International Engineering Journal for Research & Development

Vol. 9
Issue 2

DAMPING POWER SYSTEM OSCILLATIONS USING AN SSSC-BASED HYBRID SERIES CAPACITIVE COMPENSATION SCHEME

[1]Roshni Murodiya, Ms. Shradha N. Waghade, Ms. Apeksha P. Sonare, Ms. Hirkanya P. Bhole, Ms. Minal R. Wadyalkar

Assistant Professor, Department of Electrical Engineering[1], Assistant Professor, Department of Electrical Engineering[2], Department of Electronics and Communication Engineering[3], Department of Basic science and Humanities[4], Department of Electronics and Communication Engineering[5]
TGPCET, Nagpur

ABSTRACT

Interconnection of electric power systems is becoming increasingly widespread as part of the power exchange between countries as well as regions within countries in many parts of the world. In cases of long distance AC transmission, as in interconnected power systems, care has to be taken for safeguarding of synchronism as well as stable system voltages, particularly in conjunction with system faults. These long distance power transfers cause, however, the system low-frequency oscillations to become more lightly damped. As a result, many power network operators are taking steps to add supplementary damping devices in their systems to improve the system security by damping these undesirable oscillations. With the advent of voltage sourced converter-based series compensation, AC power system interconnections can be brought to their fullest benefit by optimizing their power transmission capability, safeguarding system stability under various operating conditions and optimizing the load sharing between parallel circuits at all times. This paper reports the results of digital time-domain simulation studies that are carried out to investigate the effectiveness of a phase imbalanced hybrid single-phase-Static Synchronous Series Compensator (SSSC) compensation scheme in damping power system oscillations in multi-machine power systems. Time-domain simulations are conducted on a benchmark model using the Electro Magnetic Transients Program (EMTP-RV). The results of the investigations have demonstrated that the hybrid single-phase-SSSC compensation scheme is very effective in damping power system oscillations at different loading profiles.

1. INTRODUCTION

Growth of electric power transmission facilities is restricted despite the fact that bulk power transfers and use of transmission systems by third parties are increasing. Transmission bottlenecks, non-uniform utilization of facilities and unwanted parallel-path or loop flows are not uncommon. Transmission system expansion is needed, but not easily accomplished. Factors that contribute to this situation include a variety of environmental, land-use and regulatory requirements. As a result, the utility industry is facing the challenge of the efficient utilization of the existing AC transmission lines. Thus, the transmission systems are being pushed to operate closer to their stability and thermal limits. Although electricity is a highly engineered product, it is increasingly being considered and handled as a commodity. Thus, the focus on the quality of power delivered is also greater than ever.

Series capacitive compensation of power transmission lines is an important and the most economical way to improve power transfer capability, especially when large amounts of power must be transmitted through long transmission lines. However, one of the impeding factors for the increased utilization of series capacitive compensation is the potential risk of Subsynchronous Resonance (SSR), where electrical energy is exchanged with turbine-generator shaft systems in a growing manner which can result in shaft damage [1]. Figure 1.1 shows a typical time response of a turbine-generator shaft torsional torque during and after clearing a fault on a series capacitive compensated transmission line in the presence of the SSR phenomenon. It is worth noting here that this shaft is designed to withstand a maximum torsional torque of 2 per unit. Another limitation of series capacitive compensation is its inability to provide adequate damping to power system oscillations after clearing system faults. Figure 1.2 shows a typical time response of a generator load angle, measured with respect to a reference generator load angle, during and after clearing a three-phase fault on a series capacitive compensated transmission line. As it can be seen from this figure, the oscillations are not 2 completely damped after the first few seconds from fault clearing which results in degrading the power quality of the system.

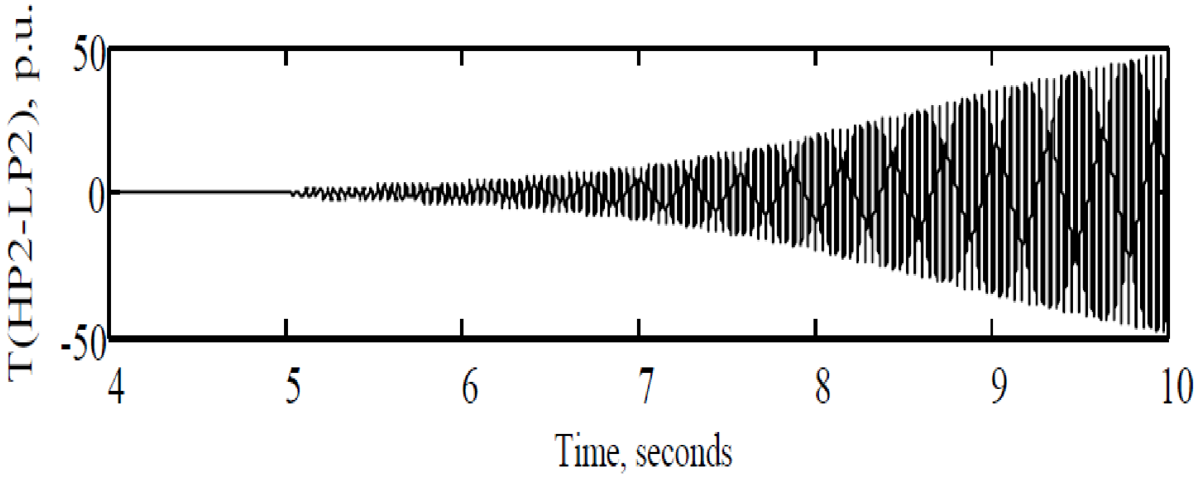

Figure 1.1: Transient time response of a turbine-generator shaft torsional torque during and after clearing a system fault on a series capacitive compensated transmission line.

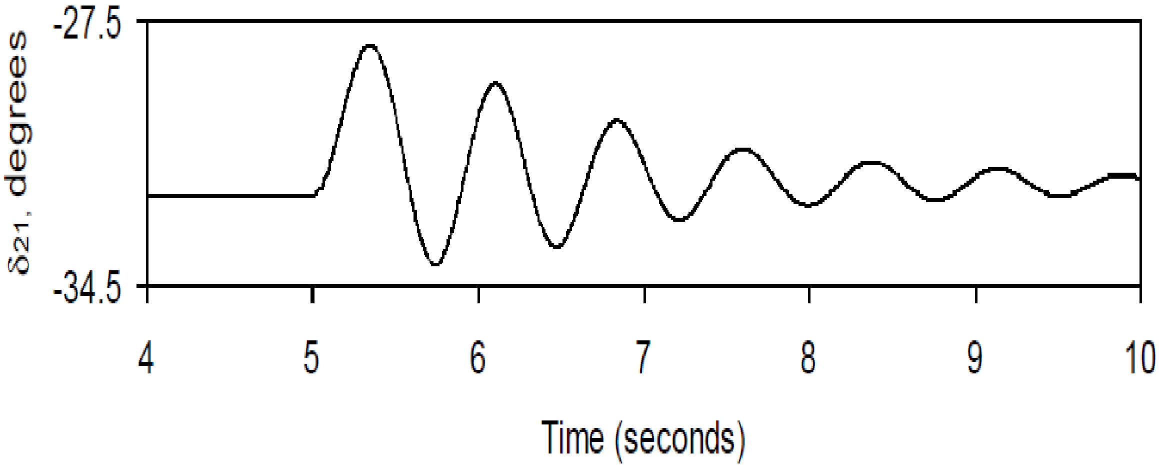

Figure 1.2: Transient time response of a generator load angle, measured with respect to a reference generator load angle, during and after clearing a system fault on a series capacitive compensated transmission line.

2. STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

A SSSC is a series connected FACTS devices which is operated as a series compensator. It is very effective in controlling power flow in a transmission line with the capability to change its reactance characteristic from capacitive to inductive [3]. The SSSC controls the power flow in transmission lines where it is connected by controlling the magnitude of injected voltage and also the phase angle of injected voltage in series with the transmission line. It injects a controllable voltage in series with a transmission line at the fundamental frequency by using a solid-state voltage source converter (VSC) with a coupling transformer as shown in Fig 2.

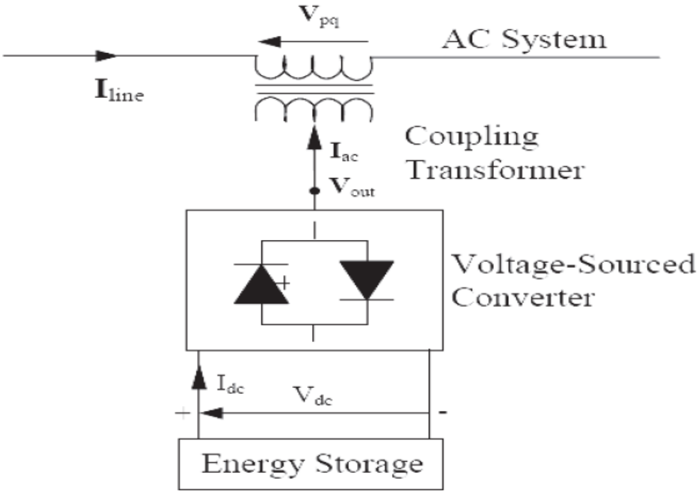

Fig -2: Static Synchronous Series Compensator (SSSC)

Typically a SSSC can be treated as an ideal synchronous voltage source which produces three-phase AC voltages of desired fundamental frequency with controlled amplitude and phase angle. This injected voltage is a nearly-sinusoidal ac voltage with variable magnitude and phase angle. The quadrature component of the injected voltage can be leading or lagging the line current by 90° such that the reactive power is absorbed or generated. This provides both inductive and capacitive compensation. On the other hand the component of the injected voltage in phase with the line current enables the SSSC to exchange active power and provide resistive compensation. The resistive compensation is very beneficial when it comes to the power oscillation damping [4].

Typically a SSSC can be treated as an ideal synchronous voltage source which produces three-phase AC voltages of desired fundamental frequency with controlled amplitude and phase angle. This injected voltage is a nearly-sinusoidal ac voltage with variable magnitude and phase angle. The quadrature component of the injected voltage can be leading or lagging the line current by 90° such that the reactive power is absorbed or generated. This provides both inductive and capacitive compensation. On the other hand the component of the injected voltage in phase with the line current enables the SSSC to exchange active power and provide resistive compensation. The resistive compensation is very beneficial when it comes to the power oscillation damping [4].

3. SSSC-BASED DAMPING CONTROLLER

The function of POD controller is to provide an additional input signal to damp power system oscillations. Some of the commonly used input signals are bus voltage, line current from bus, line power from bus, line reactive power from bus [13].

To modulate the SSSC injected voltage a two stage lead-lag structure type controller shown in Fig. 3 is proposed as a SSSC-based damping controller to control the injected voltage Vqinj of SSSC in this paper. This structure consists of a gain block, washout block and two stage lead-lag blocks. The gain block is used to dampen the oscillations. The two stage lead-lag blocks (time constants T1, T2, T3 and T4) provide suitable phase-lead characteristics to compensate for the phase lag between input and the output signals.

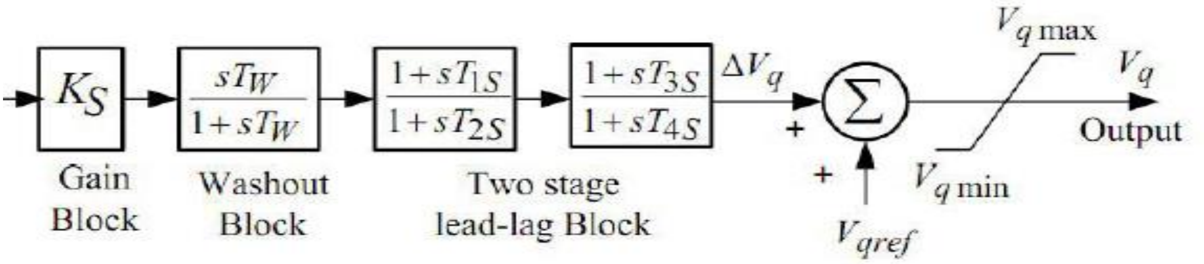

Fig- 3: Design Structure of POD controller

4.BLOCK DIAGRAM

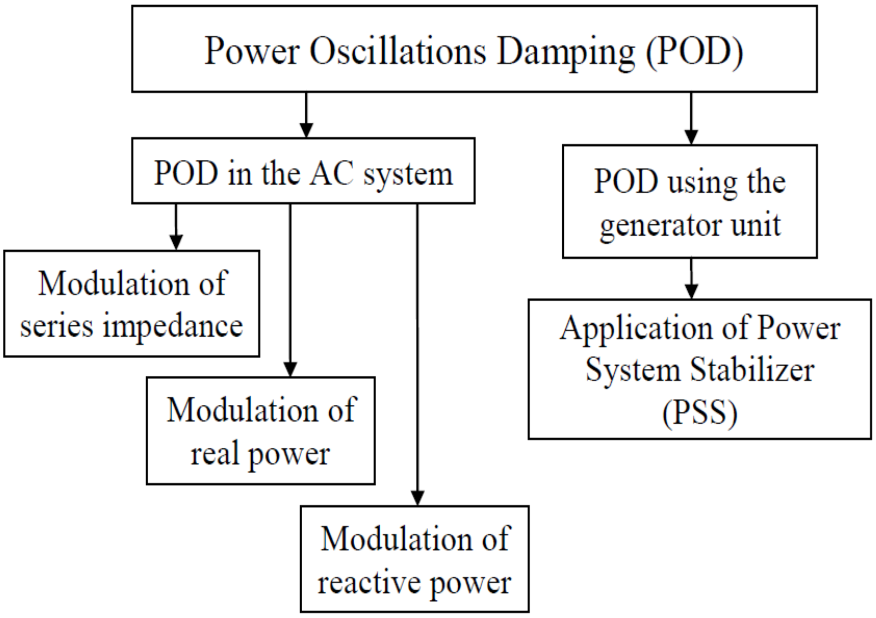

Figure 4.1: Strategies to damp power system oscillations.

FACTS Controllers are power electronic based controllers which can influence transmission system voltages, currents, impedances and/or phase angles rapidly [8], [9]. These controllers have the flexibility of controlling both real and reactive power, which could provide an excellent capability for improving power system dynamics. FACTS technology provides an unprecedented way for controlling transmission grids and increasing transmission capacity.

FACTS Controllers can be classified in two ways. They can be categorized according to their connection into the power system (series or shunt) or according to their power electronic configuration (thyristor-based or Voltage-Sourced Converter (VSC)-based types). For example, the Thyristor-Controlled Series Capacitor (TCSC) is a thyristor type series-connected controller, the Static Synchronous Series Compensator (SSSC) is a VSC type series-connected, the Static Var Compensator (SVC) is a thyristor type shunt-connected controller, the Static Series Compensator (STATCOM) is a VSC type shunt-connected controller and the Unified Power Flow Controller (UPFC) is a VSC type combined-shunt-series-connected controller. In studies conducted in this thesis, attention is focused on the SSSC Controller. The SSSC is a powerful FACTS Controller that can provide series capacitive compensation as well as it has the ability to damp power system oscillations.

5. TEST SYSTEM DESCRIPTION

The power system under consideration comprises of 4 buses. It consist of two interconnected generating stations and one major load center at Bus no. 3. One of the generating stations has a rating of 2100 MVA and the other has a rating of 1400 MVA. The load centre consists of 2200 MW. One of the generating stations is connected to the load through transmission lines. Line 1 is 320 km long and Line 2 is split into two segments of 180 km in order to simulate a three phase fault (using a fault breaker) at the midpoint of the line. The generation substation 2 is also connected to the load by a 50-km line (Line 4). SSSC is connected to Bus no. 2 in series with Line 1.Unsymmetrical faults are applied at Bus no. 4 The results discussed in this section are obtained from Matlab/Simulink software.

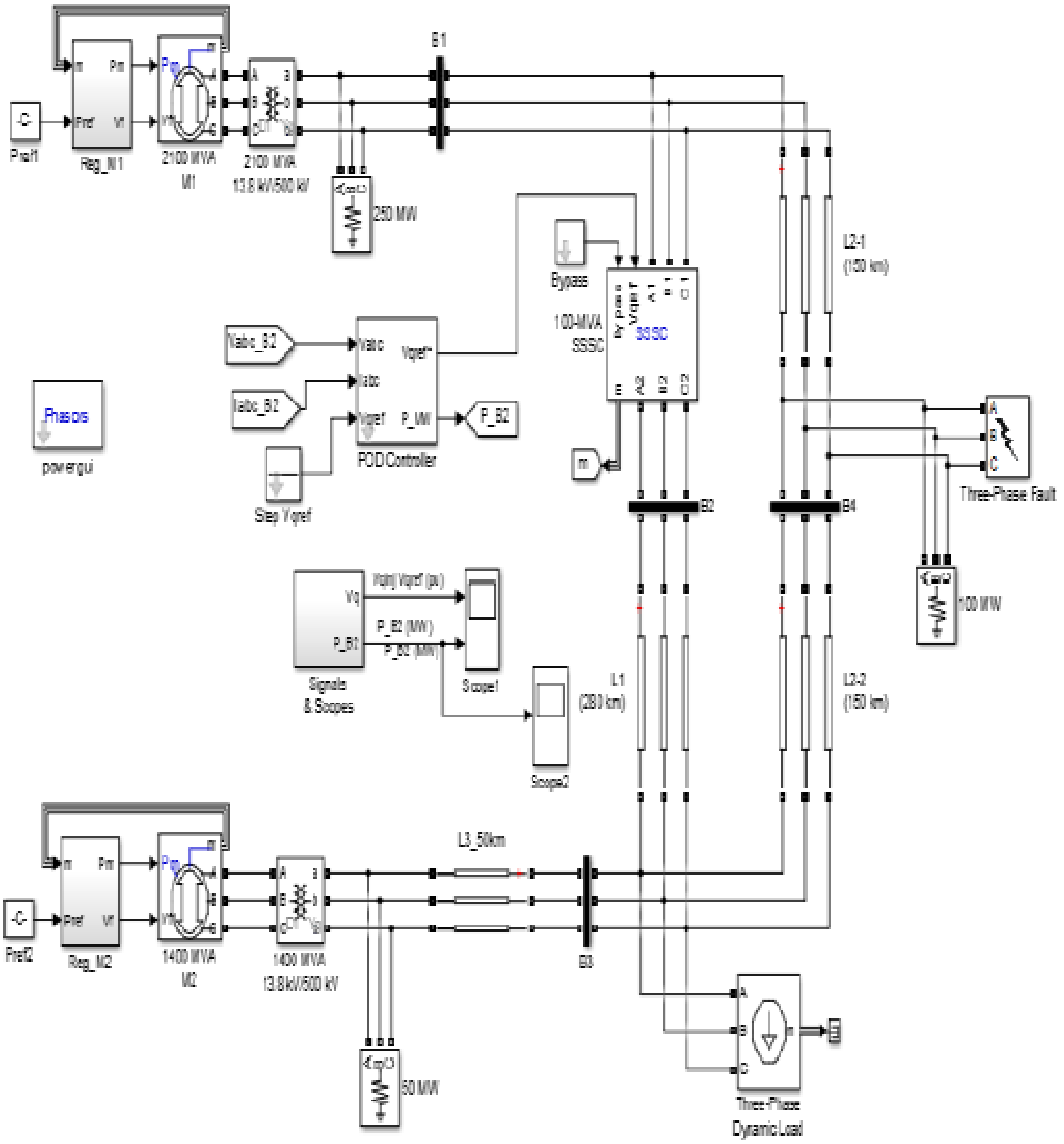

Fig -5: Simulink model of SSSC used for power oscillation damping controller

6. SIMULATION AND RESULT

For analyzing the effect of SSSC Based POD controller in damping out power oscillation following cases are considered.

In which we create unsymmetrical fault for two conditions when POD is OFF and second when POD is ON. We created Line to ground (LG) fault and double line to ground (LLG) fault at time t = 1.33 second and after 10 cycles fault was cleared. The results discussed in this section are obtained from Matlab/Simulink software. The simulation results are obtained after applying unbalanced fault at bus no. 4. The effects of fault on sytem parameter like active and reactive power is analyzed.

Simulation results of line active and reactive power flow and the Vqref and Vqinj for with and without SSSC damping Controller under LG and LLG fault conditions for bus 2 and all other buses are as shown in the figure given below.

Case Study I: Line to Ground Fault when POD is OFF

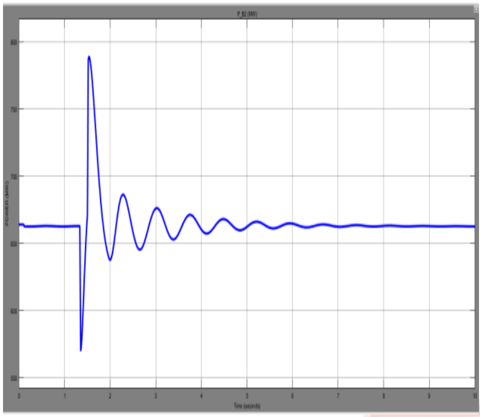

Fig 1: Response of active power at bus-2

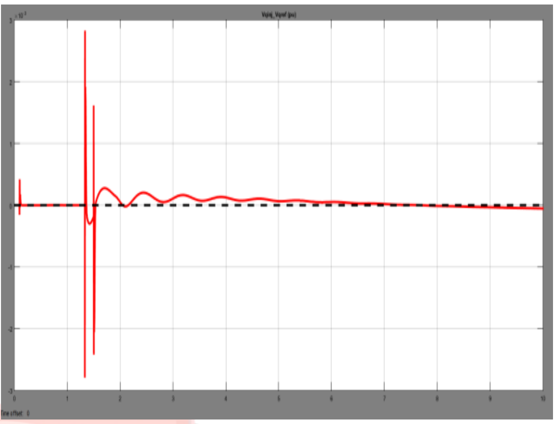

Fig 2: Vqref. And Vqinj for LG Fault

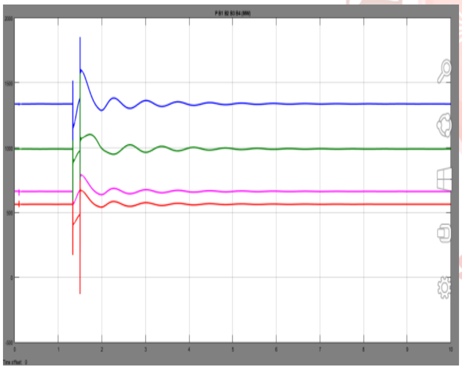

Fig 3: Active Power at all the buses

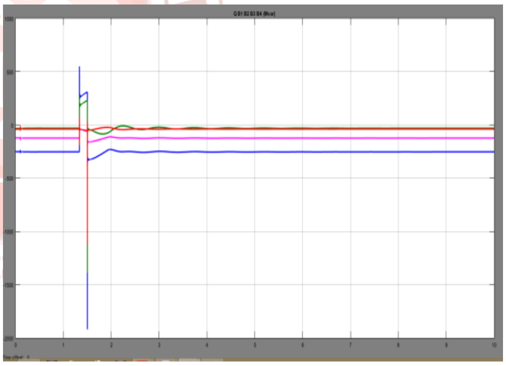

Fig 4: Reactive Power at all the buses

Case Study II: Line to Ground Fault when POD is ON condition

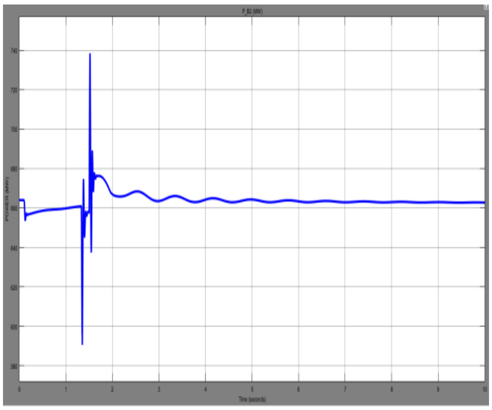

Fig 5: Response of active power at bus-2

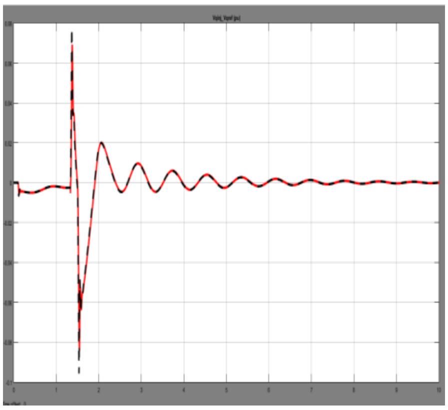

Fig 6: Vqref. And Vqinj

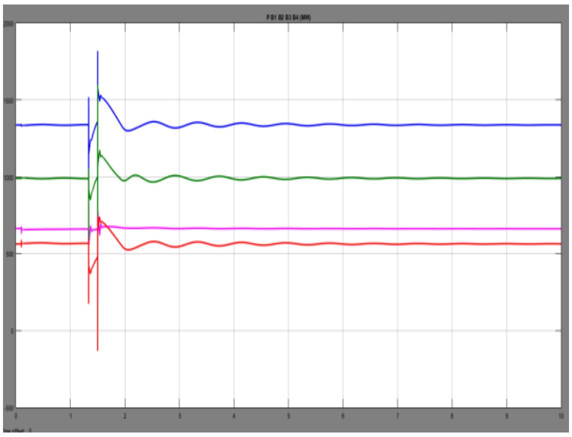

Fig 7: Active Power at all the buses

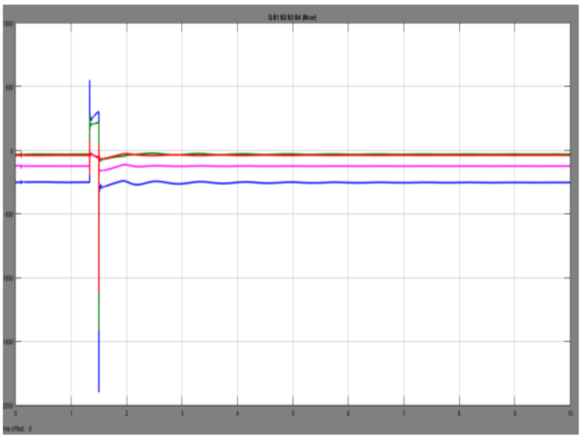

Fig 8: Reactive Power at all the buses

Case Study III: Double line to ground fault when POD is OFF

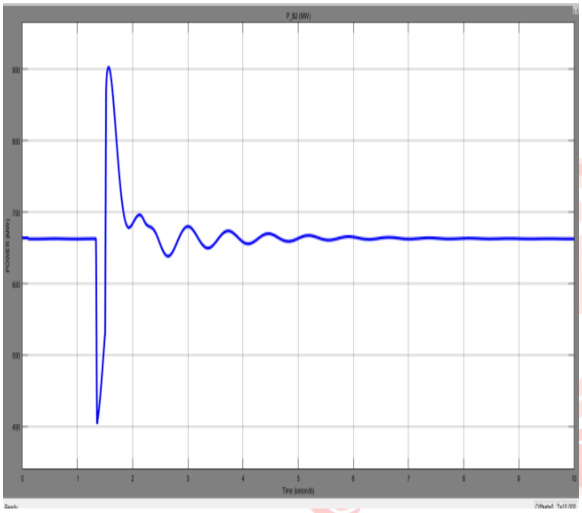

Fig 9: Response of active power at bus-2

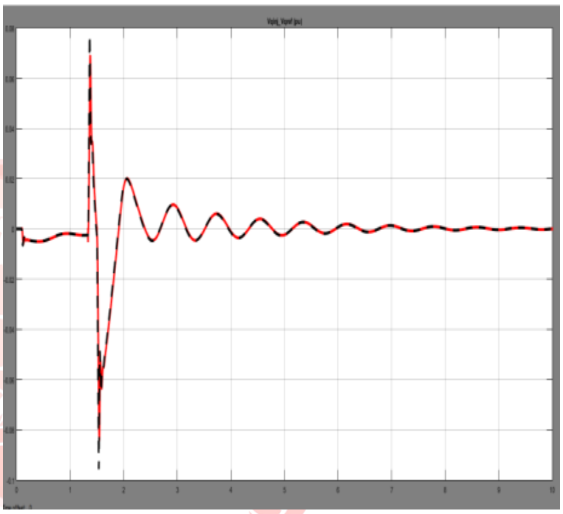

Fig 10: Vqref. And Vqinj

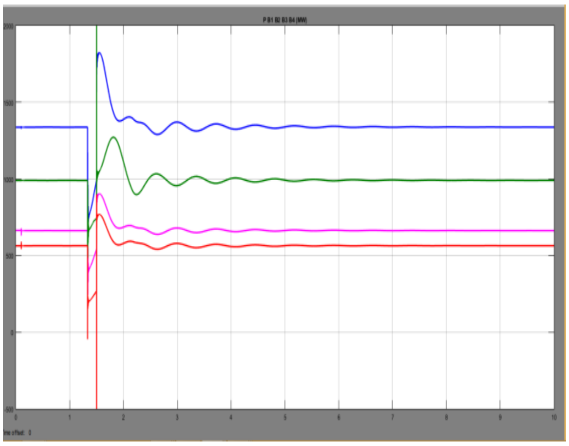

Fig 11: Active Power at all the buses

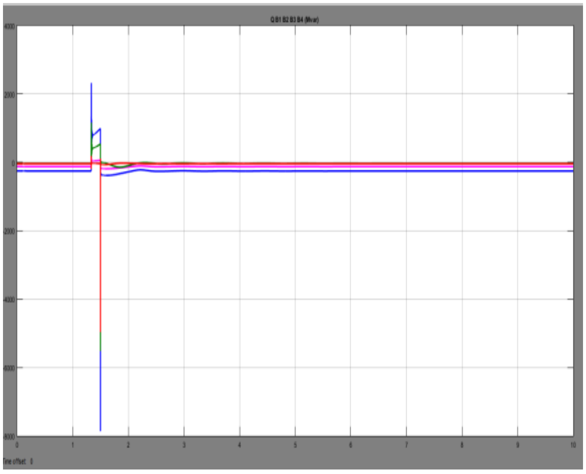

Fig 12: Reactive Power at all the buses

Case Study IV: Double line to ground fault when POD is ON

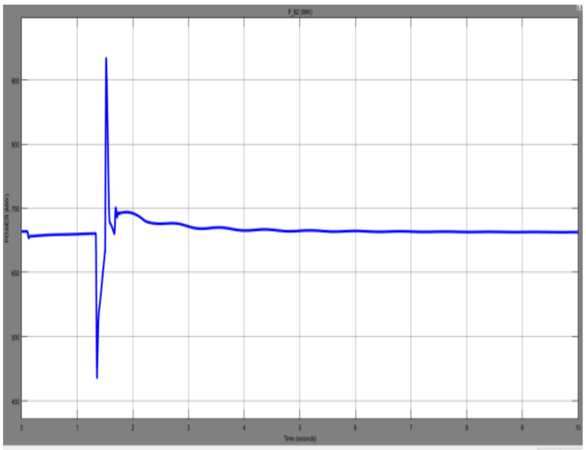

Fig 13:Active Power on bus B-2

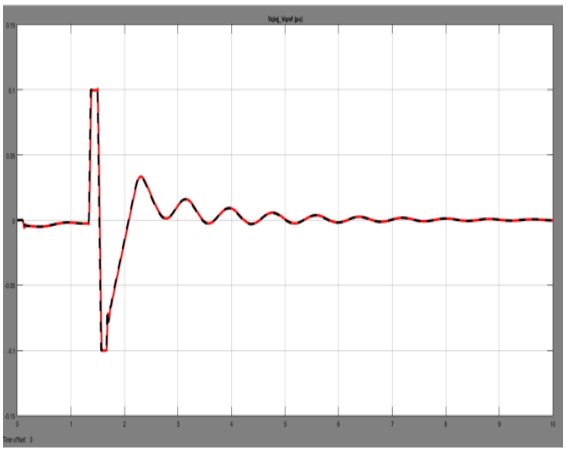

Fig 14: Vqref. And Vqinj

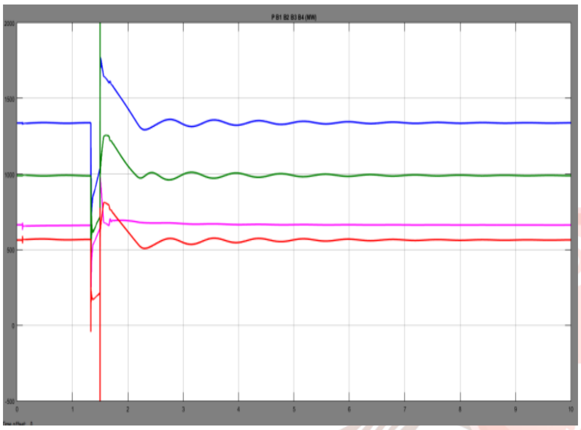

Fig 15: Active Power at all the buses

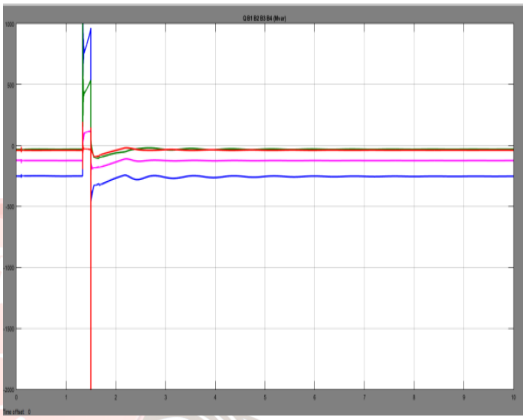

Fig 16: Reactive Power at all the buses

Table 1: Comparison of results with & without SSSC POD Controller

PARAMETER	SETTLING TIME PERIOD (SEC)	
FAULT STATUS CONTROLLER	SSSC with POD controller OFF	SSSC With POD Controller ON
LG-FAULT	6.5 SEC	3.3 SEC
LLG FAULT	6.3 SEC	3.2 SEC

By installing the SSSC with POD the voltage stability has been enhanced and power oscillations are damped perfectly when compared to the two machine system without POD. The simulation results show that this controller gives best performance to the system during normal and fault condition. POD controller can accomplish oscillation damping, rapid response and finally stabilizing power system [5]. Fig 5 and Fig 13 show the power response after implementing SSSC with POD controller. The overshoot of oscillation is slightly reduced and settling time is substantially reduced if compared with case I and case III without any POD controller.

7.CONCLUSION

The studies conducted in this thesis yield the following conclusions for the system under study:

The series capacitor compensated system is first swing stable for three-phase faults, but the post-contingency oscillations are not well damped. Although the system has two natural modes of oscillation, generators 2 and 3 tend to oscillate at a single frequency (approximately 1.4 Hz). The hybrid single-phase-SSSC compensation scheme has shown to be, in general, very effective in damping power system oscillations at different loading profiles. Increasing the proportion of the single-phase-SSSC to the fixed capacitor of its phase results in improving the damping of system oscillations. Increasing the proportion of the hybrid single-phase-SSSC compensation scheme to the total fixed capacitor compensation (i.e. installing the scheme in more transmission line circuits replacing fixed capacitor compensation) enhances significantly the damping of system oscillations. Choosing the values of such two proportion options can be considered as an optimization task between dynamic stability improvements and economical and reliability advantages of fixed series capacitors. The performance of the SSSC supplemental controller when the deviation of generator 2 load angle, with respect to generator 1 load angle, is used as the stabilizing signal is better than when the deviations in the generator speeds or the transmission line real power flows are utilized.

In the majority of the case studies, adequate power system oscillation damping is obtained with proportional-type SSSC supplemental controllers. With the hybrid single-phase-SSSC compensation scheme installed in all circuits of lines L1 and L2, the best performance of the SSSC supplemental controllers is obtained when the deviation of generator 3 load angle, with respect to generator 1 load angle, is used as the stabilizing signal for all controllers. The reduction of the generator first swings depends on the proportion of the hybrid single-phase-SSSC compensation scheme to the total fixed capacitor compensation in the system. It is observed, however, that in one case there is a slight increase in the first swing of one generator. It should be emphasized here that the main task of the supplemental controller of the hybrid single-phase-SSSC compensation scheme is to damp power system oscillations in the "already stable" system under study. For transient stability control of marginally stable power systems, different SSSC control methodologies are usually used.

REFERENCES

[1] P.M. Anderson, *Subsynchronous Resonance in Power Systems*, New York, IEEE Press, 1990.

[2] P.M. Anderson and R.G. Farmer, Series Compensation of Power Systems, PBLSH!, 1996.

[3] R. Billinton, M. Fotuhi-Firuzabad and S.O. Faried, "Power System Reliability Enhancement using a Thyristor Controlled Series Capacitor," IEEE Transactions on Power Systems, Vol. 14, No. 1, February 1999, pp. 369-374.

[4] J.L. Batho, J.E. Hardy and N. Tolmunen, "Series Capacitor Installations in the B.C. Hydro 500 kV System," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-96, No. 6, November/ Decem ber 1977, pp. 1767.1776.

[5] "Increased Power Transmission Capacity on 500 kV Grid by Installation and Refurbishing of Series Capacitors," ABB online web site, [http://www05. abb.com/global/s cot/scot221.nsf/veritydis play/ 7f8d670d8379cc50c1256fda003b4d0a/$File/McLeese%20A02-0159E.pdf].

[6] D.N. Kosterev, C.W. Taylor, W.A. Mittelstadt, "Model Validation for the August 10, 1996 WSCC System Outage," IEEE Transactions on Power Systems, Vol. 14, No. 3, August 1999, pp. 967-979.

[7] R. Witzmann, "Damping of Interarea Oscillations in Large Interconnected Power Systems," Proceedings of the International Conference on Power Systems Transients (IPST01), Rio de Janeiro, Brazil, June 24-28, 2001, paper No. 197.

[8] Y.H. Song and A.T. Johns, Flexible AC Transmission Systems (FACTS), London, Institution of Electrical Engineers, 1999.

[9] N.G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, New York, IEEE Press, 2000.

[10] F.A.R. Al Jowder, B.T. Ooi, “Series Compensation of Radial Power System by a Combination of SSSC and Dielectric Capacitors,” IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005, pp. 458-465.

[11] M. Poshtan, B.N. Singh, P. Rastgoufard, “A Nonlinear Control Method for SSSC to Improve Power System Stability,” Proceedings of the International Conference on Power Electronics, Drives and Energy Systems 2006 (PEDES ‟06), December 12 - 15, 2006, New Delhi, India.

[12] G.N. Pillai, A. Ghosh, A. Joshi, “Torsional Interaction Studies on a Power System Compensated by SSSC and Fixed Capacitor,” IEEE Transactions on Power Delivery, Vol. 18, No. 3, July 2003, pp. 988-993.