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Improvement of Transient Stability with SSSC Controller in a Three-Machine Power System for Asymmetrical Faults

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Abstracts

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 asymmetrical disturbance conditions in the power system. The obtained results justify that the proposed SSSC controller is found to be robust for 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.

Keywords: Three-machine power system; static synchronous series compensator (SSSC); transient stability.

Introduction

Series capacitive compensation was introduced decades ago to cancel a portion of the reactive line impedance and there-by increase 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 source 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[5, 6]. Static Synchronous Series Compensator (SSSC) has been one of the important members of FACTS family which may be installed in series in the transmission lines. The ability of SSSC to operate in capacitive as well as inductive mode makes it very effective in controlling the power flow of the system [7, 8]. With the capability to change its reactance characteristic from capacitive to inductive, the SSSC is very effective in controlling power flow in power systems [9, 10]. 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 [11, 12]. The applications of SSSC for power oscillation damping, stability enhancement and frequency stabilization can be found in several references [13-19].

Power system model

The three-machine power system with SSSC has been shown in Fig. 1 is consider in this paper. The system consists of three generators divided into two subsystems and are connected through an inter-tie line. 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 asymmetrical fault disturbance, the two subsystems swing against each other resulting as 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. Bus 1 are connected to inductive load and bus 2, bus 3, bus 4 are connected with resistive load.

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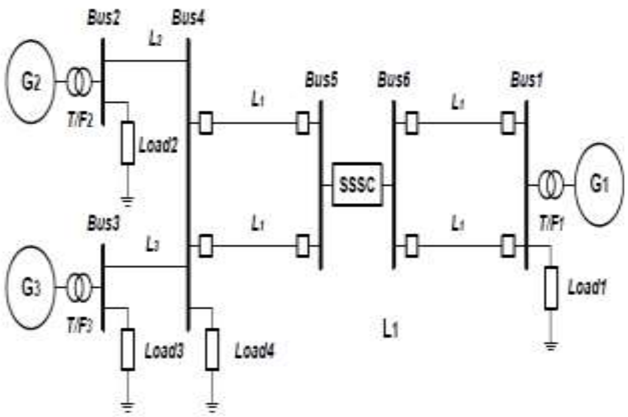

Fig. 1: Three-Machine Power System with SSSC

Mathematical modeling 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 view point of the washout function, the value of T_W is not critical and may be in the range of 1 to 20 seconds [20]. 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}.

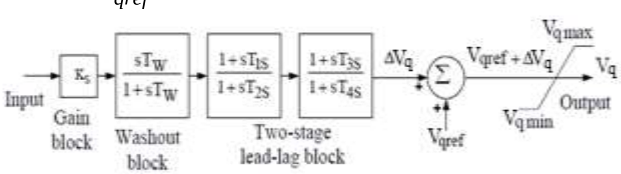

Fig. 2: The SSSC Controller

The transfer function of the SSSC controller 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 ΔV_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, ΔW_L and ΔW_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 ΔW_L is ($\omega_2 - \omega_3$), and the inter-area mode ΔW_I is [($\omega_2 - \omega_1$) + ($\omega_3 - \omega_1$)], where ω_1, ω_2 and ω_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.

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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/Matlab [1].

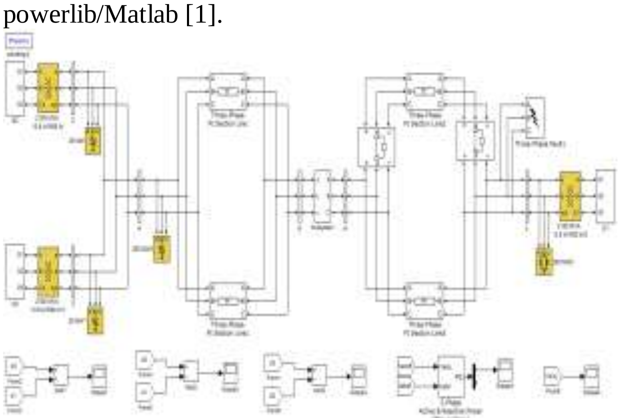

Fig. 3: Simulink Schematics of SSSC Controller in a Three-Machine Power System for Asymmetrical Fault Near Bus One

The effectiveness of the proposed controller to unbalanced faults is also examined by applying self-clearing type unsymmetrical faults namely single line-to-ground, double line-to-ground, and line-to-line of 3-cycle duration, at bus 1. The figure shows the inter-area and local modes of oscillations against time respectively. It is clear from the simulation results that the modal oscillations are poorly damped in uncontrolled case even for the least severe fault and the SSSC controller effectively stabilizes the modal oscillations under various unbalanced fault conditions.

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

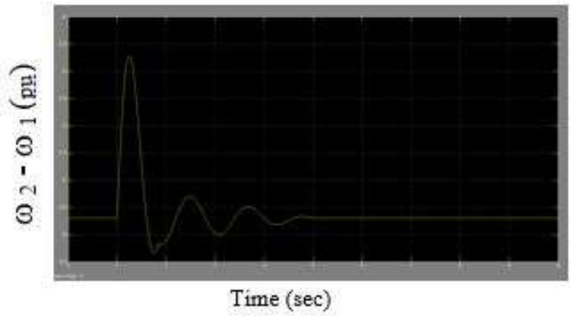

Fig. 4: Inter-Area Mode of Oscillation ($\omega_2 - \omega_1$) for LG Disturbance with SSSC

Fig. 5 shows the Inter-area mode of oscillation ($\omega_2 - \omega_1$) for LLG fault disturbance with SSSC. It may observed that overshoot has been decreased and settle after 4 sec. with use the SSSC controller

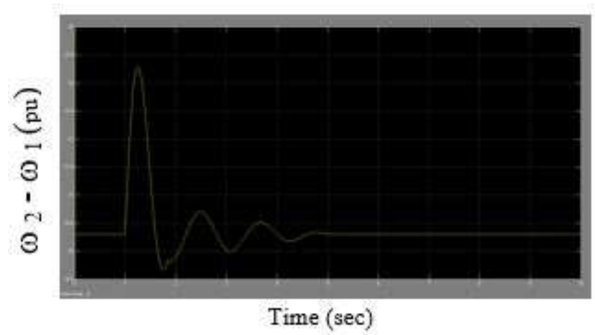

Fig. 5: Inter-Area Mode of Oscillation ($\omega_2 - \omega_1$) for LLG Fault Disturbance without SSSC

Fig. 6 shows the Inter-area mode of oscillation ($\omega_2 - \omega_1$) for LL fault disturbance with SSSC. The overshoot and settling time has been decreased with use the SSSC controller

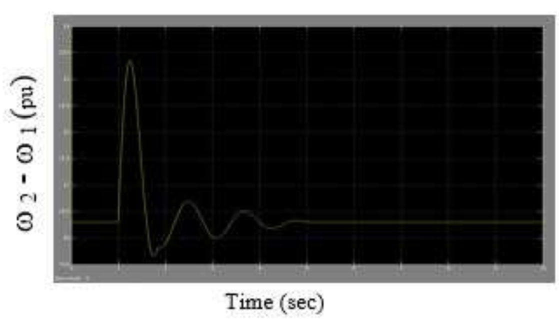

Fig. 6: Inter-Area Mode of Oscillation ($\omega_2 - \omega_1$) for LL Fault Disturbance with SSSC

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Fig. 7 shows the Local mode of oscillation ($\omega_2 - \omega_3$) LG fault disturbance with SSSC. In this figure it may be observed that the overshoot and settling time is decreased with use the SSSC controller

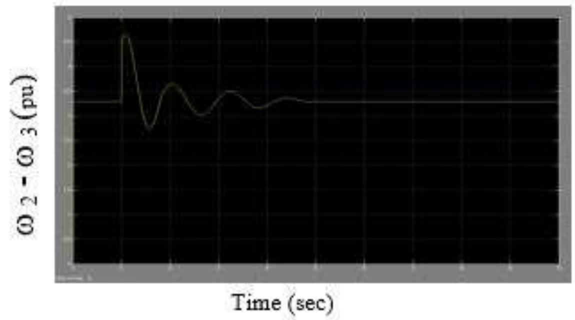

Fig. 7: Local Mode of Oscillation ($\omega_2 - \omega_3$) for LG Fault Disturbance with SSSC

Fig. 8 shows the Local mode of oscillation ($\omega_2 - \omega_3$) for LLG fault disturbance with SSSC. In this figure it may be observed that the overshoot and settling time is decreased with use the SSSC controller

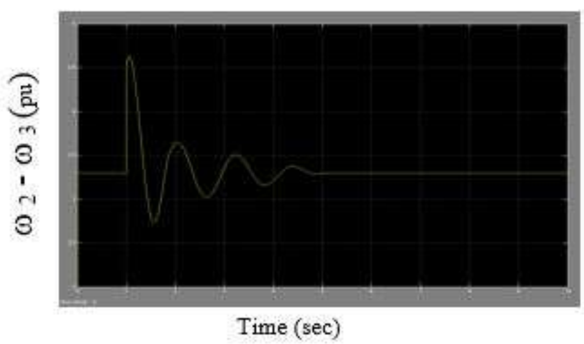

Fig. 8: Local Mode of Oscillation ($\omega_2 - \omega_3$) for LLG Fault Disturbance with SSSC

Fig. 9 shows the Local mode of oscillation ($\omega_2 - \omega_3$) for LL fault disturbance with SSSC. In this figure it may be observed that the settling time is 4.3 sec. with use the SSSC controller

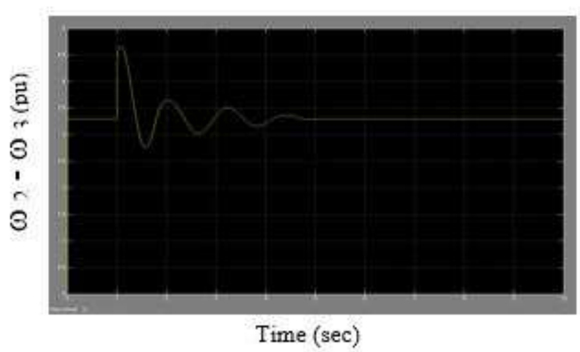

Fig. 9: Local Mode of Oscillation ($\omega_2 - \omega_3$) for LL Fault Disturbance with SSSC

Fig. 10 shows the Variation of tie-line power flow for a three-cycle, asymmetrical fault near Bus 1 cleared by a three-cycle line tripping with SSSC controller.

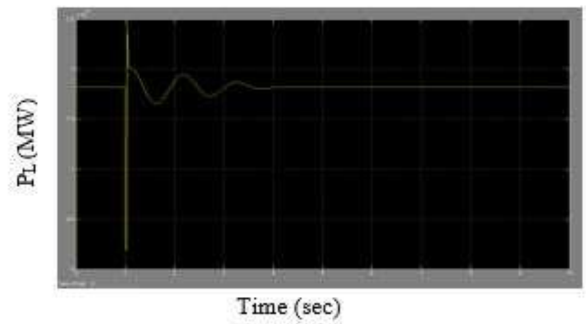

Fig. 10: Variation of Tie-Line Power Flow for a Three-Cycle, Asymmetrical Fault Near Bus 1 Cleared by a Three-Cycle Line Tripping with SSSC

Fig. 11 shows SSSC injected voltage (V_q) variation for asymmetrical fault disturbance

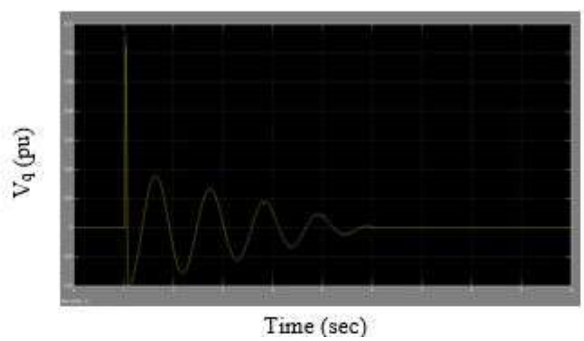

Fig. 11: SSSC Injected Voltage (V_q) Variation for Asymmetrical Fault Disturbance

From these figures, the proposed SSSC controller significantly improves the power-system stability by subsiding the damping oscillations.

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. 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

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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 asymmetrical 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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