# Improvement of Transient Stability with SSSC Controller in a Three-Machine Power System for Three Phase Symmetrical Fault

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*Abstract*— An Improvement of transient stability performance with the help of Static Synchronous Series Compensator (SSSC) controller has been presented in this paper. The SSSC is used to control active and reactive powers as well as damping power system oscillations in transient mode. The results obtained from simulations validate the effectiveness of proposed modeling and tuning approach for power system stability improvement. The simulation results also show that the proposed SSSC controller is effective in the three-phase symmetrical disturbance conditions in the power system.The obtained results justify that the proposed SSSC controller is found to be robust to fault location and change in operating conditions. For the simulation purpose, the model of three-machine power system with SSSC controller has been developed in MATLAB/SIMULINK using Sim Power System (SPS) block set.

***Key words:*** Three-machine power system, static synchronous series compensator (SSSC), transient stability

## I. INTRODUCTION

Series capacitive compensation was introduced decades agoto cancel a portion of the reactive line impedance and there-byincrease the transmittable power [1]. The recent development of power electronics introduces the use of Flexible AC Transmission System (FACTS) controllers in power systems [2].Subsequently, within the FACTS initiative, it has been demonstrated that variable series compensation is highly effective in both controlling power flow in the lines and in improving stability [3, 4]. The voltage sourced converter based series compensator, called static synchronous series compensator (SSSC) provides the virtual compensation of transmission line impedance by injecting the controllable voltage in series with the transmission line. The ability ofSSSC to operate in capacitive as well as inductive mode makes it very effective in controlling the power flow of the system [5, 6]. Static Synchronous Series Compensator (SSSC) is one of the important members of FACTS family which can be installed in series in the transmission lines. With the capability to change its reactance characteristic from capacitive toinductive, the SSSC is very effective in controlling power flow in power systems [5]. An auxiliary stabilizing signal can also be superimposed on the power flow control function of the SSSC so as to improve power system oscillation stability [7].The applications of SSSC for power oscillation damping, stability enhancement and frequency stabilization can be found in several references [8-11].

## II. POWER SYSTEM MODEL

The three-machine power system with SSSC shown in Fig. 1 is considered. The system consists of three generators divided into two subsystems and are connected through an inter-tie. The generators are equipped with hydraulic turbine and governor (HTG) and excitation system. The HTG represents a nonlinear hydraulic turbine model, a PID governor system, and a servomotor.The excitation system consists of a voltage regulator and DC exciter, without the exciter's saturation function. In this system three phase symmetrical fault disturbance, the two subsystems swing against each other resulting in instability. To improve the stability the line is sectionalized and a SSSC is assumed on the mid-point of the tie-line. In Fig. 1, $G_1$, $G_2$ and $G_3$ represent the generators; $T/F_1$, $T/F_2$ and $T/F_3$ represent the transformers and $L_1$, $L_2$ and $L_3$ represent the line sections respectively.

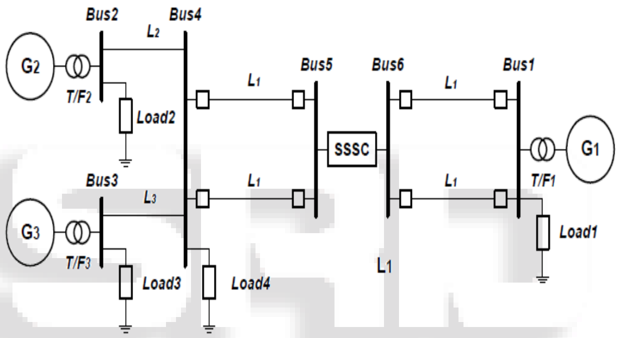


Fig. 1: Three-machine power system with SSSC

## III. CONTROL SYSTEM OF SSSC

The SSSC controller, to modulate the SSSC injected voltage $V_q$. The structure consists of a gain block with gain $K_S$, a signal washout block and two-stage phase compensation block as shown in Fig.2. The signal washout block serves as a high-pass filter, with the time constant $T_W$, high enough to allow signals associated with oscillations in input signal to pass unchanged. From the viewpoint of the washout function, the value of $T_W$ is not critical and may be in the range of 1 to 20 seconds [11]. The phase compensation blocks (time constants $T_{1S}$, $T_{2S}$ and $T_{3S}$, $T_{4S}$) provide the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. In the Fig. 2, $V_{qref}$ 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 $V_{qref}$ is assumed to be constant during large disturbance transient period. The desired value of compensation is obtained according to the change in the SSSC injected voltage $V_q$ which is added to $V_{qref}$.

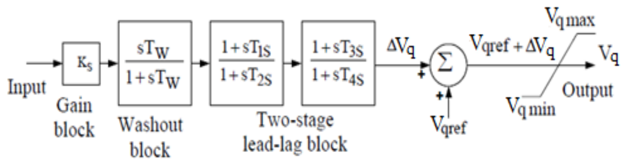


Fig. 2: The SSSC controller

The transfer function of the SSSCcontroller is:

$$U_{SSSC} = K_S \left(\frac{sT_W}{1+sT_W}\right)\left(\frac{1+sT_{1S}}{1+sT_{2S}}\right)\left(\frac{1+sT_{3S}}{1+sT_{4S}}\right)y, \quad (1)$$

Where, $U_{SSSC}$ and $y$ are the output and input signals of the SSSC-based controller respectively. In this structure, the washout time constants $T_W$ and the time constants $T_{2S}$ and $T_{4S}$ are usually pre-specified. In the present study, $T_W = 10s$ and $T_{2S} = T_{4S} = 0.3s$ has been used. The controller gain $K_S$ and the time constants $T_{1S}$ and $T_{3S}$ have to be determined. During steady state conditions $\Delta V_q$ and $V_{qref}$ are constant [8]. During dynamic conditions the series injected voltage $V_q$ has modulated to damp system oscillations. The effective $V_q$ in dynamic conditions is given by:

$$V_q = V_{qref} + \Delta V_q \quad (2)$$

The SSSC controller is designed to minimize the power system oscillations after a large disturbance so as to improve the power system stability. It is worth mentioning that the SSSC controller is designed to minimize the power system oscillations after a large disturbance so as to improve the power system stability. These oscillations are reflected in the deviations in power angle, rotor speed and line power. Minimization of any one or all of the above deviations could be chosen as the objective. In the present study, an integral time absolute error of the speed signals corresponding to the local and inter-area modes of oscillations is taken as the objective function. The objective function is expressed as:

$$J = \int_{t=0}^{t=t_{sim}} \left(\sum \Delta W_L + \sum \Delta W_I\right).t.dt \quad (3)$$

Where, $\Delta W_L$ and $\Delta W_I$ are the speed deviations of inter-area and local modes of oscillations respectively and $t_{sim}$ is the time range of the simulation. In the present three-machine study, the local mode $\Delta W_L$ is $(\omega_2 - \omega_3)$, and the inter-area mode $\Delta W_I$ is $[(\omega_2 - \omega_1) + (\omega_3 - \omega_1)]$, where $\omega_1$, $\omega_2$ and $\omega_3$ are the speed deviations of machines, 1, 2 and 3 respectively.With the variation of the SSSC controller parameters, these speed deviations will also be changed. For objective function calculation, the time-domain simulation of the power system model has been carried out for the simulation period. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots.

## IV. Simulation Results And Discussion

In order to optimally tune the parameters of the SSSC controller, as well as to assess its performance and robustness under wide range of operating conditions with three-phase fault disturbances and fault clearing sequences, the test system depicted in Fig. 3 has been considered for analysis. The MATLAB/SIMULINK model of the example power system has been developed using SPS blockset. The system consists of three hydraulic generating units divided into two subsystems. The ratings of the generators are taken as 2100 MVA each (G2 and G3) in one subsystem and 4200 MVA (G1) in the other subsystem [4]. The generators are represented by a sixth-order model and are equipped with Hydraulic Turbine & Governor (HTG) and Excitation systems. The HTG represents a nonlinear hydraulic turbine model, a PID governor system, and a servomotor. The excitation system consists of a voltage regulator and DC exciter, without the exciter's saturation function. The generators with output voltages of 13.8KV has been connected to an intertie through 3-phase step up transformers. The machines has been equipped with Hydraulic Turbine and Governor (HTG) and Excitation system. These blocks are available in the SPS library powerlib/Machines [1].

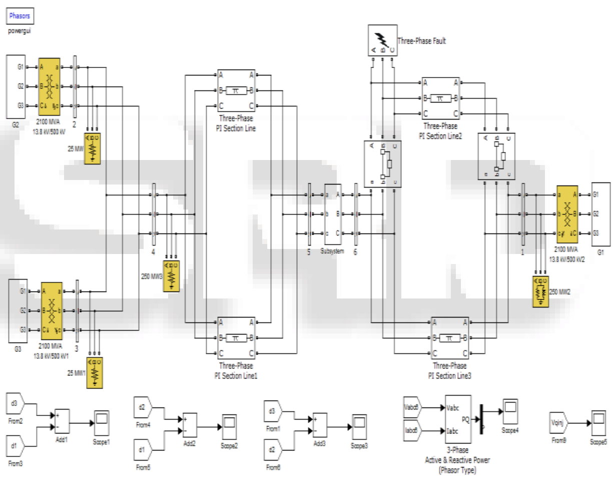

Fig. 3: Simulink Schematics of SSSC Controller in a Three-Machine Power System for Three Phase Fault Near Bus Six

A three-cycle, three-phase fault is applied at one of the line sections between Bus 1 and Bus 6, near Bus 6, at t =1 sec. The fault is cleared by opening the faulty line, and the line is reclosed after three cycles. The original system has been restored after the fault clearance.

Fig. 4(a) shows the Inter-area mode of oscillation ( $\omega_2 - \omega_1$ ) for 3-phase fault disturbance with SSSC. It may observed that overshoot and settling time has been decrease with use the SSSC controller

 

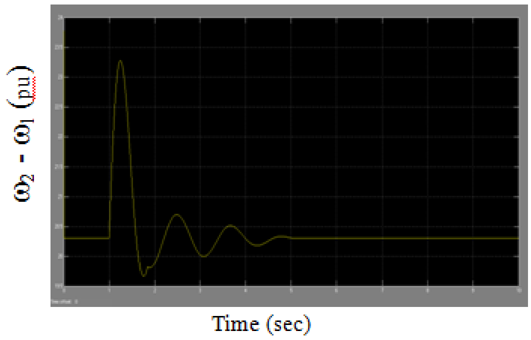


Fig. 4(a): Inter-Area Mode of Oscillation ( $\omega_2 - \omega_1$ ) for 3-Phase Fault Disturbance with SSSC

Fig. 4(b) shows the Inter-area mode of oscillation ( $\omega_2 - \omega_1$ ) for 3-phase fault disturbance without SSSC. In this figure it may be observed that the overshoot and settling time has been high without SSSC controller.

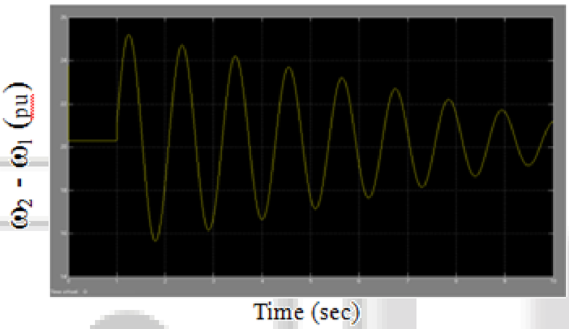


Fig. 4(b):Inter-Area Mode of Oscillation ( $\omega_2 - \omega_1$ )for 3-Phase Fault Disturbance without SSSC

Fig. 5(a) shows the Inter-area mode of oscillation ( $\omega_3 - \omega_1$ ) for 3-phase fault disturbance with SSSC. The overshoot and settling time has been decrease with use the SSSC controller

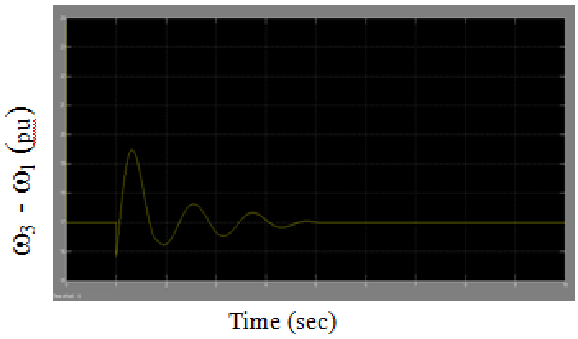


Fig. 5(a):Inter-Area Mode of Oscillation ( $\omega_3 - \omega_1$ ) for 3-Phase Fault Disturbance with SSSC

Fig. 5(a) shows the Inter-area mode of oscillation ( $\omega_3 - \omega_1$ ) for 3-phase fault disturbance without SSSC. The overshoot and settling time has been high without SSSC controller

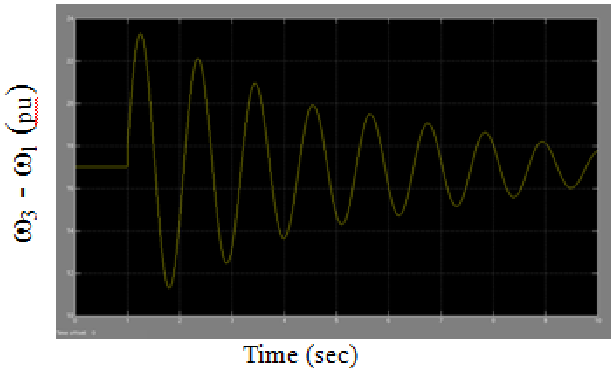


Fig. 5(b):Inter-Area Mode of Oscillation ( $\omega_3 - \omega_1$ ) for 3-Phase Fault Disturbance without SSSC

Fig. 6(a) shows the Local mode of oscillation ( $\omega_2 - \omega_3$ ) for 3-phase fault disturbance with SSSC.In this figure it may be observed that the overshoot and settling time is decrease with use the SSSC controller

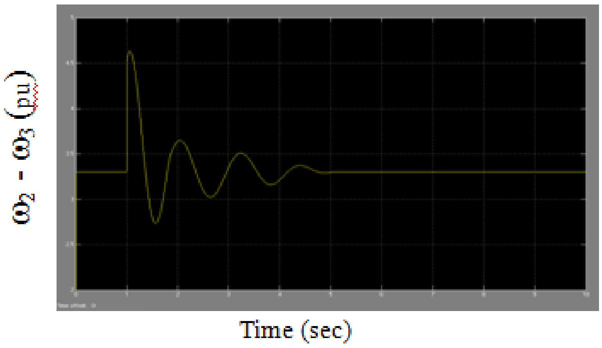


Fig. 6(a):Local Mode of Oscillation ( $\omega_2 - \omega_3$ ) for 3-Phase Fault Disturbance with SSSC

Fig. 6(b) shows the Local mode of oscillation ( $\omega_2 - \omega_3$ ) for 3-phase fault disturbance without SSSC.The overshoot and settling time has been high without SSSC controller

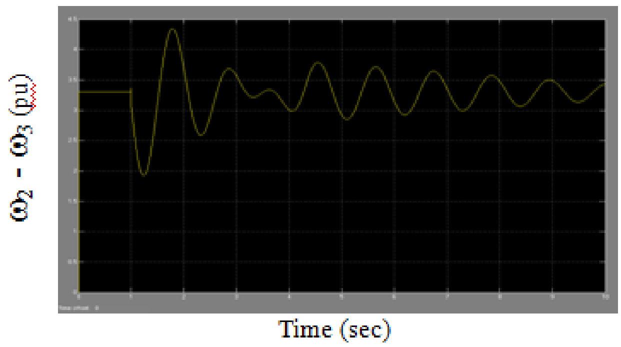


Fig. 6(b):Local Mode of Oscillation ( $\omega_2 - \omega_3$ ) for 3-Phase Fault Disturbance without SSSC

Fig. 7(a) shows the Variation of tie-line power flow for a three-cycle, three-phase fault near Bus 6 cleared by a three-cycle line tripping with SSSC controller.

 

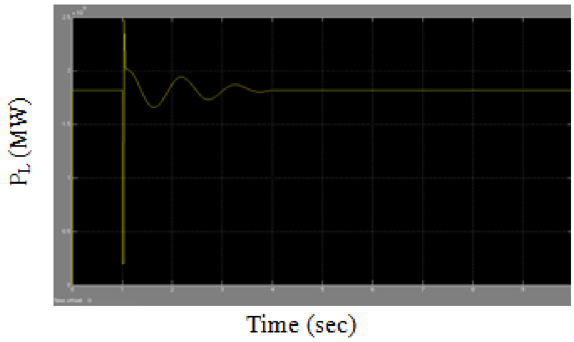


Fig. 7(a):Variation of Tie-Line Power Flow for a Three-Cycle, Three-Phase FaultNear Bus 6 Cleared by a Three-Cycle Line Tripping with SSSC

Fig. 7(b) shows the Variation of tie-line power flow for a three-cycle, three-phase fault near Bus 6 cleared by line tripping without SSSC controller.

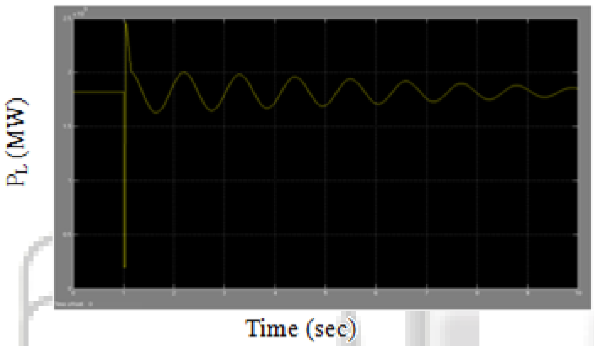


Fig. 7(b):Variation of Tie-Line Power Flow for a Three-Cycle, Three-Phase FaultNear Bus 6 Cleared by Line Tripping without SSSC

Fig. 8 shows SSSC injected voltage ($V_q$) variation for 3-phase fault disturbance

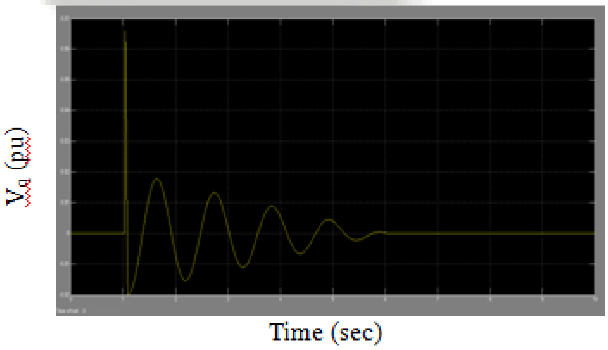


Fig. 8: SSSC Injected Voltage ($V_q$) Variation for 3-Phase Fault Disturbance

From these figures, it may be seen that the inter-area and local modes of oscillations are highly oscillatory in the absence of SSSC controller, and the proposed SSSC controller significantly improves the power-system stability bysubsidingthe damping oscillations.

## V. Conclusions

This paper presents a systematic procedure for modeling, simulation SSSC controller in a multi- machine system for enhancing power system stability. For the SSSC controller design problem, a parameter-constrained, time-domain based, objective function, has been developed to improve the performance of power system subjected to a disturbance. Then, real coded genetic algorithm employed to search for the SSSC controller parameters. The controller has been tested on example power system subjected to various types of disturbances. The simulation results show that, the genetically tuned SSSC controller improves the stability performance of the power system and power system oscillations are effectively damped out under severe disturbance conditions. Further it is observed that the proposed SSSC controller is effective in damping the modal oscillations resulting from unbalanced fault and small disturbance conditions. It may be concluded that, the local and inter-area modes of oscillations of power system can be effectively damped for various disturbances by using the proposed SSSC controller.

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