Damping Power system Oscillation using Static Synchronous Series Compensator (SSSC)

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Abstract - *In today's interconnected power system network power oscillation is a major source of concern for power utilities due to its negative impact on power system stability and reliability. This paper discusses the basic operating principle and application of Static Synchronous Series Compensator (SSSC). SSSC is FACTS family device which is effectively utilized for power flow control in the power system. In this paper a SSSC-based power oscillation damping (POD) controller is proposed for transient stability enhancement and to eliminate the power oscillation damping in power system. A Multi machine Multi bus system with SSSC is simulated in MATLAB/Simulink software. Simulation results show the effectiveness of this controller for power system stability enhancement under different fault conditions.*

***Key Words*: Static Synchronous Series Compensator (SSSC), Power Oscillation Damper (POD) Controllers, FACTS Device, Active and Reactive Power flow, transient stability.**

1. INTRODUCTION

In today's interconnected power system network Power oscillation has become a major source of concern for electrical and control engineers. . Due to high non linear characteristics of modern power system, the major operating parameter changes continuously. Unwanted power differences through the transmission lines and increasing the load over the transmission lines also result in power oscillation in the system. 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. It becomes very important to damp out these oscillations as soon as possible. These unnecessary oscillations may cause mechanical wear in power plant and create several power quality disturbances and power system stability problems.

The advent of FACTS systems is giving rise to a new family of power electronic equipment for controlling and optimizing the dynamic performance of power system [1-2]. In recent years flexible ac transmission system (FACTS) devices equipped with a power oscillation damper (POD) have been in demand for efficiently damping power oscillations [3-6]. Generally, there are two kinds of power oscillation damping controllers in power systems: power system stabilizer (PSS) which is used for eliminating the electromechanical oscillations and Power electronics based FACTS controllers i.e. FACTS POD controllers [10-12].

Power electronics based FACTS controllers damp out the oscillations with high speed and thus enhances the stability of the system. FACTS devices operate by increasing or reducing voltage, supplying or absorbing reactive power and controlling the series impedance of transmission lines or phase angle [13-15]. FACTS controller can be classified in four main categories [3-4]: shunt controller, series controller, series-series controller and series-shunt controller [5-6]. Series connected FACTS devices can directly control active power flow control by changing its line reactance. TCSC, GCSC, SSSC are the series FACTS devices.

Among various FACTS devices Static Synchronous Series Compensator (SSSC) plays a very vital role in active, reactive and voltage control. Application of SSSC for rotor angle stability, voltage stability, power flow control and power system oscillation damping is found in several reference papers [7-10]. The output voltage from the FACTS device is in quadrature to the line current. The purpose of this series controller is to increase or decrease the overall reactance of the transmission line in order to control the reactive voltage drop across the line and thereby controlling the transmission line electric power.

Most of the available literatures pertaining to SSSC basically discuss either about its operation, its control or structure (in terms of VSC) as a whole but very few of them clearly highlight the dynamic role of this series device in mitigation of power transients (with suitable controller) and facilitating real/reactive power compensation simultaneously to stabilize the system [11-13].

Hence SSSC-based power oscillation damping controller design is proposed in this paper and an effort has been made to analyze the dynamic behavior of a SSSC compensated 2 machine, 4 bus power system with and without effective controller for power oscillation damping when it is subject to different disturbances as well as to introspect the impact of SSSC on overall system stability of the power system.

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 1.

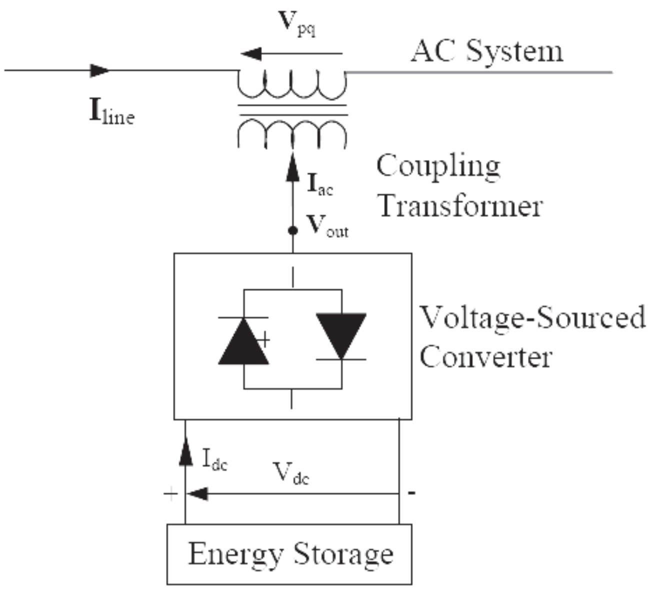


Fig -1: Static Synchronous Series Compensator (SSSC)

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].

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. 2 is proposed as a SSSC-based damping controller to control the injected voltage V_{qinj} 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 T_1, T_2, T_3 and T_4) provide suitable phase-lead characteristics to compensate for the phase lag between input and the output signals.

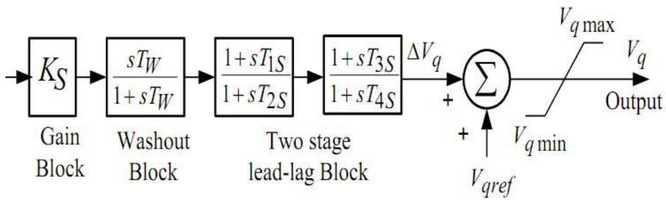


Fig- 2: Design Structure of POD controller

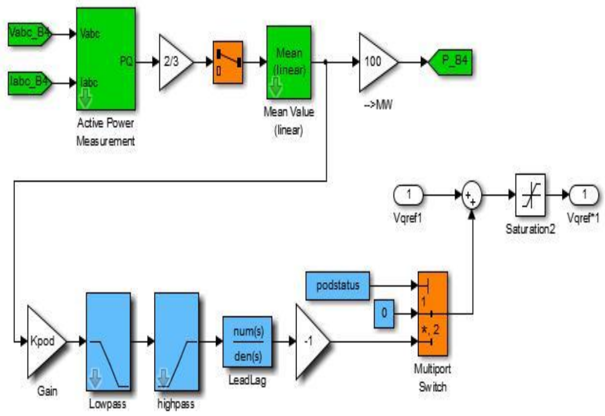


Fig.-3: Simulink Model of POD controller

Vqref is the desired reference value of the compensation voltage to be injected in transmission line under steady state condition. Resultant effective value of compensation voltage Vq is obtained by adding the modulated voltage (ΔVq) to the Vqref. This Vq output signal from controller is given to the SSSC internal control System.

$$Vq = Vqref + \Delta Vq.$$

The washout block acts as a high pass filter with the time constant Tώ to allow signals related with oscillations to pass as it is.The inputs to the POD controller are the voltage at Bus no.4 and the current flowing in Line 2.The Power Oscillation Damping Controller takes input as Vabc , Iabc & it convert it as power. If no faults has happen then switch will remains open. But the switch is closed when fault happen. After filtering or damp out oscillation, it also gives an error signal and finally two error signal has been added, this is Vqref.

4. 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..

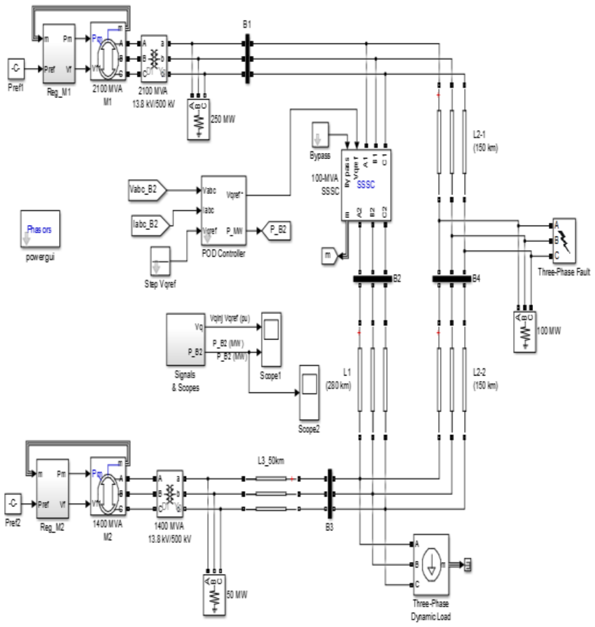


Fig -4: Simulink model of SSSC used for power oscillation damping controller

5. 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

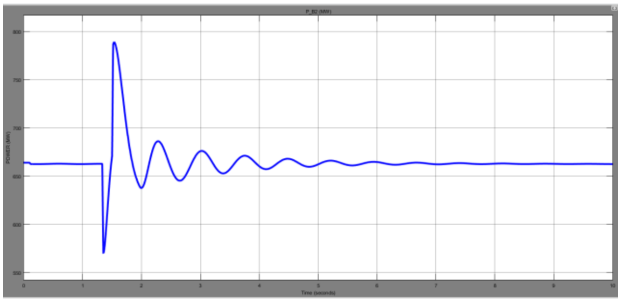


Fig 5: Response of active power at bus-2

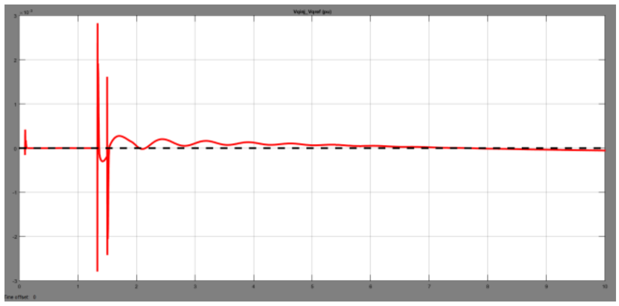


Fig 6: Vqref. And Vqinj for LG Fault

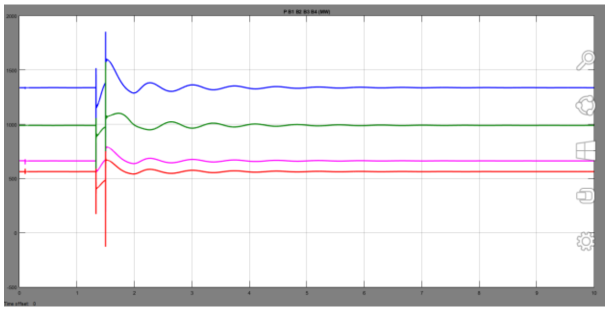


Fig 7: Active Power at all the buses

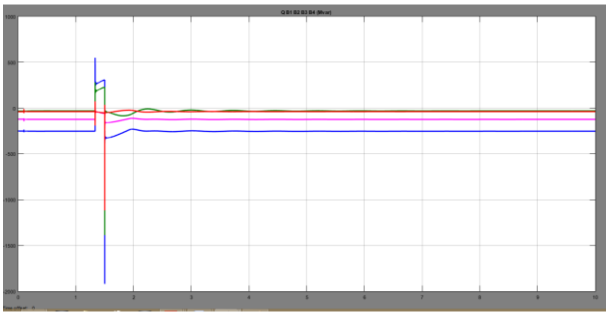


Fig 8: Reactive Power at all the buses

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

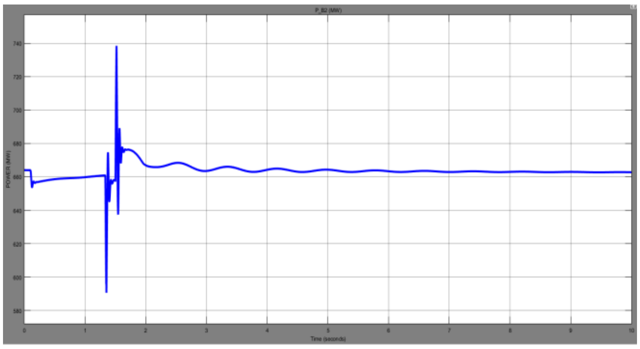


Fig 9: Response of active power at bus-2

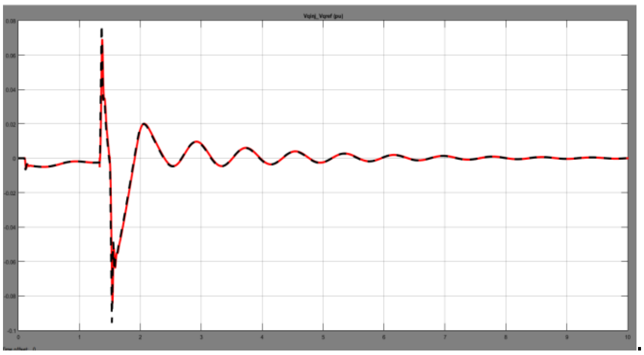
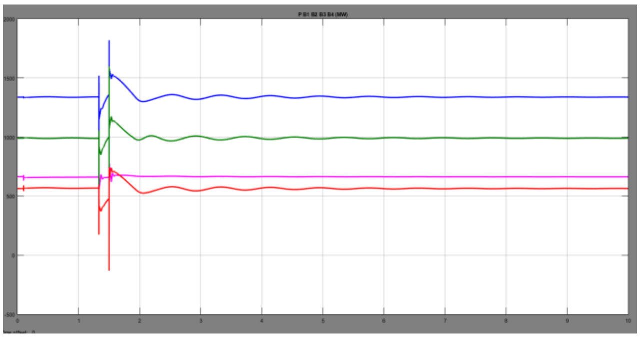


Fig 10: Vqref. And Vqinj



. **Fig 11**: Active Power at all the buses

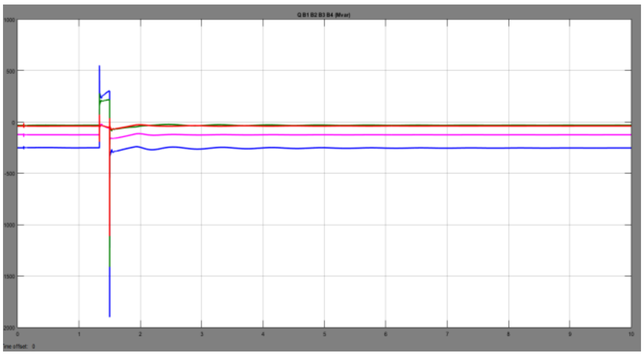


Fig 12: Reactive Power at all the buses

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

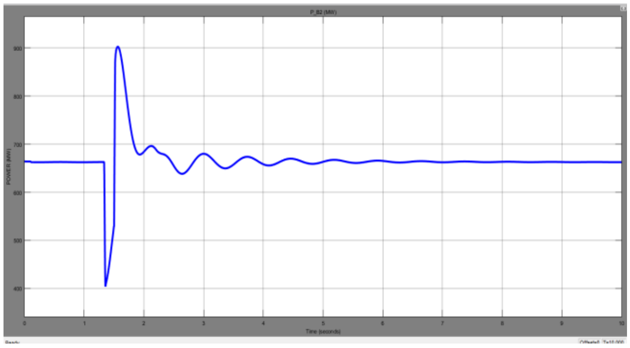


Fig 13: Response of active power at bus-2

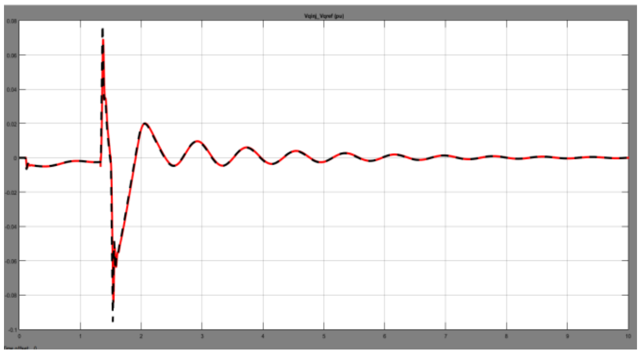


Fig 14: Vqref. And Vqinj

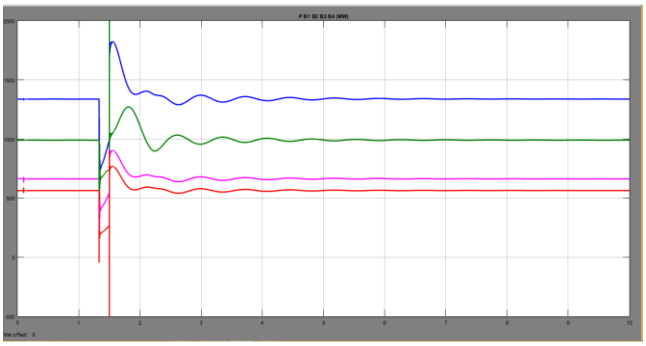


Fig 15: Active Power at all the buses

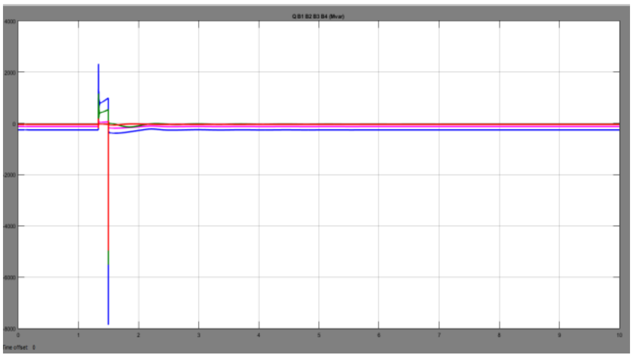


Fig 16: Reactive Power at all the buses

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

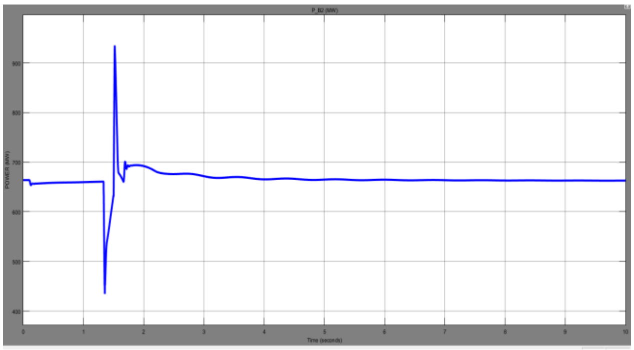


Fig 17:Active Power on bus B-2

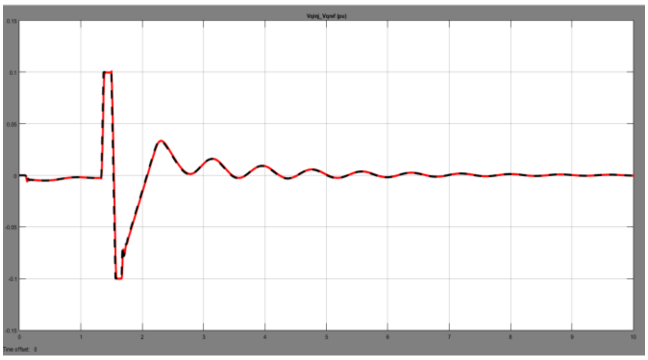


Fig 18: Vqref. And Vqinj

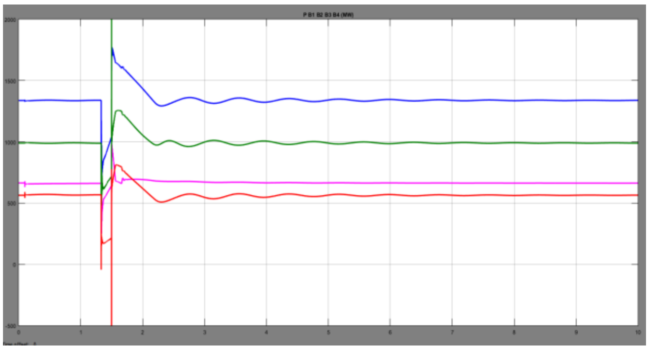


Fig 19: Active Power at all the buses

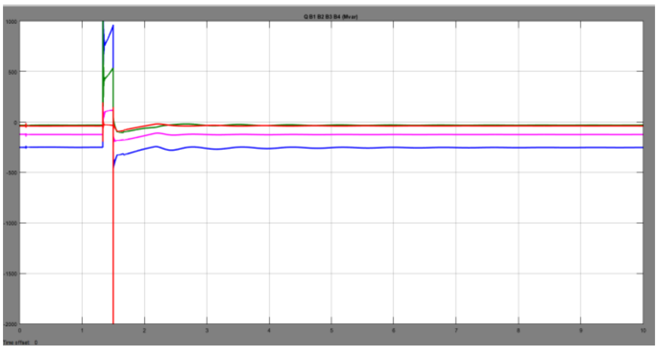


Fig 20: Reactive Power at all the buses

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 9 and Fig 17 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.

6. CONCLUSIONS

In this paper simulation and performance analysis of two machine four bus power system with and without SSSC based Power oscillation Damping (POD) controller under various unsymmetrical faults is considered. The output results illustrate that the settling time for power system oscillations are reduced by considerable amount. The result also shows that SSSC is proficient in maintaining desired power flow on all the buses by injecting a fast changing voltage in series with the transmission line under various contingency conditions.

In future proposed Power System Controller can be applied for any interconnected multi-machine power system network for stability improvement. The proposed controller can be applied to another FACTS devices namely STATCOM, UPFC whose controllers may be controlled externally by designing different types of controllers which also may be tuned by using different algorithm i.e. Fuzzy logic, ANN, Genetic algorithm, FSO etc. for both transient and steady state stability improvement of a power system.

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