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Stability Improvement and Power Oscillation Damping Using Static Synchronous Series Compensator (SSSC)

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ABSTRACT: This paper investigates the problem of power flow control in a transmission line with the help of Static Synchronous Series Compensator (SSSC). Because of the enormous demand on power system has initiated the system to load heavily leading to voltage unbalance conditions. The static synchronous series compensator (SSSC) is capable of delivering a compensating voltage with an inductive and capacitive range. The complete simulation is done in the MATLAB/Simulink background. Simulation results confirm that the voltage and power oscillations can be damped well using Static Synchronous series Compensator (SSSC) with a PI controller under fault conditions. The transient mode is created by L-G fault. In order to tune the circuit and also to provide zero steady state error PI Controller is used here.

KEYWORDS: Flexible AC Transmission System (FACTS), Active and Reactive powers Static Synchronous Series Compensator (SSSC), Voltage Stabilization, and MATLAB/Simulink.

I. INTRODUCTION

Nowadays, the utility of deregulation has been increased due to the expectation of fast power flow control in the transmission networks. We can also increase the utilization degree to efficiently operate the power transmission system. The effective resistance can be decreased with the help of series compensation and also it is used to reduce transmission capacity. Considering the stability conditions the long transmission power transfer capability is limited. Since the FACTS devices are more advantageous in controlling the power in the transmission lines. Because of the presence of the FACTS controller the power system stability has been improved under different fault conditions [1].

The stability, performance can be improved using the static synchronous series compensator (SSSC), one of the types of FACTS controllers is examined in this paper. A Static Synchronous Series Compensator (SSSC) is a series controller of FACTS family is connected in series with the transmission lines. The SSSC controller mainly depends on the output amplitude of voltage source converter (VSC) [12] with several semiconductor, switches or thyristor switches. The SSSC circuit model has a voltage source converter (VSC), DC capacitor and a coupling transformer. Coupling transformer is connected in series with power system which couples the SSSC with the transmission line. The convention made design configuration is nothing but more number of VSCs are connected together through a transformer. The transformer valves and its configuration depend mainly on the SSSC's AC output waveform. The line side transformer winding allows the series compensation of the line. The SSSC is considered as power flow controller of transmission lines for the power transfer from or to the lines. If the losses are neglected SSSC produces an AC voltage with different magnitudes in quadrature with line current. There can be a capacitive reactance or an inductive reactance depending upon the injected voltage so that the line resistance of the total transmission line and power flow will increase or decrease [2] [3]. Normally the SSSC which is seen as voltage source is capable to produce a three phase AC voltage at the fundamental frequency with different phase angle and magnitude. Working of synchronous compensator is also same as SSSC but the only difference is that the synchronous compensator can generate or absorb real power; here SSSC can generate or absorb reactive power if a DC capacitor is used. The small SSSC capacitor is used to reduce the switching losses and also neglect the real power since SSSC is allowed only for reactive power

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exchange with the power system. Real power can also be exchanged with power system if the energy storage system is used instead of DC capacitor.

II. RELATED WORK

- Prashant Dhoble introduces a control scheme of SSSC and operating modes to maintain the voltage magnitude, phase angle and line impedance of power transmission system
- Sen.K.K. proves that the SSSC is capable to control power flow in a transmission line at a desired point under three phase fault with PI controller[2]
- A.Teheri compares the outputs of twelve pulse and PWM controlled SSSC control circuits to provide the voltage stability and also to damp power oscillations and shows that both the techniques has some merits and demerits while designing the process
- R. Mihalic proves that the SSSC control system based on mathematical models of d-q reference frame enables the operation of the device in reverse flow of power

III. SERIES COMPENSATION

The power transmission capacity can be improved by series compensation method in the transmission lines [4], [5], [6]. VAR compensation is of series type. The transmission line resistance at fundamental frequency will be reduced in series compensation system because of the capacitors. The line transfer resistance is balanced with the usage of series capacitor which in turn produces the reactive power. The result is improved in the power transmission system with voltage stability, power angle stability improvement, optimized parallel circuits power sharing.

Fig.1. and Fig.2 shows that the Series compensation can be used as voltage source or current source devices like a shunt. The unity power factor at E_2 [6] is achieved from the series compensation results through an adjustment of the voltage source. In the series compensation the angle of load side voltage E_2 is changed by adding the V_{COMP} voltagebetween the line and the load. In Fig.2 since the V_{COMP} voltage lags I_p [6] the voltage is generated in opposite direction by the V_{COMP} voltage which produces the voltage drop in the line inductance. As shown in phasor that the V_{COMP}voltage is suitably adjusted to attain a unity power factor this will again reach at E2

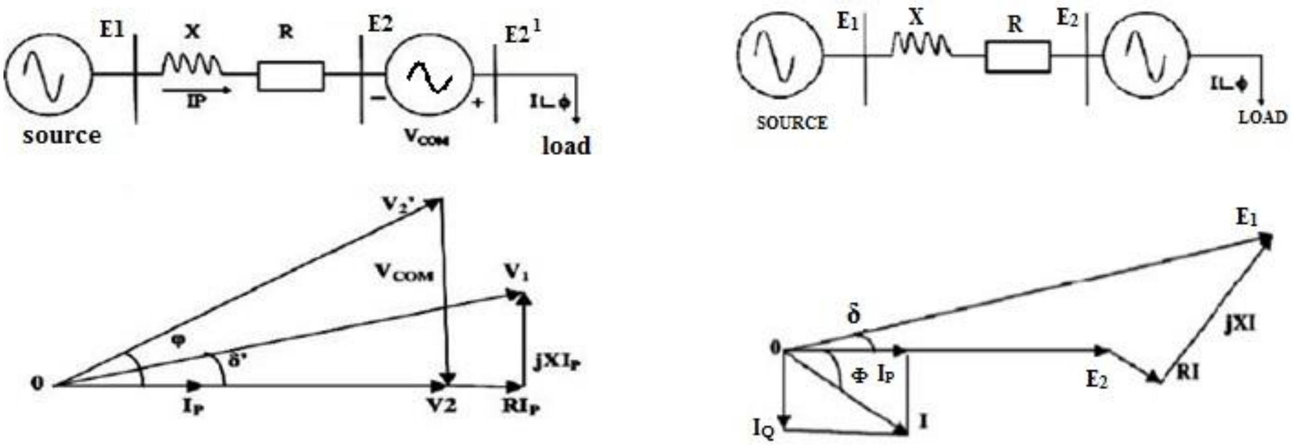

Fig.1.Without compensation in a powersystemFig. 2. Series compensation principles with voltage source

The following benefits are provided by Series compensation,

- Reduces line voltage drop
- Increases system stability
- Limit load- dependent voltage drops
- Transfer capability improvement
- Transmission angle will be reduced

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IV. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

Electric power utilization can be improved with consistency, stability, minimizing power loss and security even though the electric power systems are more complex nowadays. So the new concepts are needed for the efficient use of power system resources by not reducing the stability problems. Flexible AC Transmission System (FACTS) is the well-known concept which is more needed [4] [7]. The FACTS devices have main purposes of power flow regulation, power loss reduction, power oscillation damping, cost reduction and transmission routes power flow control [8]. The of FACTS devices has many advantages that are listed below,

- Control of Power flow
- Rise of transmission capability
- Increase the loading capability
- Reactive power compensation with controllers
- System security
- Provides greater flexibility
- The problem of voltage fluctuation and flickers can be reduced
- Reduce the reactive power flows and loop flow [9]
- Prevention of cascading outages by contributing to emergency control [10]

V. BASIC OPERATING PRINCIPLES OF SSSC

Fig.3. Shows the functional model of SSSC which includes an energy storage device as a DC capacitor in order to allow power exchanges like real or reactive power with the power system network. The injected voltage is in quadrature with line current since the real power source is not used by SSSC. The SSSC's operation either as capacitive reactance or inductive reactance compensator depends upon the magnitude of injected voltage. Coupling transformer which couples SSSC to the transmission network is connected to a Voltage-Sourced Converter (VSC) whose amplitude can be varied. The voltage Vpq is produced from a DC voltage source when the VSC uses the power electronic devices.

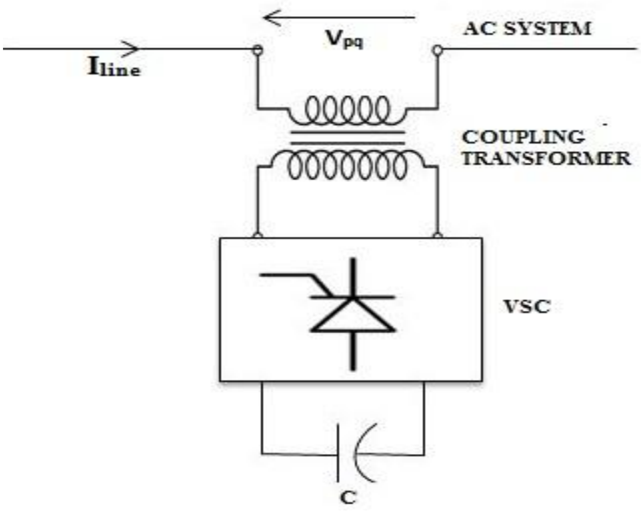

Fig. 3. Functional model of SSSC

If there is an increase in the amplitude of VSC, then the power flows from the FACTS controller to the power system so the system by generating the reactive power. If the amplitude of the VSC is reduced, then the current starts flowing from the alternating system to the SSSC and the absorption of power take place. The phase angle and VSC's magnitude can be changed to control the power flow in the transmission lines. The injected voltage and phase displacement plays a major role in permitting the real and reactive power exchanges with the power system.Four quadrant operation of SSSC is possible, assuming a DC capacitor connected across the voltage source converter that is shown in the Fig.4.

The reference phasor is chosen as line current phasor I_{line}, the maximum inserted voltage Vmaxpq which is the SSSC's injected voltage phasor rotated about an axis of the circle. Because of the operating constraints of the practical power system the injected voltage has some restrictions in the four quadrant operation of SSSC. Here the power flow can be increased or decreased depending upon the capacitive or inductive reactance.. In capacitive mode, the line current leads the SSSC injected voltage by 90^o; therefore the SSSC tends to operate like a series capacitor so the injected voltage will be $V_{pq} = - JKX_CI_{line}$ where k is a variable and kXc is the variable capacitance. Due to this the line currents and in voltage across the impedance so that this action will reduce the total transmission reactance as shown in Fig.5.The injected voltage can be reversed by 180^o, i.e., $-V_{pq}= JKX_CI_{line}$ here the line current and transmitted power will change because of increase in transmission line resistance.The above equation for V_{pq} shows the phasor magnitude variations which can be misleading to some extent; since the magnitude of line current and injected voltage magnitude are equal, but the inserted voltage magnitude is set to control the SSSC which is untrue in reality.

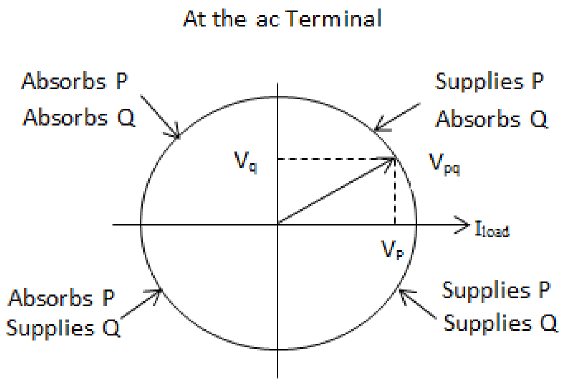

Fig. 4. SSSC phasor diagram

In Fig.5. If the losses of SSSC are assumed to zero the SSSC operate from the power system point of view is limited by the line current and SSSC injected voltage.The transmission line resistance, voltage drop is in phase with the inserted voltage in inductive mode. The power flow reverses if the voltage drop in the transmission line resistance is less than the injected SSSC voltage. The receiving end voltage will change if the SSSC controller evaluation is high. The current can be measured from maximum to minimum by controlling the output of voltage source converter so that the generation and absorption of reactive power is under control and leads to appropriate working of power system successfully and efficiently by improving the performance of the system. Line current also depends upon the levels of inductive and capacitive reactance compensation.

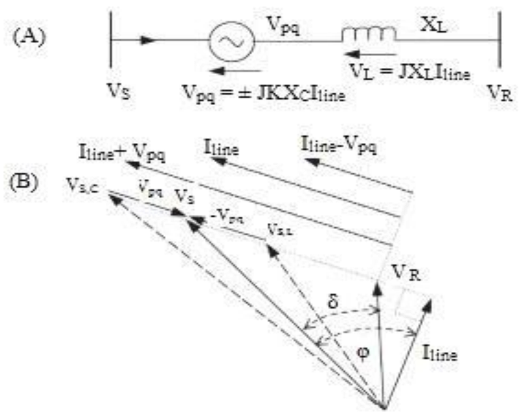

Fig. 5. Series compensation by a SSSC

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VI. SSSC CONTROL STRUCTURE

In SSSC control structure, SSSC operation is analogous to the series compensation since the system conditionsand also the loads determine the changes in injected voltage and current. According to the transient changes created in the power system the FACTS controller can be utilized. The transformer is connected to a voltage source converter and VSC has a DC capacitor in its other side. Here DC capacitor is assumed as an energy storage device. Depending upon the control circuit the SSSC works along with the transient change. The DC capacitor produces a voltage which is given as input to VSC and finally it converts the DC form to Ac form and then injects the AC voltage through the insertion transformer which injects voltage from SSSC to the line.For controlling the power flow, the voltage, current and reactive powers in d-q references are calculated and compared to produce the error signal. This error signal is given as input to the PI controllers. The main purpose of PI controller is to eliminate or reduce steady state error.

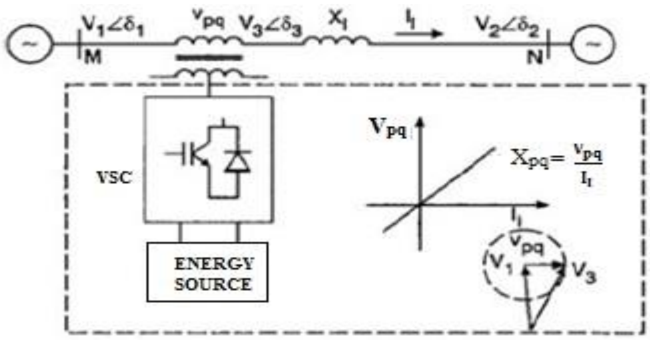

Fig.6. SSSC Control structure

Fig.6. Shows a SSSC control structure connected in series with the transmission line. The structure connects the source voltage 'Vs' and a load voltage source 'V_R'respectively [11]. On-off controller operation takes place with the use of PI controller. Since the PI controller will have relative stability and accurate tracking capacity. However, there is an adverse effect due to the integral mode in overall performance.

VII. TWO MACHINE MODEL OF SSSC

The two machine model has generation substations and one load. The generation substation (G1) has a rating of 2100 MVA and the other substation (G2) which has a rating of 1400 MVA. The transmission lines are used to connect the load and the machines. Simulation is performed under single phase fault in the transmission line applied across the selected bus.. The SSSC is situated near the bus B2, which is in series with the transmission line as shown in the figure Fig.7. In the simulation the power flow control is done by utilizing the SSSC in the transmission systems. The power system consists of 3 buses (B1, B2, B3) connected through the transmission lines L1, L2 separately.

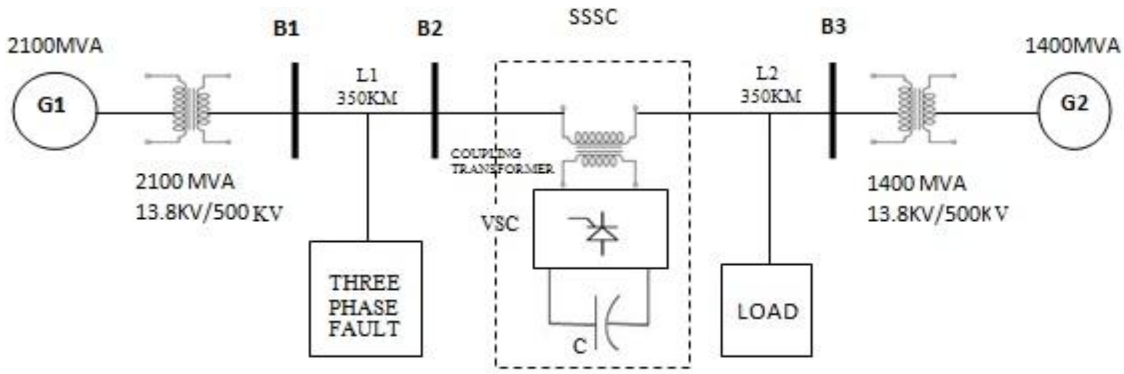

Fig. 7. Single line diagram of two machine power system

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VIII. SIMULATION RESULTS

Here the two machine power system and three buses have been simulated in the MATLAB Environment under single phase fault at bus 2 with and without SSSC. The line power, real power, reactive power and bus voltages have been obtained. The SSSC is a series controller connected to the transmission line and the results have been given in Table.1. Shows the voltage stability and line power, active power, reactive power of bus 2. An output comparative analysis is done with and without SSSC in the two machine system.

A. TWO MACHINE SYSTEMS WITHOUT SSSC

The two machine systems with three buses are connected using the transmission lines without SSSC. Here the transient mode is created by a single phase fault at the selected bus using the transition time which is set as follows [5 6]. The simulation results show the system performances like voltage, line power, active power and reactive power.

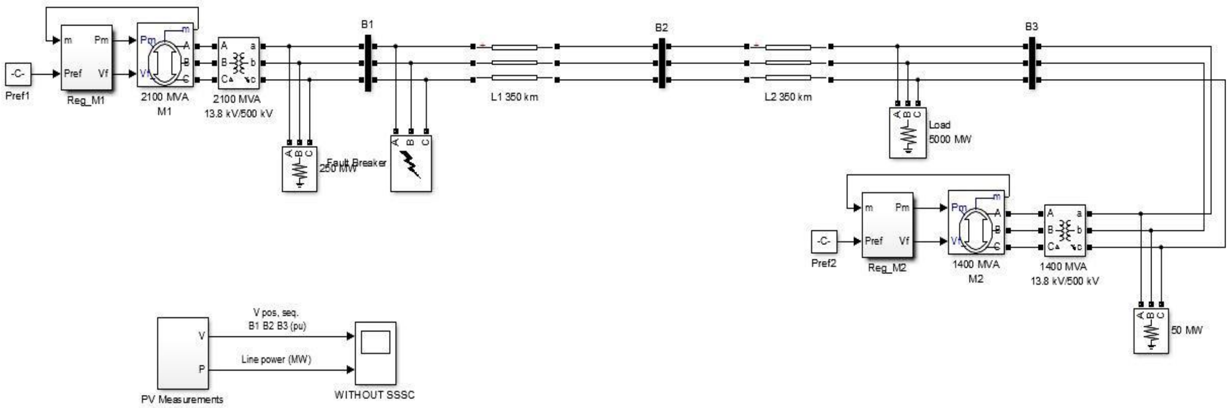

Fig. 8. Two machine systems without SSSC

In Fig.8. The simulation model is designed using MATLAB/SIMULINK software which has fault breaker. Fig. 9. Shows the voltage of the bus-2 becomes stable within 8s with some oscillations.

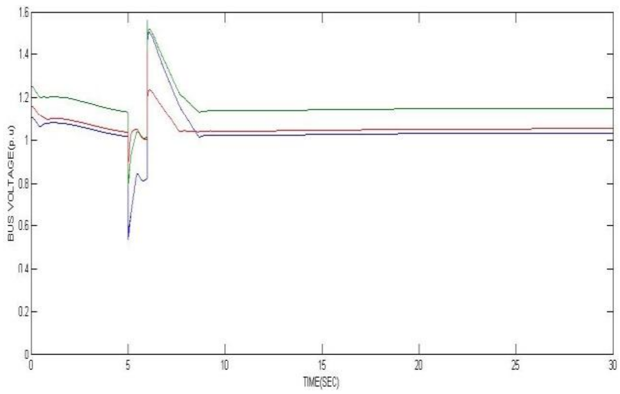

Fig. 9. Bus voltage without SSSC

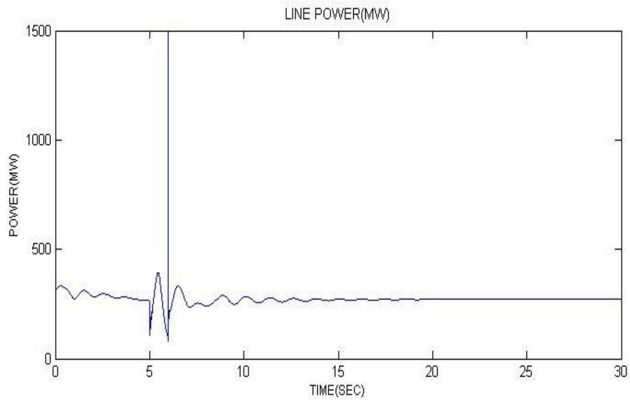

Fig. 10. Line power without SSSC

Fig. 10. Shows the line power it becomes stable within 20s. Fig.11. shows the active power for the systems which becomes stable within 15s with more positive oscillations. Fig. 12. Shows the reactive power of bus 2 which attains stability at 13s with more negative oscillations. From these results, we can come to the conclusion that large disturbances are produced due to the fault applied in the power system.

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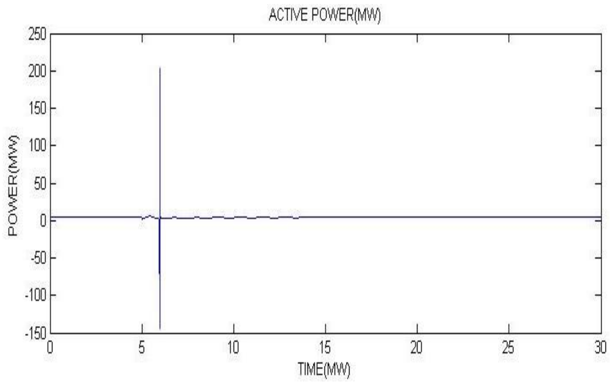


Fig. 11.Active power without SSSC

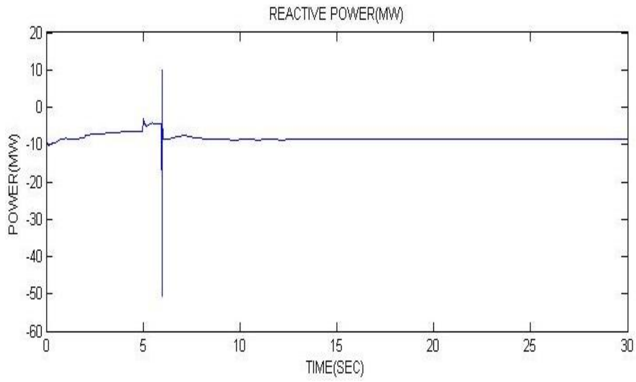


Fig. 12.Reactive power without SSSC

B. TWO MACHINE SYSTEMS WITH SSSC

In the Fig.13. The SSSC is used along with the two machine systems, three buses which are connected using the transmission lines. Here SSSC is installed between bus-1 and bus-2 and the single phase fault is created which is applied at bus 2 using the transition time is set as follows [5 6]. With the help of obtaining simulation results, the system performances has been attained and compared with the results obtained without SSSC.

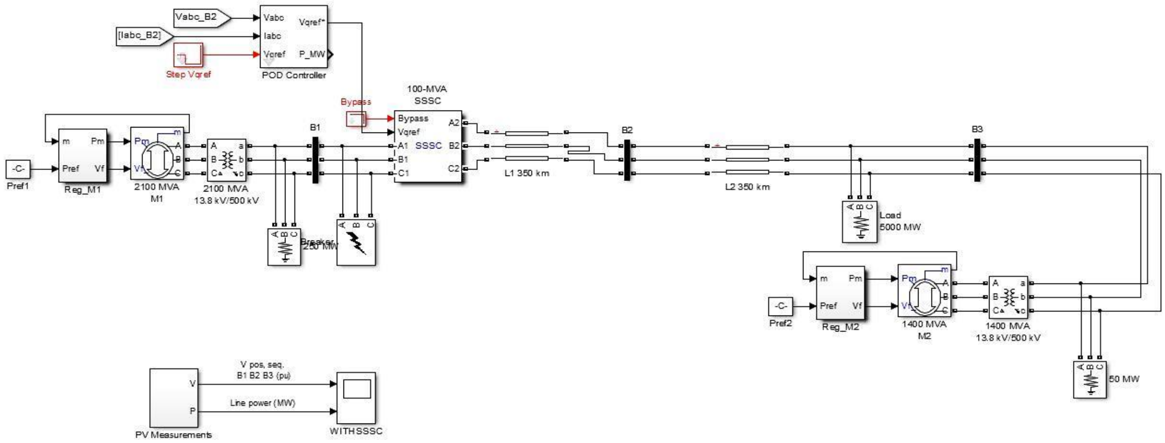
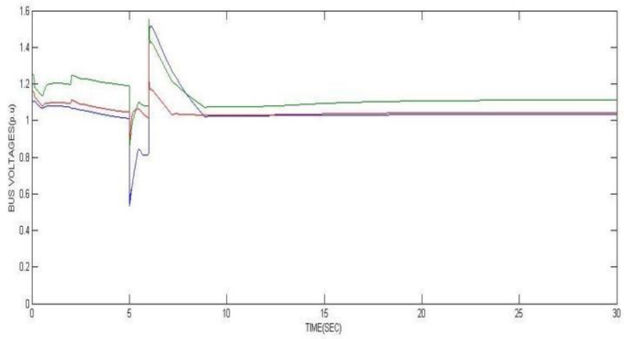


Fig. 13.Two machine systems with SSSC



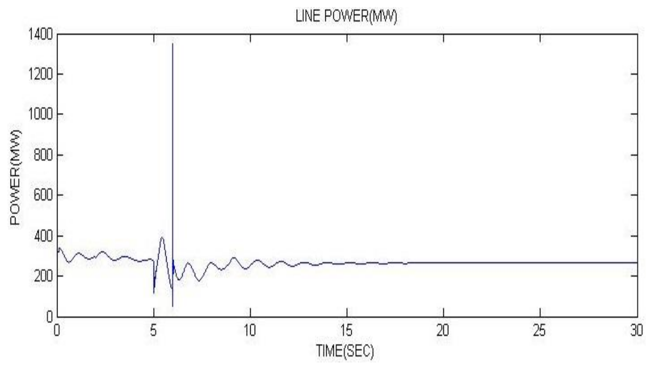


Fig.14.Bus voltage with SSSCFig. 15.Line power with SSSC

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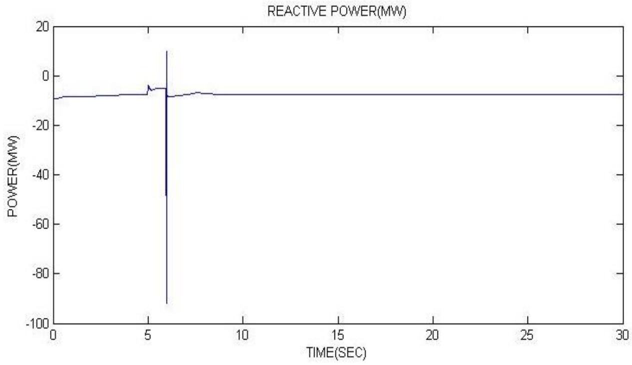

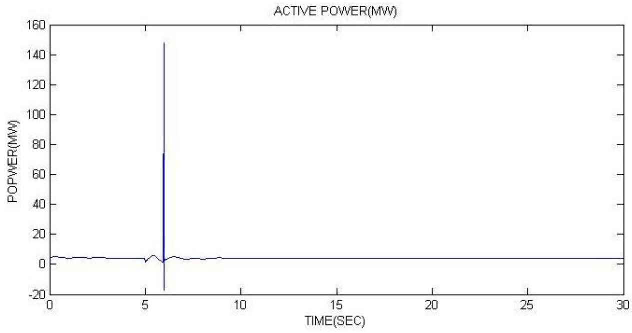

Fig. 16.Active power with SSSCFig. 17.Reactive power with SSSC

With SSSC under the L-G fault, which is modelled using MATLAB/SIMULINK software, the simulation is performed. Fig. 14. Shows the bus voltage which attains stability at 7s and less oscillations.Fig.15. Shows the line power which becomes stable within 17s with less oscillation when compared to the results obtained without SSSC. Likewise when we consider the Fig.16. It shows the active power which attains stability at 8s and also the reactive power is shown in Fig. 17. This becomes stable at 7s with fewer oscillations. Besides the simulation performed shows that the SSSC which is a series FACTS controller is efficient in damping the power oscillations and also stabilizes the voltage in a two machine system.

PARAMETERS	STABILITY TIME (SEC)		DAMPING	
	WITHOUT SSSC	WITH SSSC	WITHOUT SSSC	WITH SSSC
BUS VOLTAGE	8	7	1.56	1.52
LINE POWER	20	17	1490	1350
ACTIVE POWER	15	8	-	
REACTIVE POWER	13	7	-	

Table. 1. Comparison of results with & without SSSC

The above Table1.1. Illustrates a comparative analysis of the stability conditions of voltage, active power, reactive power and line power in a two machine system with and without SSSC. And also shows the power oscillation damping.

IX. CONCLUSION

In this paper, the SSSC has the ability to control the power flow to some extent on the transmission line. Since the purpose of SSSC is to insert a voltage with the transmission line serially and this voltage is independent of the line current magnitude. Here, the power oscillations are damped properly using SSSC in a two machine power system with an L-G fault. From the simulation results produced, the performance of the SSSC has been shown clearly in a two machine power system at selected bus-2. Results have been produced in a two machine power system with and without SSSC. Thus, by installing the SSSC in power system the voltage stability has been improved and power oscillations are damped properly when compared to the two machine system without SSSC. This future work can be extended in SSSC modeling by replacing the PI Controller with some other controllers for providing voltage stability and respective power in the power systems and a comparative study can be performed.

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BIOGRAPHY

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Dr. Rani Thottungal obtained her B.E and M.E degree from Andhra University, India and her Ph.D degree from Bharathiyar University, India. She has around 20 years of teaching Experience. She is currently working as Professor in Kumaraguru college of Technology, India. She is member of ISTE and IE. Her research interest includes power system and FACTS.

S.Mythilireceived her B.E degree in Electrical and Electronics Engineering from Karpagam College of Engineering, Coimbatore, India in 2013. She is currentlypursuing M.E degree in Power Electronics and Drives from Kumaraguru College of Technology, Coimbatore. Her area of interests is Power Electronics, FACTS devices and their control.