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Improvement in Rotor Stability in 3 Machine 9 Bus System Using TCSC, SVC, SSSC

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ABSTRACT: For every system, stability is the first and the most important term. Stability defines the stable operation of the system even when some disturbance or abnormal conditions occur. In this paper I will analyze the effect of FACTS device on the rotor angle stability when disturbances try to un-stabilized the system. Rotor angle stability is defines as the synchronism between two or more machine within the Power System when disturbance in the system tries to un-stabilized the system. The synchronism is basically defines as there should be no difference between speed and load angle between the machines of a power system. All the simulation work to for the analysis of rotor angle stability of a 3 machine 9 bus power system is completed on Matlab and conclusion drawn that SVC is better than TCSC and SSSC FACTS device for the system.

KEYWORDS: SVC, FACTS, TSCS, SSSC, VAR, Controller, Damping Oscillation

I. INTRODUCTION

A power system generally works in three stages: generation, transmission, and distribution. In the first stage, generation, the electric power is generated mostly by using synchronous generators. Then the voltage level is raised by transformers before the power is transmitted in order to reduce the line currents which consequently reduce the power transmission losses. After the transmission, the voltage is stepped down using transformers in order to be distributed accordingly.

Fundamental Requirement of a Designed Power System

1. It must supply energy at minimum cost and minimum ecological impact.
2. It must be able to meet continuously changing demand of both active and reactive power.
3. Quality of power should meet should meet certain minimum standards in
    a. Constant frequency.
    b. Constant voltage.

In modern interconnected power system the effect of instability or poor power quality is on both power system and load connected to it. Modern information age increasing use of computers and sophisticated electronic devices requires with a very good power that remains within specified limits of voltage for their proper functioning. This needs great stress on quality of electrical power being supplied to the load. Poor quality power sometimes causes serious economic consequences and cost business millions of rupees each year in revenues loss, process improvements, and scrapped product in industrial assembly lines which are increasingly automated and work on semiconductor equipments control which are sensitive to the quality of power being supplied.

The inherent power system restricts the power transaction which leads to under utilization of the existing transmission resources traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to solve much of the problems [4]. However, there are restrictions as to the use of these conventional devices. Desired performance was not being able to achieve effectively. Wear and tear in the mechanical components and slow response were the heart of the problems. There was a greater need for the alternative technology made of the solid devices with fast response characteristics. The need was further fueled by worldwide restructuring of electric utilities , increasing environmental and efficiency regulations and difficulty in getting permit and right of way for the construction of overhead transmission lines .This together with the invention of Thyristor Switch (semi conductor device), opened the door for the development of power electronic devices known as FACTS controller. The path from historical Thyristor based FACTS controller to modern state of the art voltage

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source converter based FACTS controllers was made possible due to rapid advance in high power semiconductor devices Flexible AC Transmission System (FACTS) controllers has been in use in utilities around the world since 1970's when the first utility demonstration of first formality of FACTS named as SVC was accomplished. The series devices like Thyristor Controlled Series Capacitor (TCSC) and Static Synchronous Series Compensator (SSSC) belongs to second generation of FACTS devices.

II. LITERATURE REVIEW

The SSSC, which was proposed by B.Vijyalaxmi in 2013[8], [16],[17],[19] is one of the most complex FACTS devices in a power system today. The SSSC is one of the series FACTS device based on a solid state voltage source inverter which generates a controllable ac voltage in Quadrature with the line current. Thus SSSC emulates as an inductive or capacitive reactance and hence controls the power flow in the transmission line. If the line voltage is in phase with the line current the series controller absorbs or produces reactive power. If it is not then the controllers absorbs or produces real and reactive power. SSSC is also used to damp the power system oscillations by using power oscillation damping controller.

The SVC is a shunt device of the FACTS group using power electronics to control power flow and improve transient stability on power grids [5], [18],[6],[15]. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). Several references in technical literature can be found on development of SVC. Dynamic models of SVC for transient stability and longer term dynamics is modeled on the basis of transfer function model by using conventional PI control used. In, a new SVC control for damping of power oscillations has been developed by using the phase angle signal estimated from the measurement of voltage and power at the SVC location. In, developed control laws for damping of power oscillations using SVC based on local input signal VSVC (SVC voltage). This control structure is decentralized and does not need any coordination with the other Power oscillation damping devices.

The 3-machine 9-bus system has been proposed in [9] [13].It is widely accepted that transient stability is an important aspect in designing and upgrading electrical power system. In this for various faults on test system fast clearing and load shed are analyzed to bring back the system to the stability.

The proposed definition of power system stability has been proposed in [6]. In this it is stated that how many types of stability are there in power system such as voltage, frequency and transient stability. And after that these stability can be for short duration or longer duration. In this thesis FACTS devices are used to damp this stability.

The TCSC which is a series device has been proposed in[11]. It can be used as both inductive and capacitive. It can also be used to damp the power system oscillations in the system. It is also used to increase the power transfer capability.

III. POWER SYSTEM STABILITY

Power system stability is the ability of an electrical power system for a given initial operating conditions to regain a state of operating equilibrium after being subjected to a physical disturbance with most system variable bounded so that practically the entire system remain intact.

A. Classification of Power System Stability

The classification of power system stability proposed here is based on the following considerations

1. The physical nature of the resulting mode of instability as indicated by the main system variable in which instability can be observed.
2. The size of the disturbance considered which influences the method of calculation and prediction of stability.
3. The devices, processes and the time span that must be taken into consideration in order to assess stability.

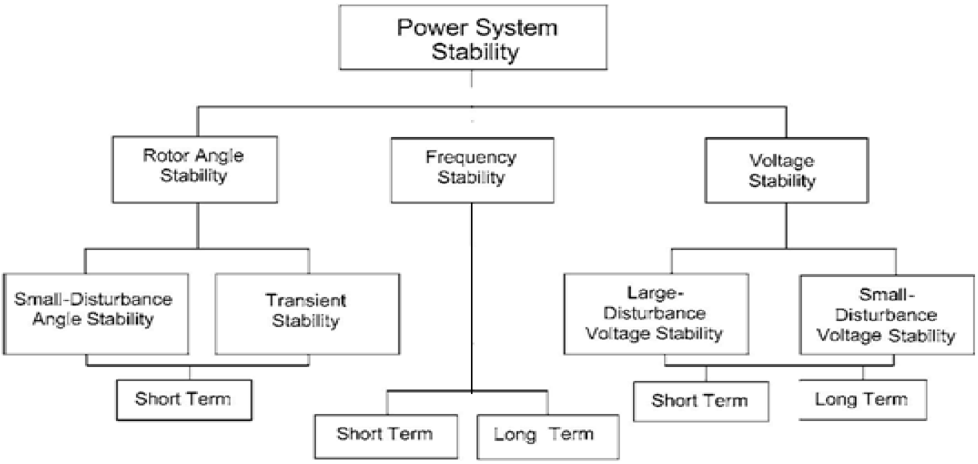

Fig 1 Classification of power system stability

Rotor Angle Stability:

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. It depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system. Instability that may result occurs in the form of increasing angular swings of some generators leading to their loss of synchronism with other generators.

The rotor angle stability problem involves the study of the electromechanical oscillations inherent in power systems. A fundamental factor in this problem is the manner in which the power outputs of synchronous machines vary as their rotor angles change. Under steady state conditions, there is equilibrium between the input mechanical torque and the output electromagnetic torque of each generator, and the speed remains constant. If the system is perturbed, this equilibrium is upset, resulting in acceleration or deceleration of the rotors of the machines according to the laws of motion of a rotating body. If one generator temporarily runs faster than another, the angular position of its rotor relative to that of the slower ma- chine will advance. The resulting angular difference transfers part of the load from the slow machine to the fast machine, depending on the power-angle relationship. This tends to reduce the speed difference and hence the angular separation. The power-angle relationship is highly nonlinear

The change in electromagnetic torque of a synchronous machine following a perturbation can be resolved into two components:

1. Synchronizing torque component in phase with rotor angle deviation.
2. Damping torque component in phase with speed deviation.

System stability depends on the existence of both components of torque for each of the synchronous machines. Lack of sufficient synchronizing torque results in *a* periodic or non oscillatory instability, where as lack of damping torque results in oscillatory instability.

Voltage Stability:

Voltage stability refers ability of a power system to maintain steady voltage at all the buses in the system after being subjected to a disturbance from a given initial operating condition. It depend upon the ability to maintain equilibrium between load demand and load supply from the power system. In-stability that may results occur in the form of a progressive rise or fall of voltage of some buses. A possible outcome of voltage instability is loss of load in an area or tripping of transmission lines and other elements by protective system leading to cascading outages. Loss of synchronism of some generators may result from these outages or from operating conditions that violate field current limit.

Progressive drop in bus voltage may also be associated with rotor angle stability. For example loss of synchronism of machine or rotor angle between two groups of machine approach 180 degree cause rapid drop in voltage at intermediate point in network close to the electrical centre. Normally protective system operate to separate the group of two machines and the voltage recover to level depending on post separation condition. If however the system is not so separated the voltage near the electrical centre rapidly oscillates between high and low values as a result of repeated

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pole slips between the two groups of machines.

Frequency Stability:-

It refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads.

Severe system upsets generally result in large excursions of frequency, power flows, voltage, and other system variables, thereby invoking the actions of processes, controls, and protections that are not modeled in conventional transient stability or voltage stability studies. In large interconnected power systems, this type of situation is most commonly associated with conditions following splitting of systems into islands. Generally, frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection equipment, or insufficient generation reserve

During frequency excursions, the characteristic times of the processes and devices that are activated will range from fraction of seconds, corresponding to the response of devices such as under frequency load shedding and generator controls and protections, to several minutes, corresponding to the response of devices such as prime mover energy supply systems and load voltage regulators. Therefore frequency stability may be a short-term phenomenon or a long-term phenomenon. An example of short-term frequency instability is the formation of an under generated island with insufficient under frequency load shedding such that frequency decays rapidly causing blackout of the island within a few seconds. On the other hand, more complex situations in which frequency instability is caused by steam turbine over speed controls or boiler/reactor protection and controls are longer-term phenomena with the time frame of interest ranging from tens of seconds to several minutes.

IV. SIMULINK MODEL AND RESULT ANALYSIS

The simulation studies in this paper are based on 230 kV 3 machine 9 bus power system consists of three generators connected in transmission line network as shown in fig. 2 each generator is of 700 MVA capacity. Three machines nine buses system having capacity of each generator equals to 700 MVA through a transmission line network. The SVC,SSSC and TCSC is installed at middle transmission line respectively in order to control the power flow through that line as well as to regulate voltage level at buses.

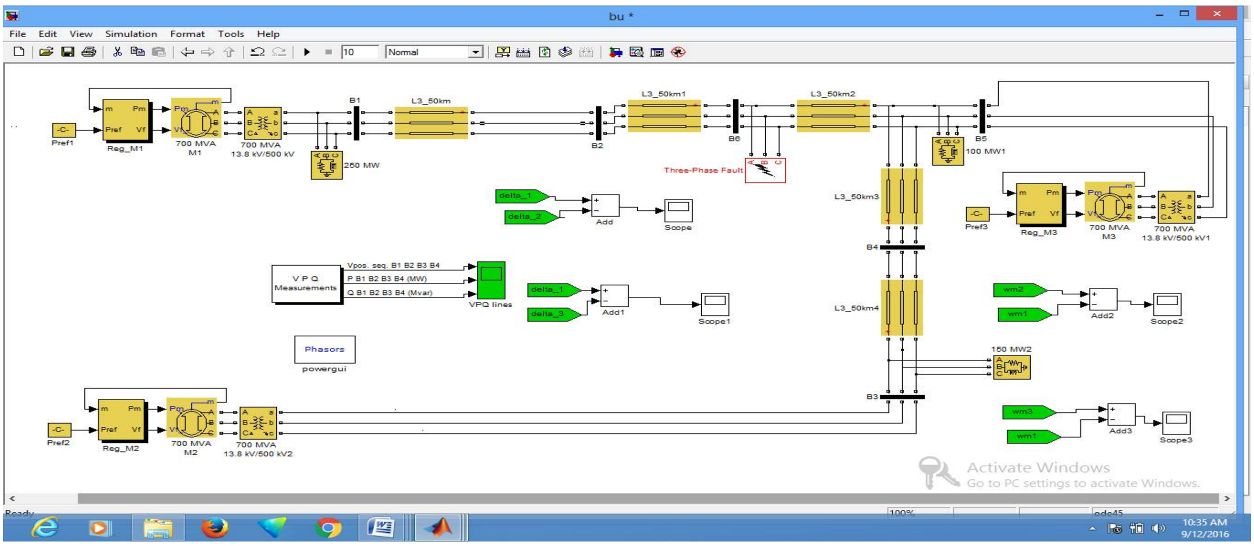

Fig 2. Simulink model of 3 machine 9 bus system

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Simulink model with SSSC

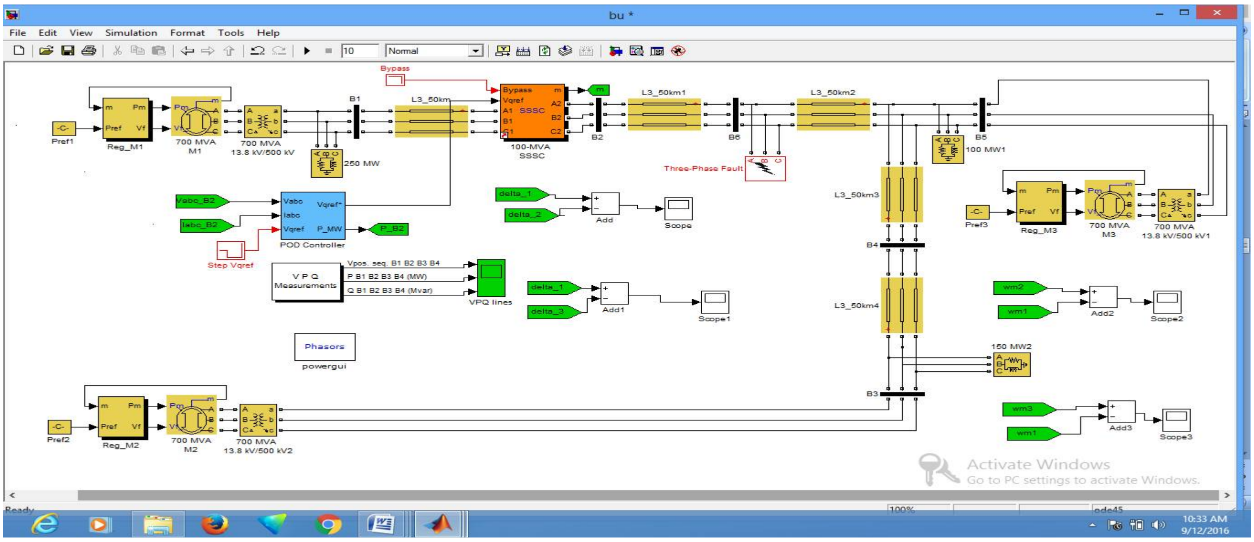

Fig 3 Simulink model with SSSC

Circuit Description

The Static Synchronous Series Compensator (SSSC), one of the key FACTS devices, consists of a voltage-sourced converter and a transformer connected in series with a transmission line. The SSSC injects a voltage of variable magnitude in quadrature with line current, thereby emulating an inductive or capacitive reactance. This emulated variable reactance in series with the line can then influence the transmitted electric power. In our thesis, the SSSC is used to damp power oscillation on power grid following a 3-phase fault.

Simulink model with TCSC

Circuit Description

Generally TCSC is used to improve power transfer capability. But we can use it also to improve transient stability in power system. It can be used in two modes inductive as well as capacitive. We can switch from one mode to other whenever it is required. It contains a capacitor controlled by the thyristor

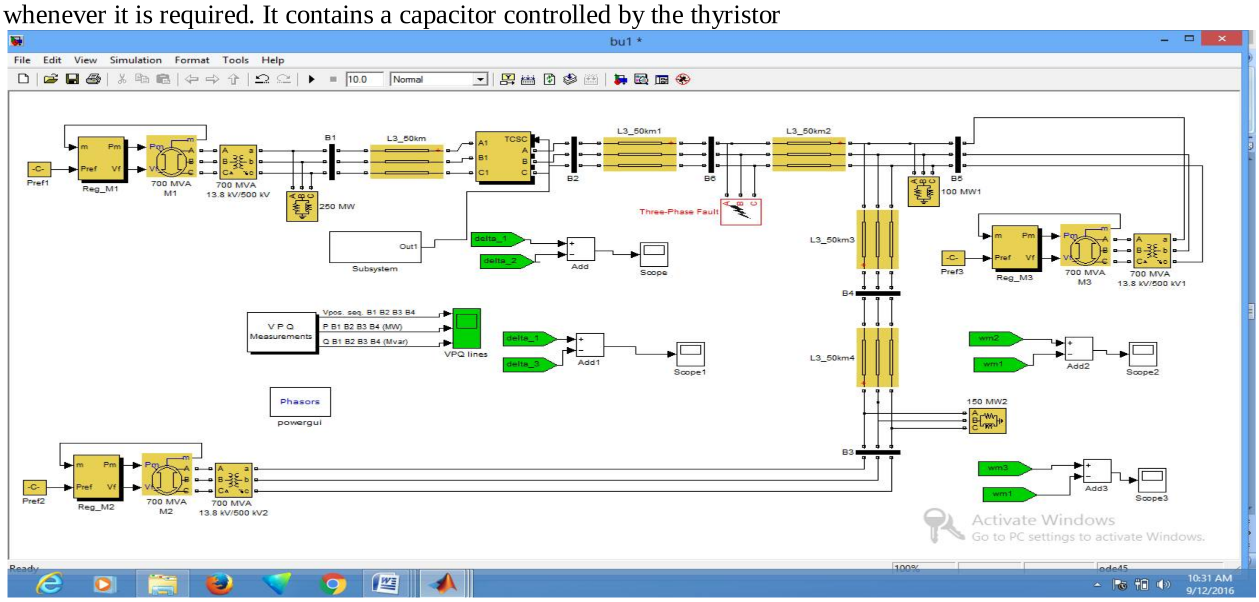

Fig 4 Simulink model with TCSC

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Simulink model with SVC

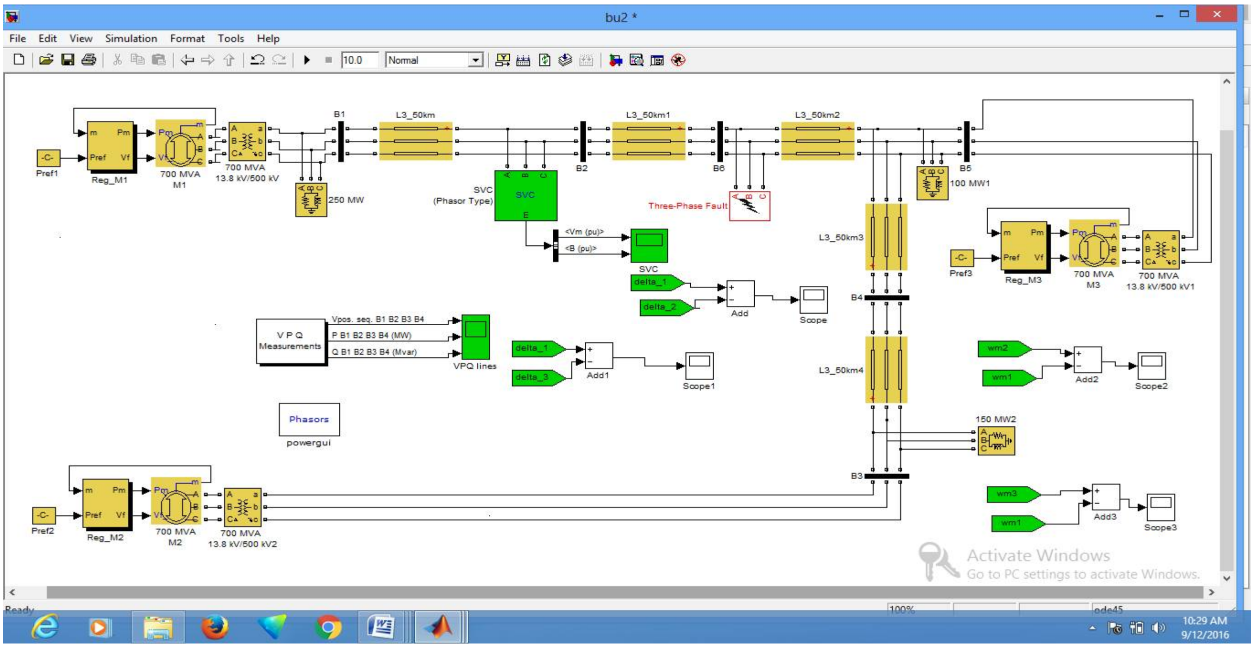
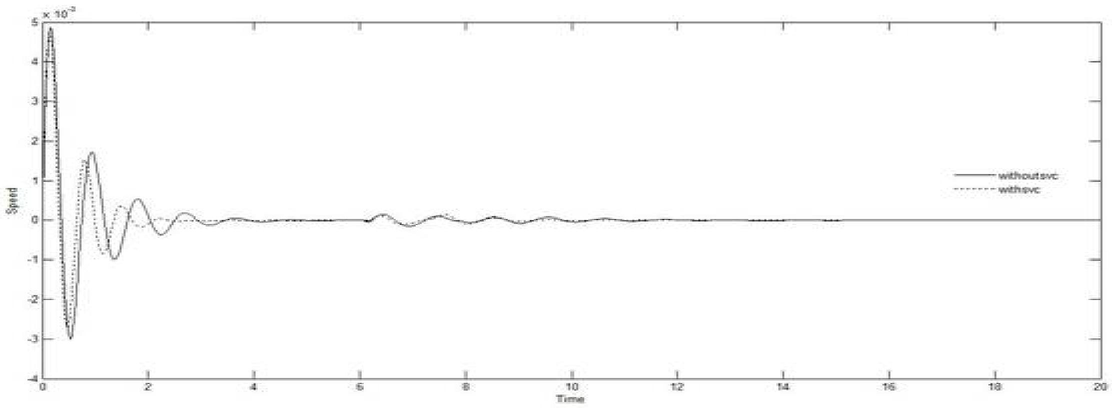


Fig 5Simulink model with SVC

Circuit Description

You will now apply a 3-phase fault and observe the impact of the SVC for stabilizing the network during a severe contingency. Verify that the SVC is in fixed susceptance mode with Bref = 0. Start the simulation. Now open the SVC block menu and change the SVC mode of operation to 'Voltage regulation'. The SVC will now try to support the voltage by injecting reactive power on the line when the voltage is lower than the reference voltage (1.009 pu). The chosen SVC reference voltage corresponds to the bus voltage with the SVC out of service. In steady state the SVC will therefore be 'floating' and waiting for voltage compensation when voltage departs from its reference set point.

A. Comparison between with and without SVC



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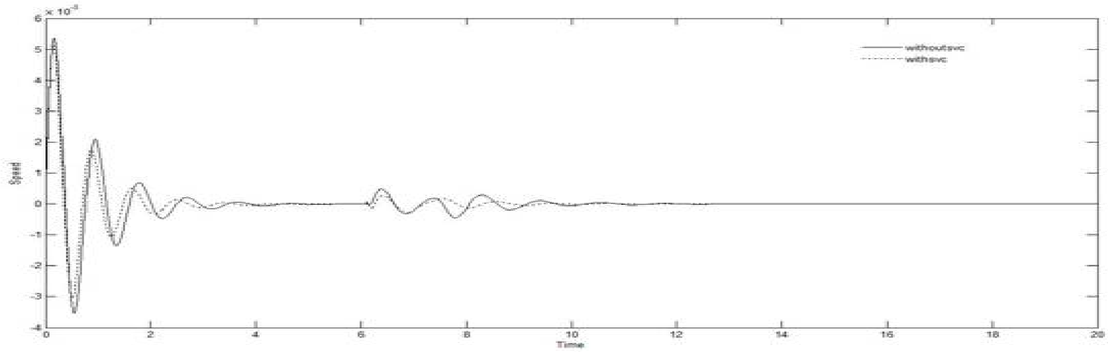

Fig 6 comparison of speed with and without SVC a) wm1-wm3 b) wm1-wm2

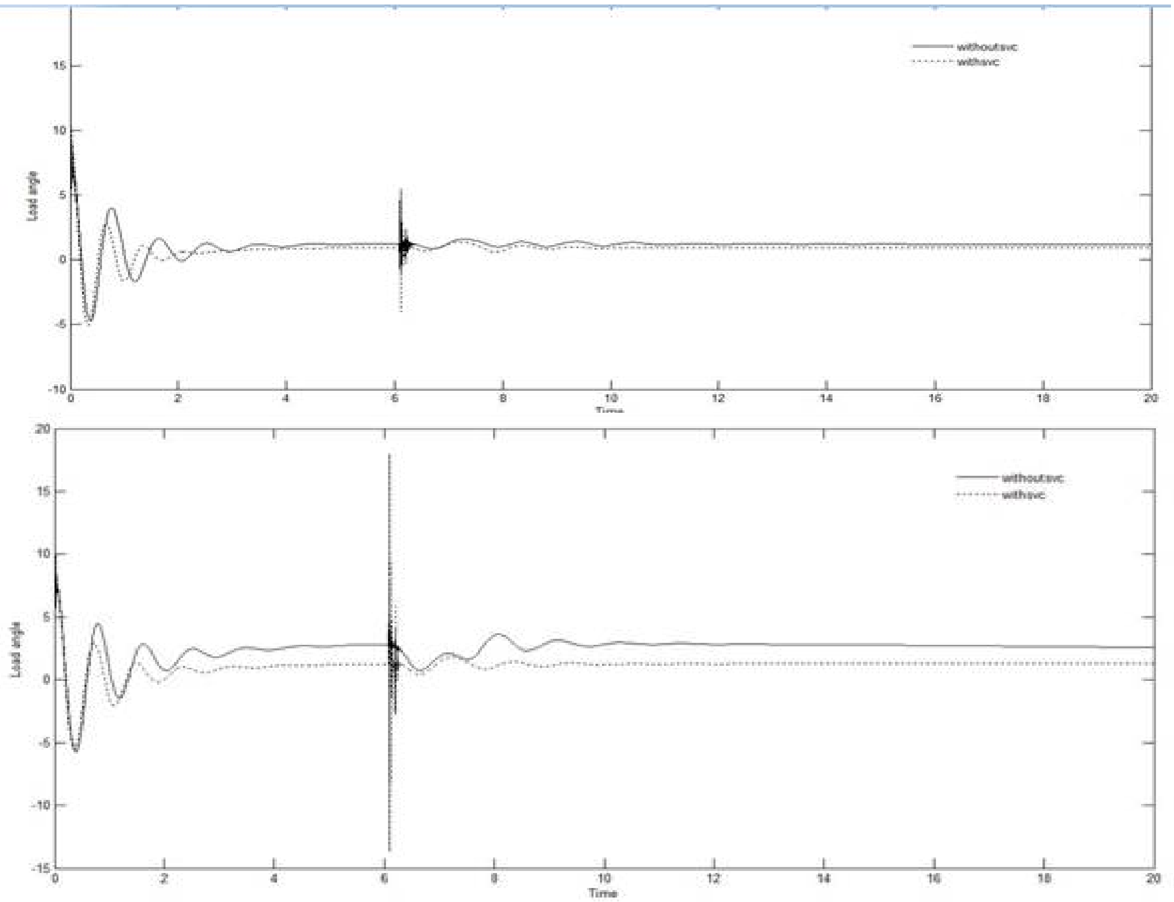

Fig 7 Comparison of load angle with and without SVC a) Delta1 b) Delta 3

Simulation results for speed, load angle, active power and voltage for synchronous machines of 3 machine 9 bus system is shown in above fig. Three phase symmetric fault of 100 milliseconds is applied at time 6.1 second. After the occurrence of fault the power curve show oscillations which are settled to steady state. It is observed that after applying SVC oscillations are damping earlier as compared to without controller in the system.

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B. **Comparison between with and without SSSC**

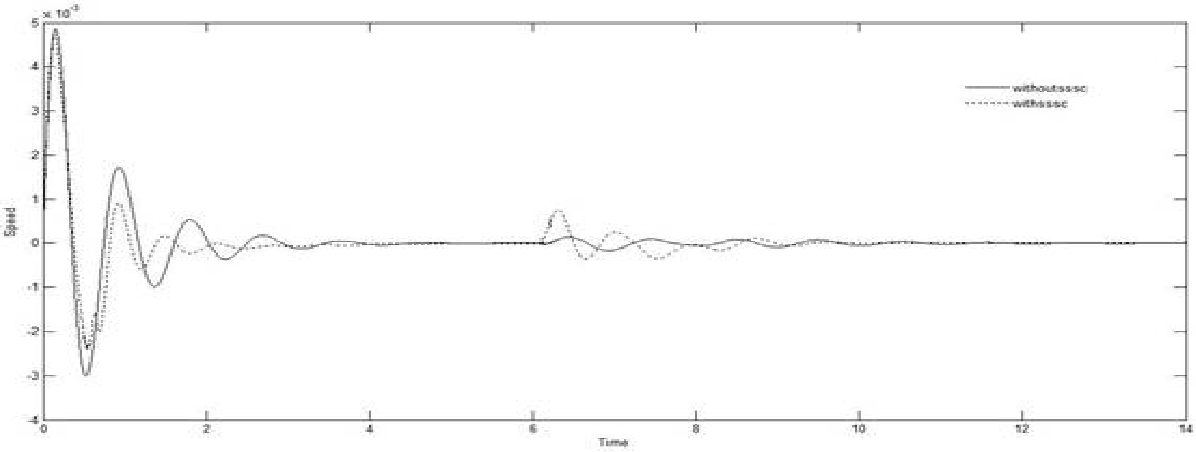

Fig 8 Comparison of speed(wm1-wm3) with SSSC and with SVC

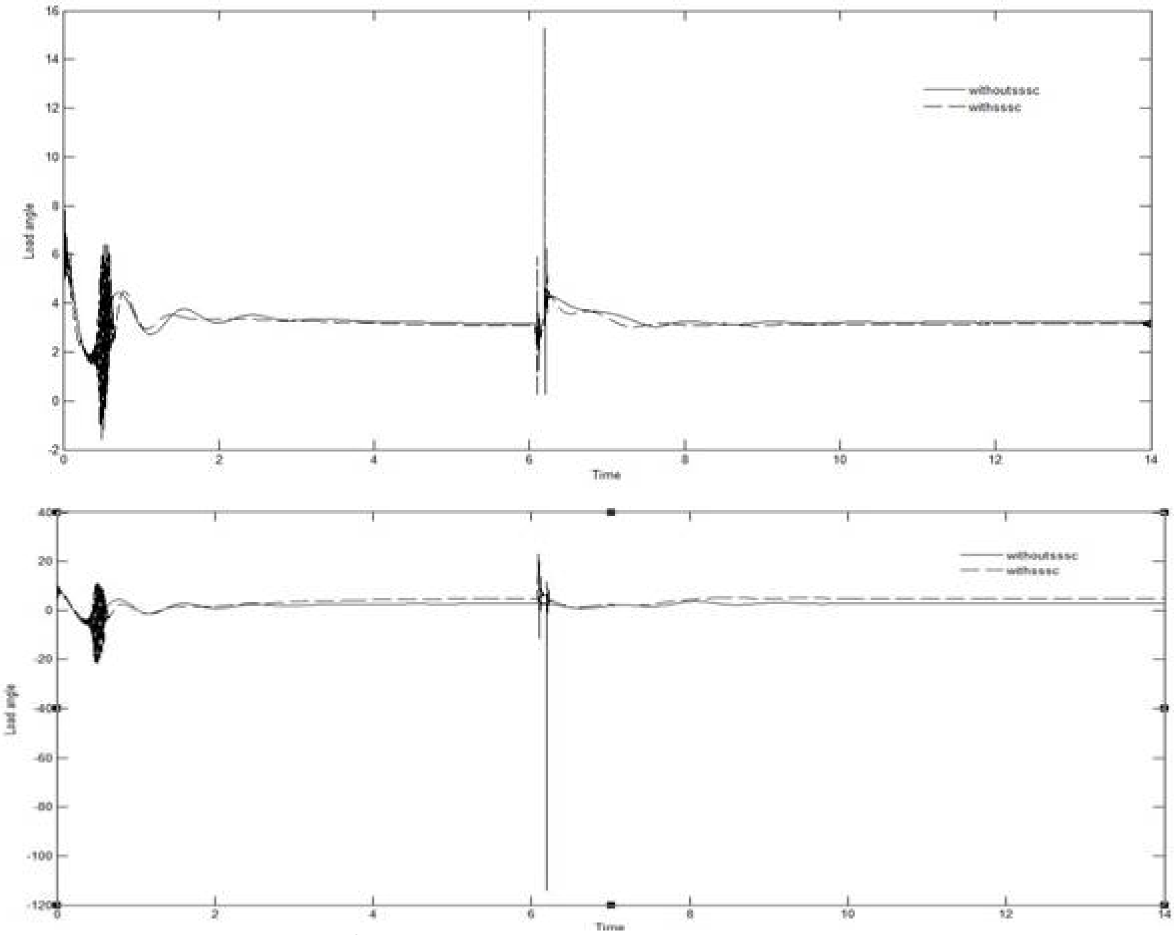

Fig 9 Comparison of Load angle with and without SSSC a) Delta1-Delta3 b) Delta1-Delta2

Simulation results for speed, load angle for synchronous machines of 3 machine 9 bus system is shown in above fig. Three phase symmetric fault of 100 milliseconds is applied at time 6.1 second. After the occurrence of fault the power

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curve show oscillations which are settled to steady state. It is observed that after applying SSSC oscillations are damping earlier as compared to without controller in the system.

C. Comparison between with and without TCSC

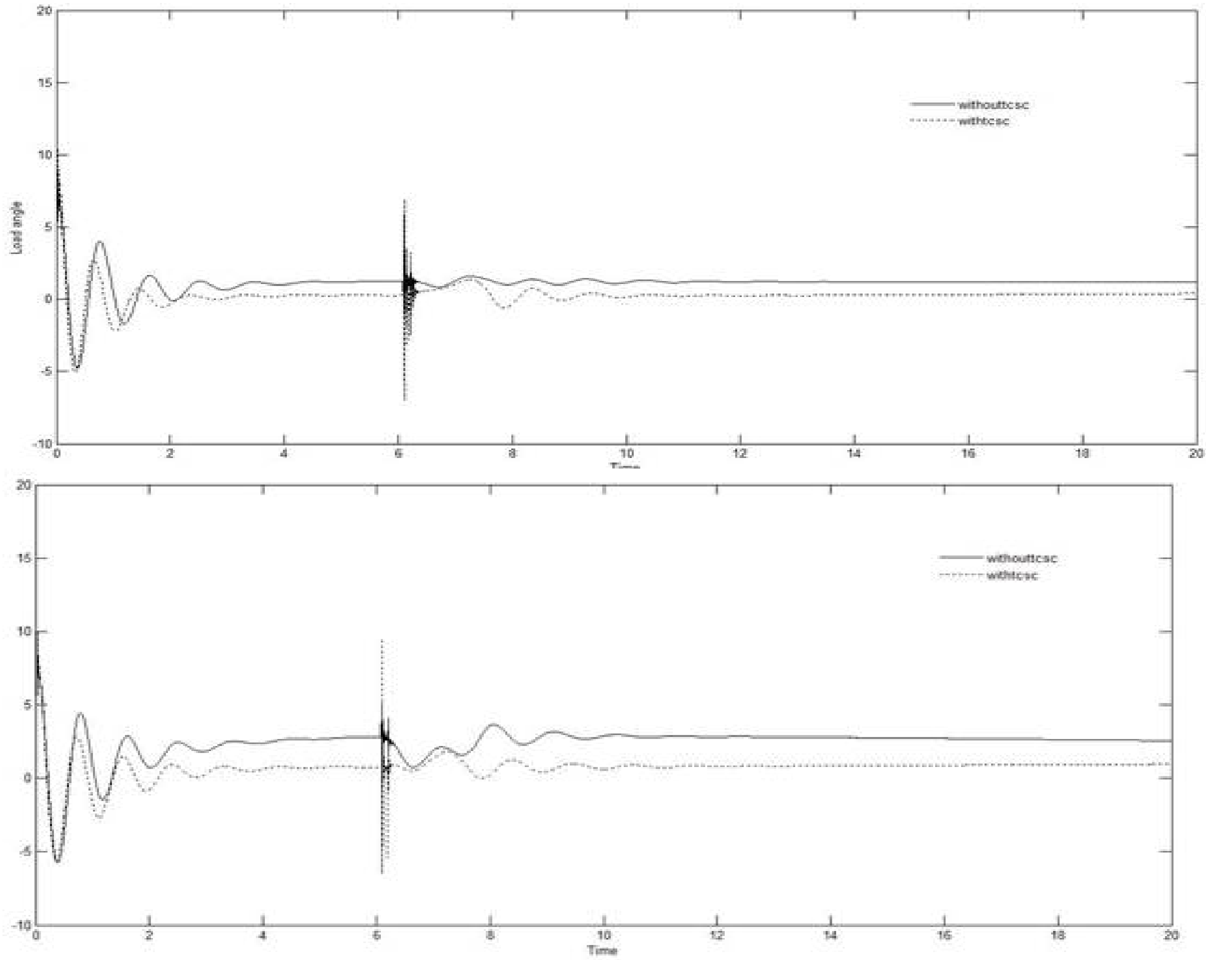

Fig 10 Comparison of Load angle with and without TCSC a) wm1-wm3 b) wm1-wm2

Simulation results for speed, load angle for synchronous machines of 3 machine 9 bus system is shown in above fig. Three phase symmetric fault of 100 milliseconds is applied at time 6.1 second. After the occurrence of fault the power curve show oscillations which are settled to steady state. It is observed that after applying TCSC oscillations are damping earlier as compared to without controller in the system.

V. CONCLUSION

In this thesis, the power system stability improvement of a 3 machine 9 bus power system by various FACTS devices such as SVC, SSSC AND TCSC is analysed. The effect of SVC, SSSC and TCSC on power system stability of 3 machine 9 bus power system is studied. The dynamics of the system is studied at the event of a major disturbance and three phase symmetric fault of 100ms and the results are discussed. Then the performance of the devices is compared for power system stability improvement . It is clear from the simulation results that there is a considerable improvement in the system performance with the presence of these devices for which the settling time is reduced. It is also observed SVC is better than SSSC and TCSC and SSSC is better than TCSC. The oscillations is also reduced and hence the power system stability is improved

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