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Comparision of Tcsc and Sssc for Damping of Sub Synchronous Oscillations in Power System

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Abstract
In this paper, a static synchronous series compensator (SSSC) and thyristor controlled series compensator (TCSC) is used to reduce the synchronous oscillation in series capacitor compensated power systems. In order to achieve an effective damping, a supplementary sub synchronous damping controller (SSDC) is added to the SSSC. The reference signal to the compensator is taken as the rotor speed deviation to generate the modulation index for controlling the injected voltage of the compensator. The main objective is to damp the sub synchronous resonance (SSR) caused by the series capacitor in the line using SSSC and TCSC and compare the simulation result obtained using MATLAB. By using the SSDC connected at the transmission line it is able to damp the SSR. The first system of IEEE second benchmark model is used to evaluate the effectiveness of SSDC on the torsional oscillations. The several simulations are used to demonstrate the superior ability of SSSC in damping the SSR when compared with TCSC.
Key Words: SSR, FACTS, TCSC, SSSC, PI, SSDC, VSC.

I.   INTRODUCTION

Series capacitor compensation has been widely used in the AC transmission systems [1] as an economical alternative for different purposes such as increasing power transfer capability through a particular interface, controlling load sharing among parallel lines, and enhances Steady state stability [2]. However, the use of series compensation may bring about some new problem to power system operation. One of the problems is possibility of Sub-Synchronous Resonance (SSR), which may lead to torsional oscillations of turbine generator shaft system and electrical oscillation with frequency below the sub synchronous frequency. Sub synchronous resonance (SSR) has gained its name from the fact that the frequencies of interest happen to lie in a region below the synchronous frequency of the network. The system of coupled masses conveying mechanical energy to the generator rotor is not a rigid system. It can have several modes of oscillations. If a linear mass-spring model is used to represent this system, then in general, it has n-1 oscillatory modes, n being the number of masses. The researcher have used many techniques to overcome this problem, and has proposed many controllers in the literatures. In general, these are divided into many categories. The first one contains the controllers based on the excitation system of generator [2–4]. The second one consists of the flexible AC transmission systems (FACTS)devices Frequency scanning, eigen value analysis and the time domain simulation are the methods used to evaluate the effect of SSR. The FACTS devices are the best compensating devices in order to compensate the

active and reactive voltage and current unbalance in the system. A lot of articles have been published about the use of these devices for damping the SSR. In this paper, two compensators such as TCSC and SSSC are compared to know their effectiveness in damping of oscillations. The SSSC is used as a voltage source in series with a fixed dc source and TCSC is used as a Thyristor controlled switch. So, this combination can prevent the Sub synchronous oscillations that may be caused by conventional fixed capacitor. This paper is divided into few sections. In section 2 SSSC is explained. In section 3 TCSC is explained. In Section 4 proposed controller structure is explained and in section 5 simulation results are presented.

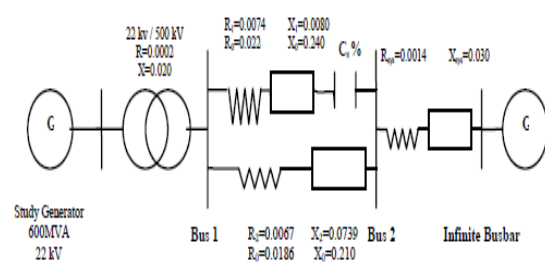## II.   STATIC SYNCHRONOUS SERIES COMPENSATOR(SSSC):

Fig. 1 Network Model Structure

If the line voltage is in phase quadrature with the line current, the series controller produces reactive power, while if it is not, the controllers absorbs or produces real and reactive power. Examples of such controllers   are   Static   Synchronous   Series

Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Reactor (TCSR), to cite a few[6]. They can be effectively used to control current and power flow in the system and also to damp systems oscillations. Among these Static Synchronous Series Compensator (SSSC) is one of the important series FACTS device. SSSC is a solid-state voltage source inverter which injects an almost sinusoidal voltage of variable magnitude and phase in series with the transmission line. The injected voltage is almost in quadrature with the line current and hence emulates the equivalent inductance and capacitance reactance in series with transmission line. The applications of the SSSC are 1) to control the power flow, 2) to increase the power transfer capability, 3) to improve the transient stability, 4) to damp out power system oscillations, 5) to mitigate Sub-Synchronous Resonance. When the series injected voltage leads the line current, it eliminates the inductive element causing the power flow and the line current decreases. When line current leads the injected voltage, it emulates the capacitive reactance thereby enhancing the power flow of the line. The VSC made up of IGBT's or thyristors is the basic block used for modern FACTS devices. The VSC generates the ac voltage from dc voltage and the phase and magnitude of the output can be controlled thereby it can either inject or absorb the power by just reversing the polarity of the current. The SSSC uses a voltage source converter(VSC) to inject a controllable voltage in quadrature with line current which is able to rapidly provide the both capacitive and inductive compensation independent of power circuit. An SSSC with a suitable design can be used for improving the effectiveness in damping low frequency power oscillations in the power network[6]. These features make the SSSC an better FACTS device for power flow control, power oscillation damping, to damp SSR and to improve the transient stability. The main function of the SSSC proposed here is to dynamically control the power flow in the transmission line. The earlier control schemes proposed were based on the line impedance control mode in which the SSSC compensating voltage is derived by multiplying the current amplitude with the desired compensating reactance Xqref. Since it is difficult to predict Xqref under varying network contingencies, the voltage control mode is considered in the proposed scheme. This controller is modified to operate the SSSC in the automatic power flow control mode. In the automatic power flow control mode, the reference inputs to the controller are reference powers P and Q, which are to be maintained in the transmission line despite system changes. Using dq transformation the line voltage and the line current are converted to corresponding d and q axis components using parks transformation.

III. THYRISTORS CONTROLLED SERIES COMPENSATOR (TCSC)

After introduction of TCSC in the late 1980s TCSC implementations have been installed in several locations in the world. As a controllable series compensation device and due to its flexible control possibilities TCSC has been found to be effective one especially in damping electromechanical and Sub Synchronous Oscillations[1,2]. Therefore replacing the existing fixed series compensation device or part of it with TCSC may become of interest especially in a case where controlling of series compensation degree of the transmission line and new control possibilities for stability enhancement of the power system are desired. In Fig.2 basic structure of single TCSC module is given. TCSC utilizes controllable TCR branch parallel with series capacitor to enable fast and flexible variation of effective fundamental reactance of the device. Depending on the firing angles of the thyristors both inductive and capacitive control modes can be achieved – though capacitive mode can be considered to be the main control mode. Boost factor Kb of the device describes the relation between effective fundamental reactance Xeff of the device to reactance X_{C0} of series capacitor.

$$K_b = X_{eff}/X_{co} \qquad\qquad ------(1)$$

According to the above equation (1) positive boost factor refers to capacitive control mode and negative boost factor refers on inductive control mode. Typically in normal operation boost factor of TCSC is in range of 1-3 depending on series compensation degree limits of the transmission line and ratings of TCSC [8]. Controllability of TCSC can be utilized in various ways to improve the overall stability of the power system. The most common ways of utilization are listed in below

• Damping of electromechanical oscillations
• Damping of sub synchronous oscillations
• Control of transmission line current/power
• Control of series compensation of
  transmission line
• Fault current limiting
• Phase balancing control

As damping of mechanical and sub synchronous oscillations emphasizes the importance of tuning and design of the control system, implementation of TCSC fault current limiting function can be considered to be more related on component ratings and sequencing the control functions.
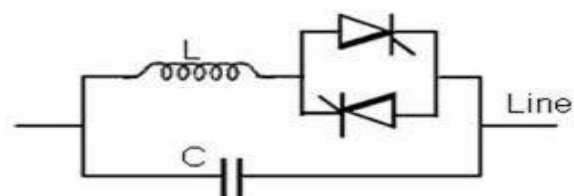

Fig 2: Basic structure of TCSC

IV. PROPOSED APPROACH
4.1. STRUCTURE OF CONTROL FOR THE SSSC AND TCSC:

Fig 1 shows the structure of the infinite bus system it consists of a infinite bus system and a generating station and line impedances and reactance's. Fig. 3 and Fig. 4 shows the SSSC and TCSC integrated with power lines. The SSSC has more compensating capability compared to the TCSC due to its reliable features such as less switching losses. Fig 5 shows the circuit diagram of control structure of both TCSC and SSSC. In this structure, there are two basic controllers implemented. In order to control V_q and V_d a conventional controller knows as PI controller is used. The principal strategy in controlling compensators for damping the SSR oscillations is to use simple stabilizing signals[11]. The generally known fact that, rotor speed deviation of generator D_w contains components of all the torsional modes. Consequently, if the rotor speed deviation is used to control the compensators then all the torsional modes in addition to the mode corresponding to the generator mass will be affected. As seen in Fig.5 the SSDC input selected is the rotor speed deviation of generator. The input after passing through low pass filter excites the derivative gain K_d. The output signal of derivative gain signifies the existence of the SSR in the system power. Therefore the SSDC uses the rotor speed deviation to modulate the SSSC-injected voltage V_q to improve the damping of the unstable torsional modes. In Fig.5 $V_q$ref represents the reference injected voltage as desired by the steady-state power flow control loop. The steady-state power flow loop acts quite slowly in practice and hence, in the present study $V_q$ref is assumed to be constant during the disturbance period. In the control system block diagram, V_{d_conv} and V_{q_conv} designate the components of converter voltage(Vconv) which are respectively in phase and in quadrature with line current. The control system consists of:

1) A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle $\theta = \omega t$) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as V_d, V_q or I_d, I_q on the diagram shown in Fig.(5).

2) Measurement systems measuring the q components of AC positive-sequence of voltages V1 and V2 (V1q and V2q) as well as the DC voltage Vdc.

3) AC and DC voltage regulators that compute the two components of the converter voltage (Vd_conv and Vq_conv) are required to obtain the desired DC voltage (Vdc ref) and the injected voltage (V$_q$ref). The V_q voltage regulator is assisted by a feed-forward-type regulator which predicts the Vconv voltage (the injected voltage on the VSC side of the transformer) from the I_d current measurement.

4.2 .PROBLEM FORMULATION:
The transfer function of SSDC(2) is

$$Y = \frac{T_w^s}{1 + T_w^s} \Delta w Kds \quad - - - - \qquad (2)$$

Although local control signals reference is obtained they may not consist of the oscillation modes. In the SSDC, the signal washout block serves as a high pass filter,
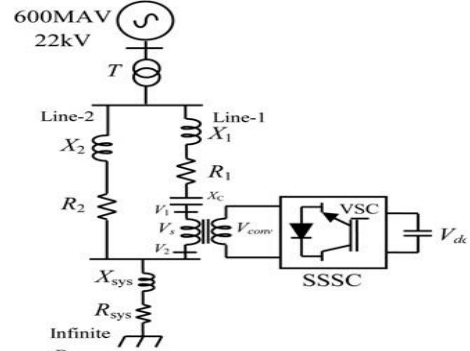

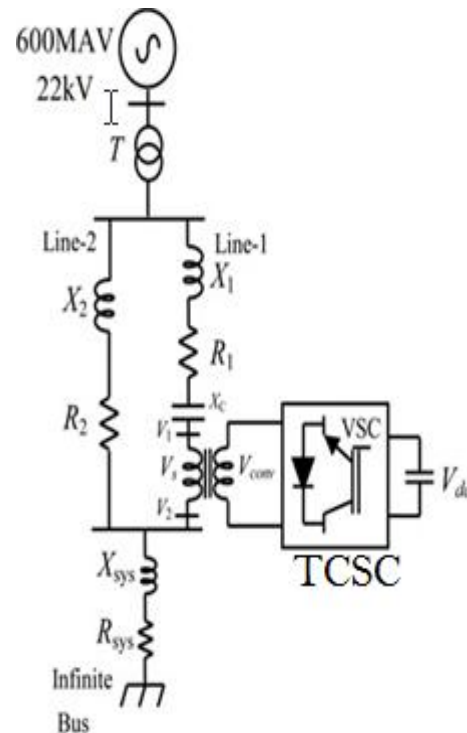Fig 3: Transmission system incorporated with SSSC

Fig 4: Transmission system incorporated with TCSC

with the time constant (TW) high enough to allow signals associated with oscillations in input signal to pass unchanged. The washout time constant TW is usually pre-specified [10]. In this paper, TW is taken as 10 s. In order to achieve a satisfactory damping, the derivative gain K_d must be determined. Under steady-state conditions, the SSDC output and $V_q$ref are constant values. During the dynamic and transient conditions the series injected voltage V_q is modulated to suppress the sub synchronous oscillations.
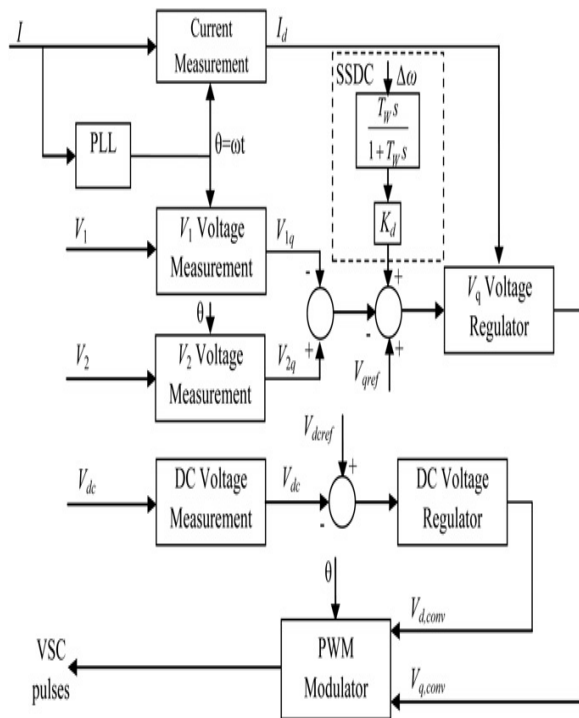
Fig 5: Control circuit of compensators

V.   SIMULATION RESULTS

The simulation is carried out using three specifications 1) The generator delivers the power of 1 p.u to the transmission line and the infinite and the generator are adjusted to 1.0 p.u .2) the compensation level produced by the capacitor compensator is 55% 3) the three-line to ground fault is applied at the end of the line2. The simulation is carried out in three modes for the two compensators and their performance is analyzed.

5.1 increases in input mechanical power:

As the first test case, a 10% decrease in input mechanical power is applied to the generator at t= 0.5s and removed at t = 1.0 s. Also, the compensation of the line 1 and the operating conditions are 55% and P=0.85p.u., Vt=1.0p.u.,respectively. It is observed that in the absence of SSSC, increase of the oscillation amplitude indicates that the generator have a growing torsional vibration, which would probably lead to great damage on the shaft. When the SSSC is applied to the system, the sub synchronous oscillation is successfully damped out. And we can absorb from the graphs that compared to TCSC, SSSC is able to compensate the oscillations in the system in a better manner. From **fig 6 -11 pink color shows the result of TCSC and black color indicates SSSC result.**
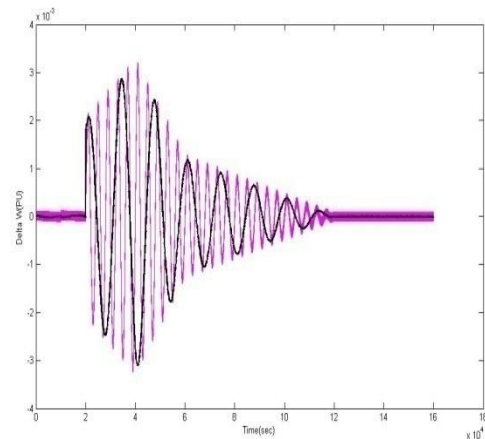

Fig. 6 Rotor speed deviation during and after a small disturbance at 2.0 sec
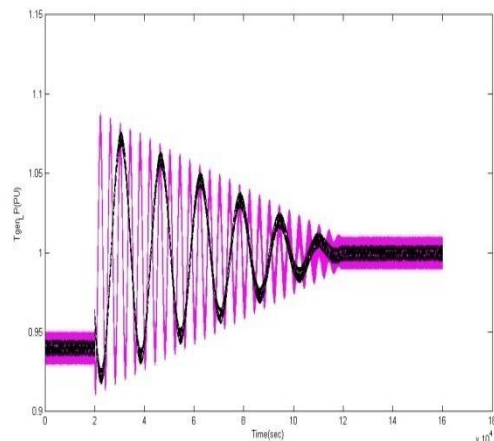

Fig. 7 Torque of Gen-LP section during and after a small disturbance at 2.0 sec

5.2 Disconnection of the line 2:

For the second simulation, it is assumed that the transmission line 2 is tripped out at t=1s and again reclosed at t = 4 s. Also, the compensation of the line 1 and the operating conditions are 55% and P=0.9p.u, Vt=0.95p.u., respectively. Fig. 8 shows the rotor speed deviation. It is clear that in this disturbance, the SSSC's performance is well compared to TCSC. The torsional oscillations on the shaft in Gen-LP section is depicted in Fig. 9. As the SSDC parameter is tuned under heavy operating conditions and with a large disturbance, the SSSC with the SSDC show a improved performance.
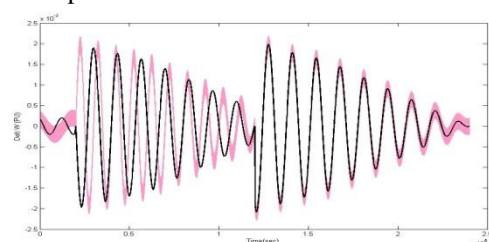

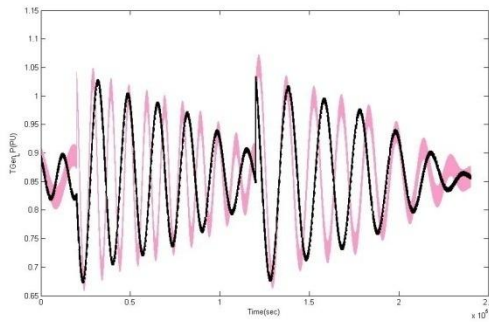Fig. 8 Rotor speed deviation during and after the disconnection of line 2 ref in fig.1

Fig. 9 Torque of Gen-LP section during and after the disconnection of line 2 in fig 1
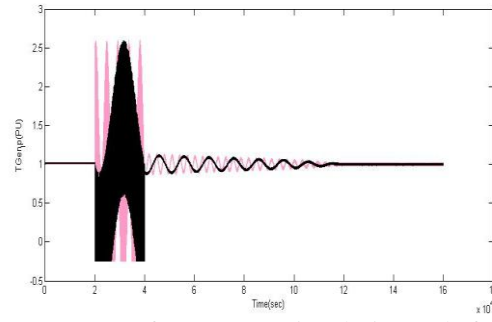
5.3 Three-line-to-ground fault:

For completeness, the performance of SSSC is also investigated under a large disturbance. To demonstrate the robustness of SSSC with the proposed SSDC, the performance of SSSC is evaluated in different operating conditions. For this purpose, it is assumed that a serious three-phase short-circuit fault occurs at the beginning of line 2 and the compensation of the line 1 and the operating conditions are 55% and P=0.95p.u., Vt=1.05p.u., respectively. The rotor speed deviation is depicted in Fig.10. It is clear that the proposed controller is robust and provides efficient damping even under large disturbance conditions. The torsional oscillation on the shaft in Gen-LP section is shown in Fig.11. For short time after the fault (about □1.0 sec), the magnitude of the oscillations is large, because of the severe impact of the fault. The SSSC with the proposed SSDC is clearly able to decrease the severe vibration on the shaft quickly . In addition to these simulations, sufficient simulations have been carried out for other operating conditions and with large but different disturbances. Totally, SSSC's performance is good in damping all the torsional modes and can satisfactorily weaken the vibrations caused by SSR in disturbances compared to TCSC device.
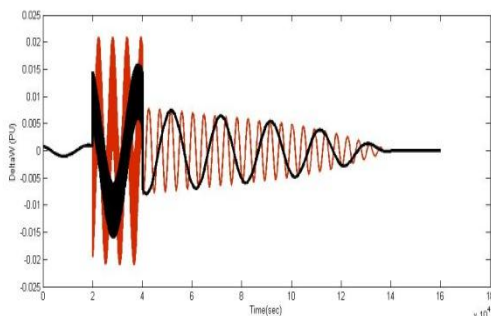

Fig.10. Rotor speed deviation during and after a 3 phase to line fault

Fig.11 Torque of Gen-LP section during and after a 3 phase to line fault

VI.   CONCLUSION

In this paper the comparison of TCSC and SSSC is done in order to damp the sub synchronous oscillations in the power system caused by series capacitance. The control system known as SSDC controller is designed in such a way that the error can be easily detected and compensated. A simple signal is chosen as the input of SSDC, this signal contains all the torsional modes so that the SSSC with the proposed SSDC can improve the stability of system. The SSSC is used as a voltage source in series with a fixed capacitor and TCSC is a thyristor controlled device which is having a fixed capacitance as well as thyristor controlled variable capacitance. From the simulation results we can conclude that the SSSC gives satisfactory results compared to TCSC and

further it can be extended using advance control techniques like fuzzy and neural network for still better performance of SSSC to damp the SSR effects.

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