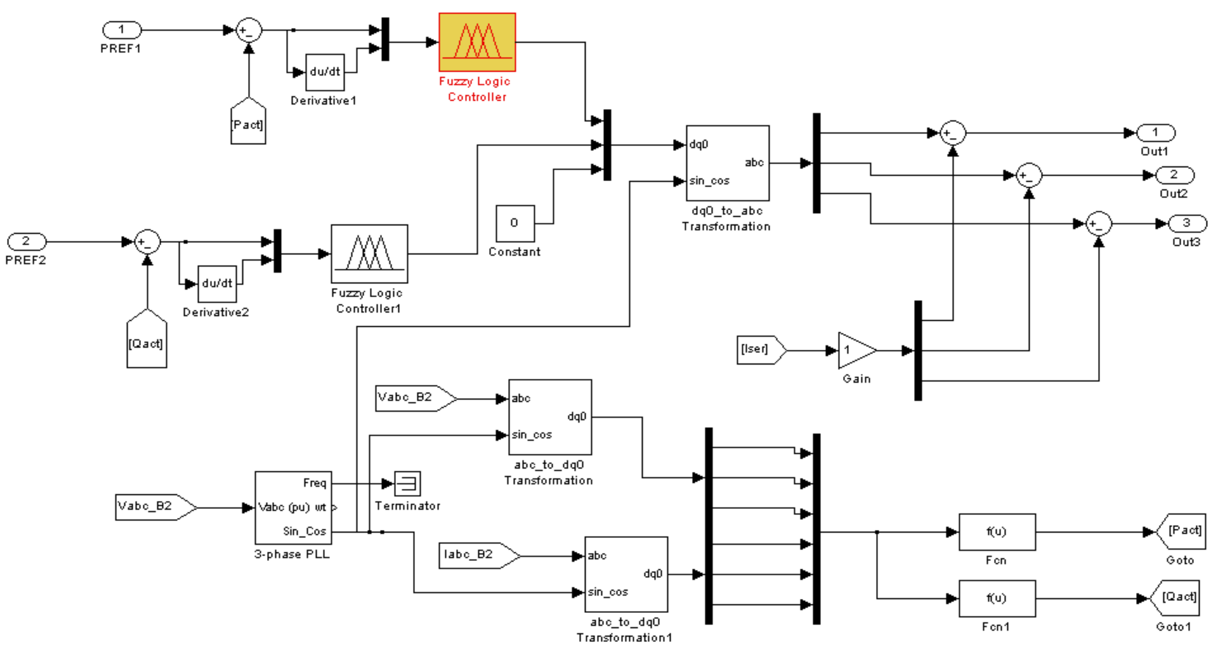

Figure-11

Control circuit of SSSC with Fuzzy logic

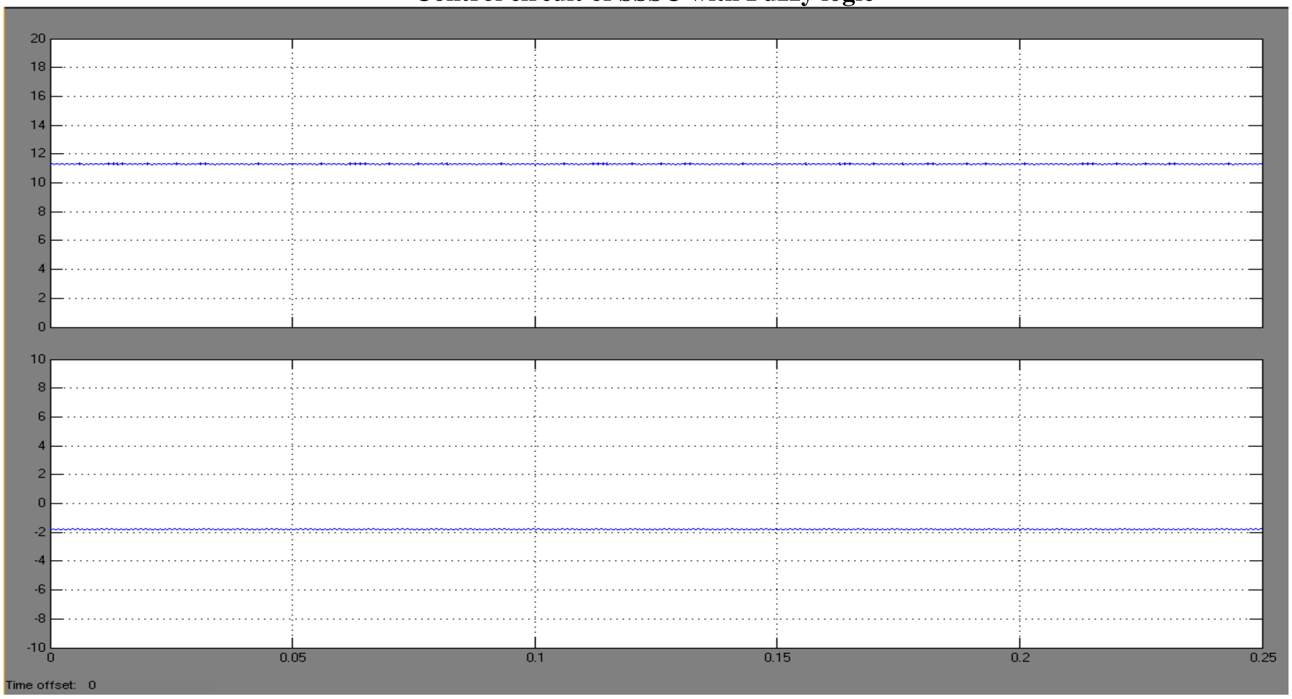

Figure-12
Active and Reactive power of Bus-2 using SSSC with Fuzzy logic

Table-3
Comparison and Analysis

Measurements	Without SSSC	With SSSC using PI controller	With SSSC using Fuzzy controller
THD Levels	6.95%	3.08%	0.04%
Settling Time	0.1 sec	0.15 sec	0 sec

Comparison Results of 3 Cases

In table-3 the comparison results of three cases is given. This shows that the SSSC implemented in bus-2 with fuzzy control operates effectively and gives stability to the system and hence Power Quality is improved.

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. 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.

SSSC is one a member of FACTS family connecting in series with transmission line. In this paper, Fuzzy controller as one of the most useful controller was utilized in SSSC control system. Simulation results and comparisons with the other controllers showed that this controller could achieve better results for any conditions, because of best nonlinear performance of Fuzzy controller it could adjust with the system, however PID controller could not do this sometimes. It was observed that by using the Fuzzy controller, can achieve their goals, i.e. oscillations damping, fast response, and finally stabilizing power system.

References

1. Kalyan Sen. K, SSSC - Static Synchronous Series Compensator: Theory, modeling and Applications, *IEEE Transactions on Power Delivery,* **13**, 241-246, **(1998)**
2. Wang H.F., University of Bath, UK, Design of SSSC Damping Controller to Improve Power System Oscillation stability, *IEEE Press*, **(1999)**
3. Nagarjun Donipala, Suresh Babu. R., An Adaptive Power System Stability Enhancement Using Static Synchronous Series Compensator (SSSC), *Int. Journal of Engineering Research and* Applications ISSN: 2248-9622, **4,1**(**Version 1),** 261-265, **(2014)**

4. Anu Rani Sam and Arul. P., Transient Stability Enhancement of Multi-machine Power System Using UPFC and SSSC, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, ISSN: 2278-3075, **3(5), (2013)**

5. Pandey Deepa and Kapoor Swati, Effects of Electronic Control Techniques on Performance of Automotive Suspension, *Res. J. Engineering Sci*., **3(8),** 7-10 **(2014)**

6. Laszlo Gyugi, Dynamic compensation of AC Transmission lines by solid state synchronous voltage sources, *IEEE Transactions Power Delivary*, **9(2), (1994)**

7. Sujata Verma S.K Singh and A.G. Rao, Overview of control Techniques for DC-DC converters, *Res. J. Engineering* Sci., **2(8),** 18-21 **(2013)**

8. Naveen Kumar Reddy M., Rajashekar G.V, and Himani Goyal, Power System Stability Enhancement Using Static Synchronous Series Compensator (SSSC), *International Journal of Modern Engineering Research (IJMER),* **3(4),** 2530-2536, **(2013)**

9. Habibur Rahman, Jewel Rana and Harun-Or-Rashid, Power System Stability Improvement By Using SSSC With Power System Controller, *International Journal of Science, Engineering and Technology Research (IJSETR),* **1(6), (2012)**

10. Kazemi, Ladjevar di M. and Masoum M.A.S, Optimal selection of SSSC based damping controller parameters for improving power system dynamic stability using genetic algorithm, *Iranian Journal of Science and Technology, Transaction B, Engineering,* 29, No. B1 Printed in The Islamic Republic of Iran, **(2005)**

11. Murali D., Rajaram M. and Reka N., Comparison of FACTS Devices for Power System Stability Enhancement", *International Journal of Computer* Applications (0975–8887), **8(4), (2010)**

12. Noroozian M., Angquist L., Ghandhari M. and Anderson G., Use of UPFC for optimal power flow control**,** *IEEE Transactions on Power Delivery*, **12(4), (1997)**

13. Jain Sandesh, Thakur Shivendra Singh and Phulambrikar S.P., Improve Power Factor and Reduce the Harmonics Distortion of the System, *Research J. Engineering Sci.,* **1(5),** 31-36 **(2012)**

14. Sridevi J., A New Active Power Factor Correction Controller using Boost Converter, *Res. J. Engineering Sci.,* **2(8),** 7-11 **(2013)**

15. Verma Sujata and Singh S.K , Miscellaneous applications of DC-DC converters, *Research Journal of Engineering Sciences***,** **2(6),52-53(2013)**