International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 7, July - 2014

Analysis of Power System Oscillation Damping & Voltage Stability Improvement Using SSSC in A Multimachine System

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***Abstract*—Now a day's most of the power systems controlling techniques are likely to depend on the rapidly acting power electronic based FACTS Controllers. This paper describes a appropriate move towards the compensation of the active and reactive power and also to damp out the oscillations in power system using Static Synchronous Series Compensator. The test system under consideration is simulated by using MATLAB/SIMULINK software. The power oscillation has been documented as one of the key problem in power system operation. This paper emphasis on the power oscillation damping using static synchronous series compensator (SSSC) based damping controllers. The results of the test system, show that the projected SSSC based POD enhances the performance of the power system at the time of a major disturbance.**

Keywords—Facts Controllers; Static Synchronous Series Compensator (SSSC); Power Oscillation Damper (POD); Voltage Source Converter (VSC)

I. INTRODUCTION

For increasing the power flow capability of the transmission lines a new approach named Flexible A.C Transmission system has been introduced in last few years. This new technology has advanced power electronics based controller. The objective of the transmission lines is to meet the requirement of utility while maintaining the power systems security and reliability. Now a day almost all the power systems of the world are interconnected. Due to unavailability to meet the power demand causes the variation in power systems parameter such as voltage profile further which disturb the stability of the system.

For eliminating the electromechanical oscillations power systems stabilizers are used up to some extent. Power electronics based FACTS controllers damp out the oscillations with high speed and thus enhances the stability of the system. The advantage of FACTS device is to give rise to a new family of power electronics based equipment for controlling and improving the dynamic performance of the system [1].

Hingorani as the pioneer has put forward FACTS and aimed to transport the control technology based on thyristors into the A.C system [2].FACTS technology is a modern power electronics based application utilized at important locations of transmission line for controlling and adjusting the key parameters of the transmission line for enhancing the power flow capability.

This recent advance technology comprises of reliable and fast acting power electronics switches such as GTO, IGBT etc in place of mechanically controlled devices. The heart of the FACTS is thyristors: small, high voltage, semiconductor based device that can switch electricity at megawatts level with in milliseconds [3].Among various FACTS devices SSSC plays a very vital role to active, reactive and voltage support. Due to high nonlinear characteristics of power system, the major operating parameter changes continuously. The power systems must able to with stand all these variations. Due to such characteristics of the power system the oscillations lasts for few seconds (3-20 sec.) after a severe fault [4]. It makes very important to damp out these oscillations as soon as possible. These unnecessary oscillations may cause mechanical wear in power plant and several power quality disturbances for improving the voltage stability and damp out the power oscillations. Some control strategy has to be implemented with existing devices. Therefore in this perspective, a POD controller has been implemented in contrast with SSSC for improving voltage profile and damping power oscillations due to power system disturbances.

II. THEORETICAL BACKGROUND

Static Synchronous Series Compensator is a series-connected converter type FACTS device. It injects a controllable voltage in series with a transmission line at the fundamental frequency by using a solid-state voltage source converter with a coupling transformer. 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 [3]. These reactive and resistive compensations influence the power flow in the transmission line.

The SSSC-based series compensating device, called Static Synchronous Series Compensator (SSSC) was proposed by Gyugyi in 1989 within the concept of using converter-based technology uniformly for shunt and series compensation as well as for transmission angle control [1]. The concept of using the SSSC for series reactive compensation is based on the fact that SSSC injects an AC voltage with the controllable magnitude and angle into the transmission line by being independent of the line current so it can rapidly change the effective reactance between the two ends of the transmission line and the power flow, whereas the compensating voltage is dependent on the line current in the series capacitor compensation case.

In the case of series capacitor compensation, the output voltage lags line current by 90 degrees. However, the output voltage of the SSSC can be reversed by a simple control action to make it lead or lag the line current by 90 degrees.

A generalized expression for the injected voltage, ***VSSSC***, can simply be written as [1, 3]

$$V_{svs} = \pm jV_{svs}(\zeta)\frac{I}{I} \qquad (1)$$

Where V_{SSSC} (ζ) is the magnitude of the injected compensating voltage by SSSC ($0 \le V_{SSSC}(\zeta) \le V_{SSSC\text{-}max}$), ζ is a chosen control parameter, and ***I*** is the line current. The series reactive compensation scheme, using a switching power converter (voltage-sourced converter) as a synchronous voltage source to produce a controllable voltage in quadrature with the line current as defined by Equation (1).

Equation (1) can be re-written for the SSSC as

$$V_{SSSC} = \pm jV_{SSSC}(\zeta)\frac{I}{I} \qquad (2)$$

Figure 1 illustrates the different operating modes at steady-state for an SSSC installed in the simple two-machine power system model of Figure 1(a). The no compensation mode of operation of the SSSC (Vsssc=0) is shown in Figure 1(b).

The capacitive compensation mode is shown in Figure 1(c) where, as a result of the SSSC injected voltage $V_{SSSC} = \pm jV_{SSSC}(\zeta)\frac{I}{I}$, the effective inductive reactance between the two buses is decreased and the line current is increased. This results in increasing the transmitted power. Figure 1 (d) shows the SSSC inductive mode of operation where the transmitted power is decreased due to the injection of $V_{SSSC} = \pm jV_{SSSC}(\zeta)\frac{I}{I}$.

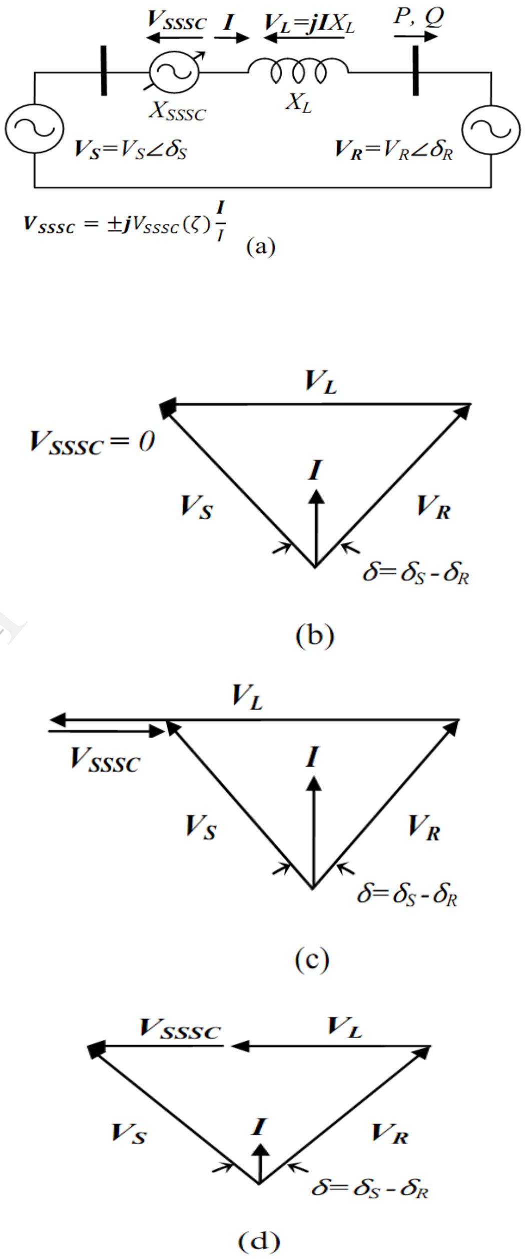
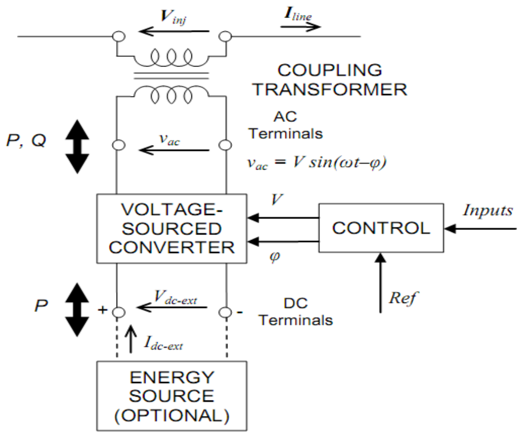


Figure 1(a) SSSC operating modes in a two- machine power system and the phasor diagram (b) no compensation (c) capacitive compensation (d) inductive compensation

Since the SSSC injects the variable compensating voltage in series by controlling the magnitude of the voltage, irrespective of the line current, the transmitted power P versus the load angle δ becomes a parametric function of the injected voltage, V_{SSSC} (ζ), and it can be expressed for a two-machine system as follows.

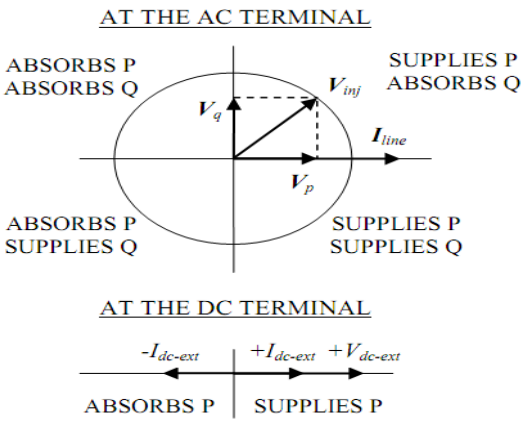
$$P = \frac{V^2}{X_L} Sin\delta + \frac{V}{X_L} V_{SSSC}(\zeta) Cos\frac{\delta}{2} \qquad (3)$$

Figure 2 shows a functional representation of a SSSC (series-connected here) which is composed of the voltage-sourced converter (VSC), a coupling transformer, an optional energy source and the control device. The references (the desired compensating reactive power $Q_{ref.}$ and active power $P_{ref.}$ or the desired compensating reactive impedance X_{ref} and resistance R_{ref} define the amplitude V and phase angle φ of the generated output voltage necessary to exchange the desired reactive and active power at the ac output. If the SSSC is operated for only reactive power exchange (real power exchange is not required), then P_{ref} (or R_{ref}) is set to zero and the SSSC becomes a self-sufficient reactive power source like an ideal synchronous condenser and the optional external energy source or storage equipment is removed [3].



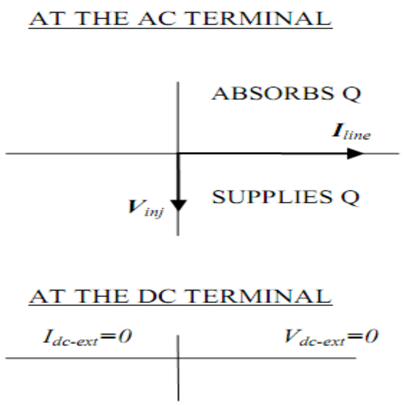
Figure

2Functional representation of the SSSC



(a)

All the potential operating modes



(b)

Figure 3 Possible steady-state operating modes and power exchange diagrams for the SSSC.

the control device. The desired compensating reactive power Qref and active power Pref or the desired compensating reactive impedance *Xref* and resistance R_{ref} define the amplitude V and phase angle φ of the generated output voltage necessary to exchange the desired reactive and active power at the ac output. If the SSSC is operated for only reactive power exchange (real power exchange is not required), then P_{ref} (or R_{ref}) is set to zero and the SSSC becomes a self-sufficient reactive power source like an ideal synchronous condenser and the optional external energy source or storage equipment is removed [3]. All the potential operating modes of the SSSC at the steady-state are shown in Figure 3(a). It operates mainly to supply only reactive output power (capacitive compensation), hence, the optional external energy source device is replaced a fixed capacitor to supply the compensating reactive power and the external dc current becomes zero as shown Figure 3(b). Here, it is assumed that all SSSC losses are neglected, therefore, V_{inj} is lagging the line current by 90 degrees. In practice, it is lagged a bit further to replenish its losses and keep the capacitor voltage at the desired constant level. In that case, the SSSC absorbs a small amount of active power from the transmission system.

III. STRUCTURE OF SSSC-BASED DAMPING CONTROLLER

One of the structures used in this paper to modulate the SSSC injected voltage is the lead-lag structure as shown in fig.4. This structure consists of a gain block, washout block and two stage lead-lag blocks. The two stage lead-lag block provide appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. The washout block behaves as a high pass filter to allow signals associated with oscillations to pass as it is. The inputs to the POD controller are the bus voltage at Bus no.2 and the current flowing in Line 1.The Power Oscillation Damping Controller takes input as V_{abc} , I_{abc} &

it convert it as power. If no faults has occurred then switch will remains open. But when fault occurred then switch is closed & after filtering or damp out oscillation, it also gives an error signal and finally two error signal has been added & this is V_{qref}.

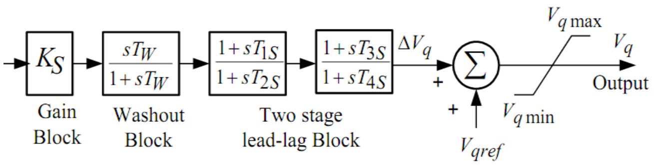


Figure 4 POD controller design structure

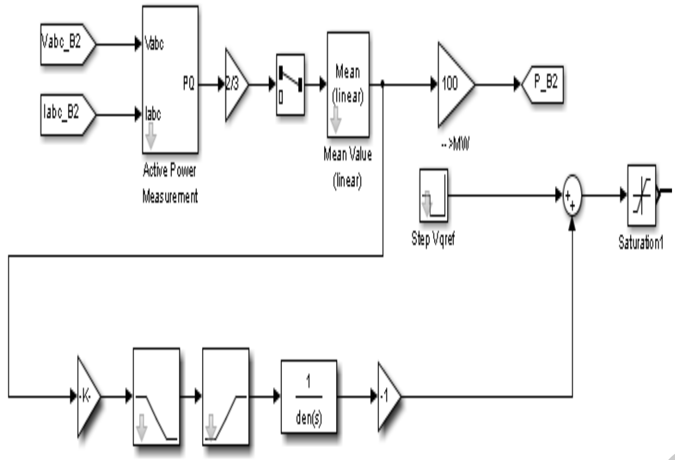


Figure 5 Simulink Model of POD controller

IV. TEST SYSTEM DESCRIPTION

The power system under consideration comprises of 4 buses. It consists of two interconnected generating stations and one major load centre 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.A three phase fault is applied at Bus no. 4

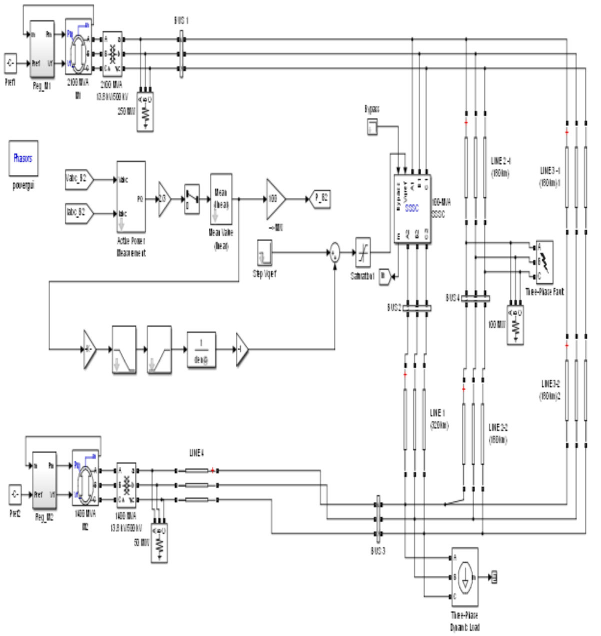


Figure 6 Simulink model of SSSC used for power oscillation damping

V. RESULTS

The results discussed in this section are obtained from MATLAB/Simulink software. The simulation results are obtained for three cases.

Case 1: Power flow under normal conditions (when pod is off, SSSC is by passed and no fault is applied)

In case 1 SSSC is bypassed from the power system. Under normal condition active power, reactive power, voltage profile is shown here.

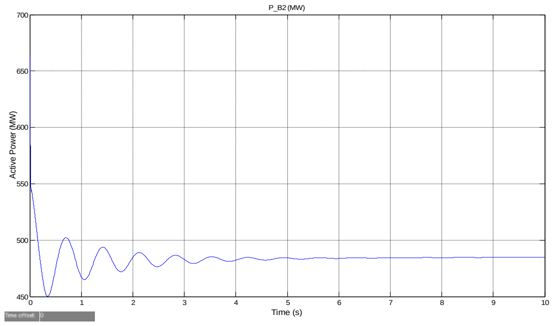


Figure 7Active Power at Bus 2 under normal condition for case 1

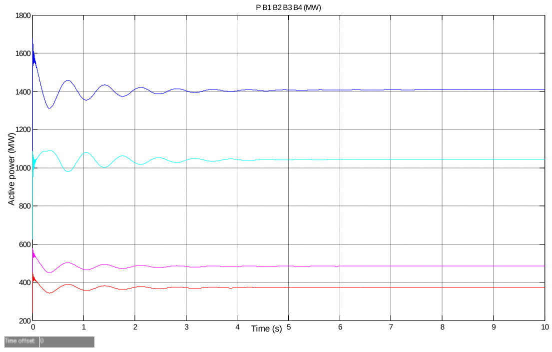


Figure 8Active Power at all buses for case 1

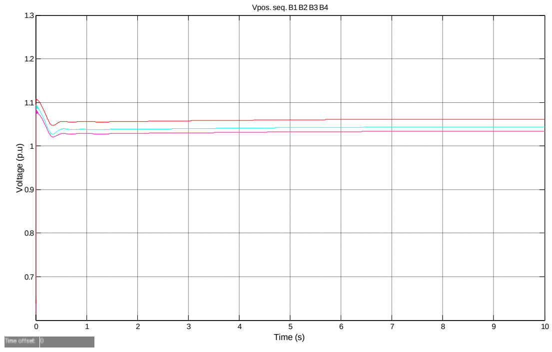


Figure 9 Positive sequence voltages at all Busesfor case 1

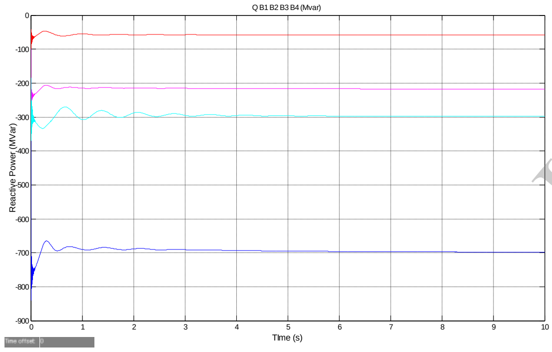


Figure10 Reactive power at all buses for case1

Case 2. SSSC under a three phase fault when POD is off

In case 2 initially V_{qref} is set to zero. At 2 sec. it is set to -0.08pu which makes SSSC to operate in inductive mode. At 6 sec. V_{qref} is set to 0.08 pu which operates SSSC in capacitive mode. A three phase fault is applied at Bus no. 4 at 0.33 sec. which lasts for 10 cycles. Figure 11 shows the power oscillations. The inductive and capacitive mode of operation can be observed easily.

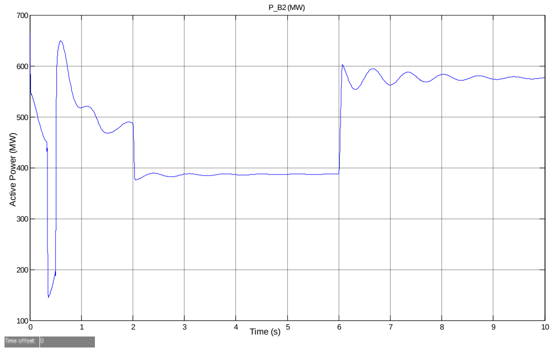


Figure 11 Active power at Bus 2 for case 2

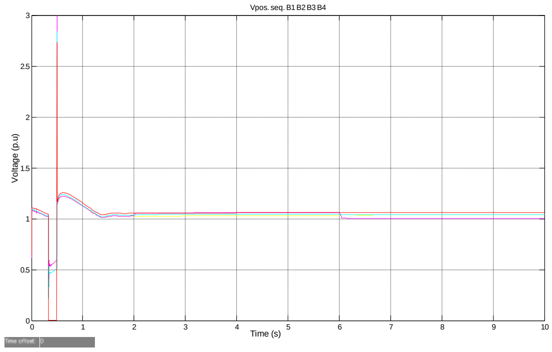


Figure 12 Positive Sequence voltages at all buses for case 2

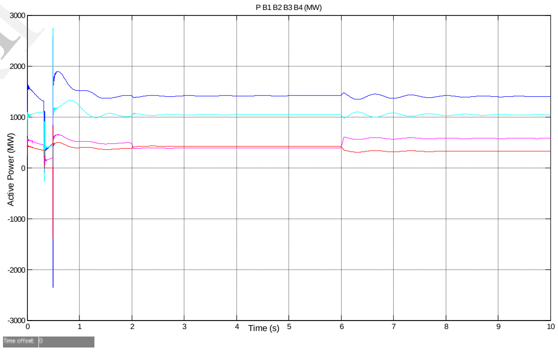


Figure 13 Active power at all buses for case 2

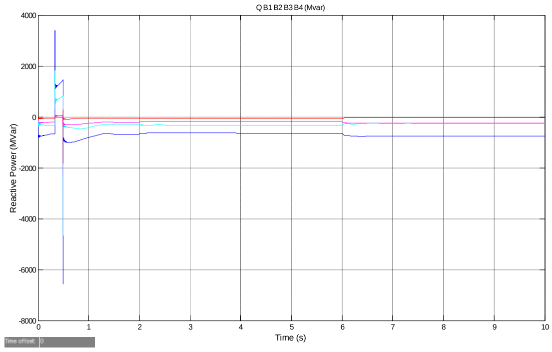


Figure14Reactive power at all buses for case2

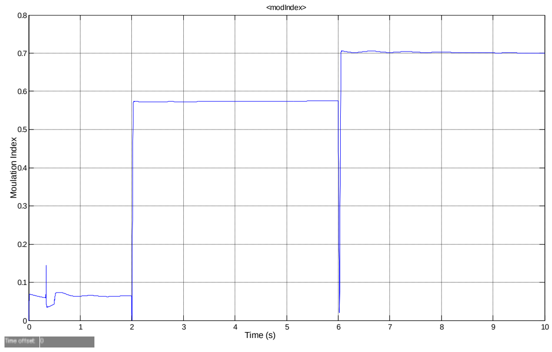


Figure 15 Modulation index for case 2

Case 3.Test system with SSSC under a three phase fault and POD is on

A three phase fault is applied at bus no. 4 at time t=0.33 sec. figure 16 clearly shows that the power oscillations damp out quickly. The injected voltage V_{inj} follows the reference voltage V_{qref} as shown in figure 17. Active power and reactive power under such condition is shown in figure 18 and 19 respectively and modulation index for this case is shown in figure 20.

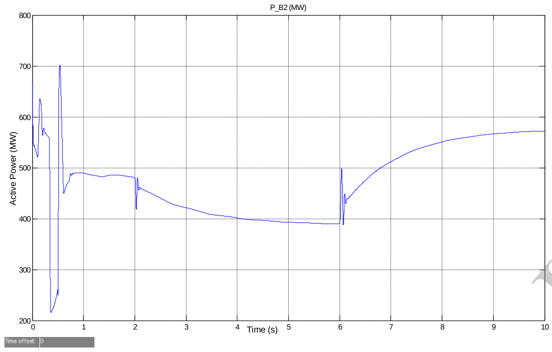


Figure 16Active power at bus 2 for case 3

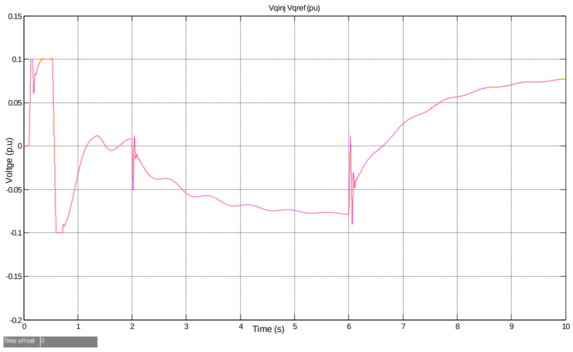


Figure 17SSSC dynamic response for voltage at three phase fault (V_{qref} and V_{qinj}) for case 3

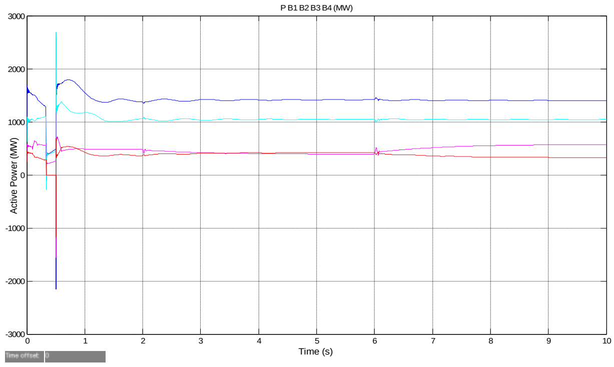


Figure 18 Active power at all buses for case 3

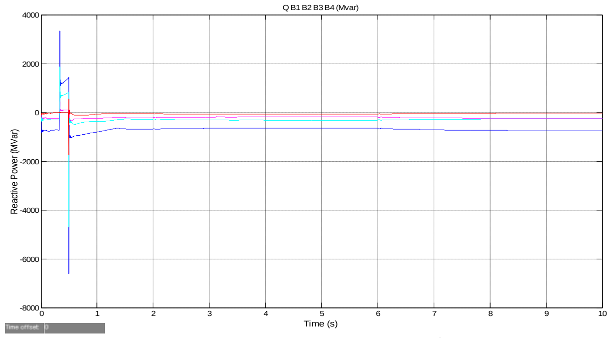


Figure 19 Reactive power at all buses for case3

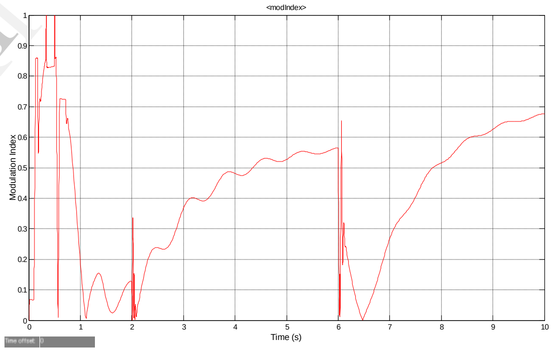


Figure 20 Modulation index for case 3

VI. CONCLUSION

This paper analyse the performance of a SSSC in a multi machine system in the presence of a three-phase short circuit fault is considered. The results illustrate that the power system oscillations are damped out very rapidly with the help of SSSC based damping controllers in few seconds. The study reveals that SSSC is proficient to enhance the power flow through the transmission line by injecting a fast changing voltage in series with the line. The injected voltage is in quadrature along with line current and hence it can provide both inductive and capacitive compensation.

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