Damping Subsynchronous Oscillations in Power System using Shunt and Series Connected FACTS Controllers

Dr. Narendra Kumar, Sanjiv Kumar and Vipin Jain

***Abstract*— Series compensation in long transmission lines is an effective solution of enhancing power transfer capacity of Power System network. In this paper, series passive compensation and shunt active compensation provided by static synchronous compensator (STATCOM) and other FACTS controllers connected at the electrical center of the transmission line are considered. The presence of series capacitors has given rise to the phenomena Subsynchronous Resonance (SSR) .But in few conditions such as in fault conditions, SSR phenomenon takes place which can damage the turbine generator shaft. In this paper SSR phenomenon is studied with modified IEEE second benchmark model and various techniques has been developed for damping of SSR by adjusting the series compensation and using the FACTS controllers. Results have been taken with the help of MATLAB simulation.**

***Index Terms*--FACTS, SSR, STATCOM, UPFC.**

I. INTRODUCTION

CONTROL by changing the network parameters is an effective method of improving transient stability. Flexible ac transmission system (FACTS) controllers due to their rapid response are suitable for transient stability control since they can bring about quick changes in the network parameters. Transient stability control involves changing the control variables such that the system state enters the stability region after a large disturbance [1].

FACTS controllers based on voltage source converters use turn off devices like Gate Turn-Off Thyristors (GTO). The magnitude and angle of the fundamental frequency voltage injected by the converter is varied by controlling the switching instants of the GTO devices. These type of FACTS controllers have the advantages of reduced equipment size and improved performance compared to variable impedance type controllers. Static VAR compensator (SVC) and thyristor controlled series capacitor (TCSC) are variable impedance type controllers. SVC is a shunt controller and TCSC is a series controller [3]. Static compensator (STATCOM), static synchronous series compensator (SSSC) and unified power flow controller (UPFC) are voltage source converter based controllers..UPFC consists of a shunt converter and a series converter, which have a common dc capacitor. UPFC injects a series voltage and a shunt current. The series and shunt branches of UPFC can generate/absorb reactive power independently and the two branches can exchange real power; therefore, UPFC has three degrees of freedom [4]. Series capacitive compensation is a very useful way for increasing the transmission capacity and improving transient stability of the transmission system.However, one problem associated with it is the risk of Subsynchronous Resonance (SSR) [2].Therefore, overcoming such a problem has been an active area of research [19].

Subsynchronous resonance is addressed in three categories (i) induction generator effect (ii) torsional effect (iii) torque amplification. In all cases SSR is due to the interaction of a series capacitor with turbine generator. The first two types are caused by a steady state disturbance, while the third is excited by transient disturbance. Flexible AC transmission system (FACTS) technology provides unprecedented way for controlling transmission grids and increasing transmission capacity [7–9]. FACTS controllers have the flexibility of controlling both real and reactive power which could provide an excellent capability for improving power system dynamics. Several studies have investigated the potential of using this capability in mitigating SSR of series capacitive compensated transmission grids [10–15].

Two IEEE benchmark models have been proposed by the IEEE-SSR Working Group. These benchmark models have obtained world-wide acceptance and are extensively used for the study of different proposed damping devices SSR countermeasures [16-17].

The use of the thyristor controlled series capacitor (TCSC),static synchronous compensator and static synchronous series compensator in their balanced mode of operations has been implemented and/or studied as means for damping SSR. Generally FACTS controllers are used for power flow control and voltage stability [18-20]. Very less research has been carried out for damping of SSR using FACTS devices. In our research paper we have shown that UPFC is an effective FACTS device for damping of SSR. [21-28].

In this research paper we have developed a transmission system in MATLAB very similar to the IEEE second benchmark model. In IEEE Second benchmark model shunt capacitance is not incorporated, but we have included shunt capacitances also. The major conclusions of the paper are

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given in Table-I. Series compensation is taken 30% of inductive reactance. Following cases have been studied.

II. SAMPLE MATLAB/SIMULINK RESULTS

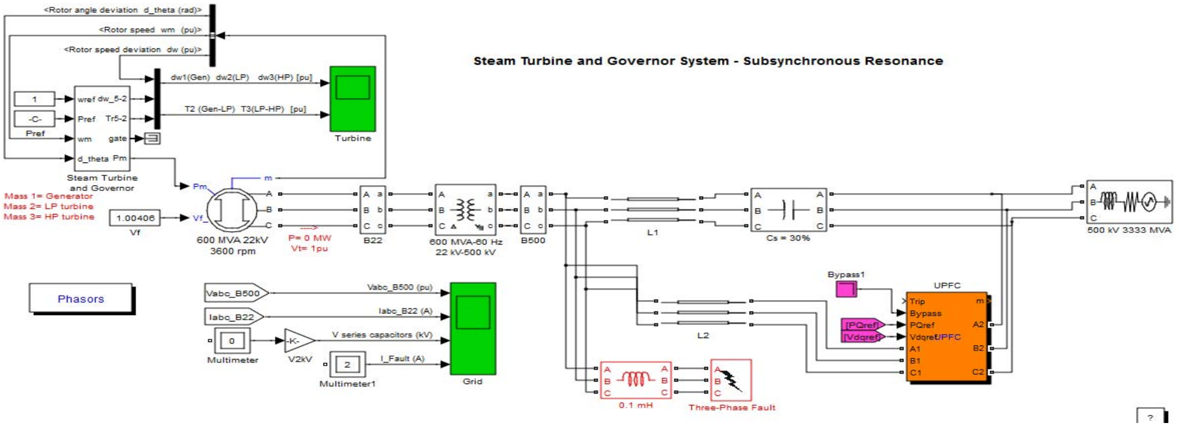


Fig.1 MATLAB/SIMULINK Unified Block Functional model of the sample T-G and infinite bus system with IEEE SSR Bench mark Model-2

Fig. 1 shows the unified block functional model of the sample turbine-generator and infinite bus system. The system is developed IEEE benchmark [17] model used to study SSR-oscillations following a three phase bolted short circuit fault has been applied and cleared on a series-compensated power system. FACTS devices are a powerful tool to improve the voltage profile of the system. In this paper SVC, SSSC, UPFC and STATCOM were simulated using MATLAB simulink technique. SVCs are responsible for the parts dealing with the voltage and the active power losses and SSSC as well as STATCOM account for the part concerning line loadings. Finally, simulations show the improvements in damping SSR and the voltages became more balanced and active power losses were reduced. The degree of series capacitance compensation is 30%.

It is helpful to look at the two SSR types within the classification which results from different sets of assumptions in our simplified model:

a) *Constant current field winding:* Only torsional interaction is present as a result of which currents and voltages at subsynchronous frequency in the stator and the shaft torque grow.

b) Damper winding on the rotor with zero initial current: Only induction generator effect is present as a result of which currents and voltages at subsynchronous frequency in the stator, current in the rotor and the shaft torque grow.

c) Constant current field winding, constant synchronous speed: Interaction at subsynchronous frequency between the stator and rotor circuits stops. If there is no resistance in the stator, the subsynchronous currents and voltages resulting from initial conditions continue to exist without growing.

Also the electromagnetic torque component on the generator rotor is present, but since with our constant speed assumption we have actually placed an independent torque source on the generator rotor which completely compensates this torque, the mechanical oscillations do not grow.

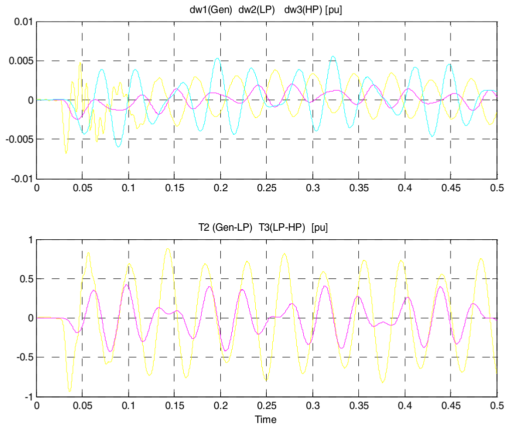
d) Damper winding with zero initial current, constant synchronous speed: Interaction at synchronous frequency between the stator and rotor circuits stops. The electrical induction effect on the stator side results in currents and voltages at subsynchronous frequency to grow.

The study cases indicate that the SSR consequences of series capacitor compensation of long transmission lines are greatly influenced by the number of bus connected parallel generating units in operation at the time of transient fault occurrence and the worst case SSR oscillations occur when two units are in operation.

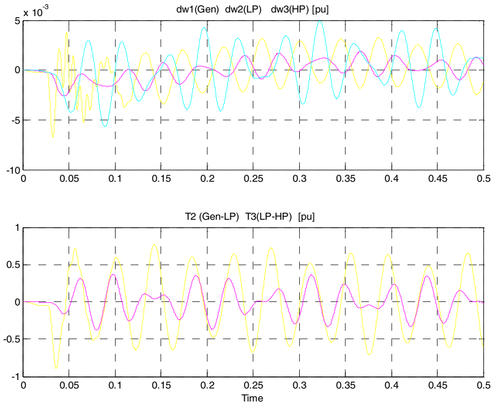
III. SERIES AND SHUNT CONNECTED FACTS CONTROLLERS FOR ANALYSIS

The following cases are discussed for investigation:

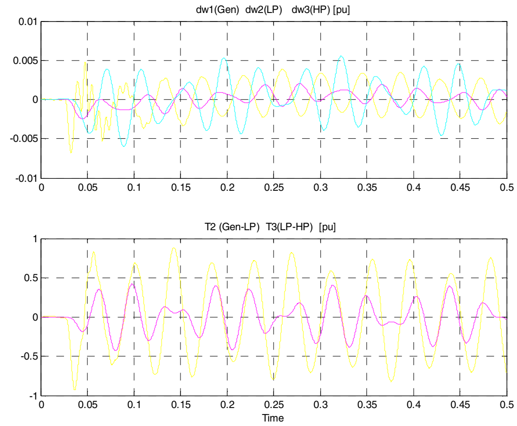
CASE-1 Without FACTS Controller



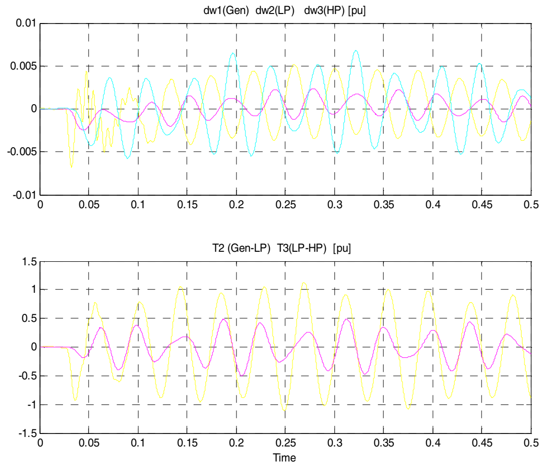
CASE-2 With UPFC



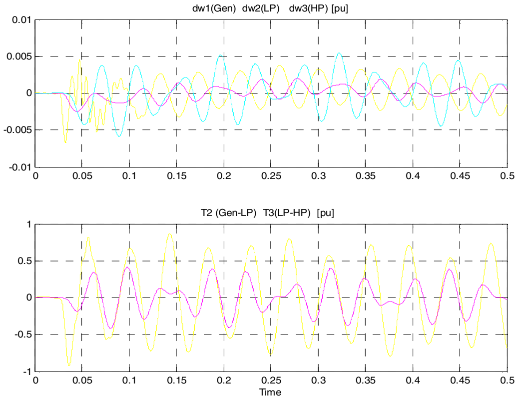
CASE-3 With SVC



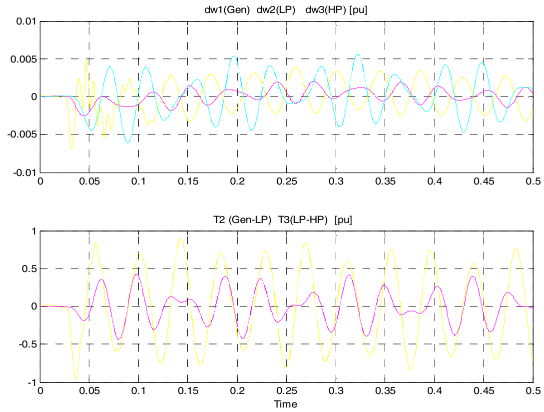
CASE-4 With SSSC



CASE-5 With STATCOM



CASE-6 Without FACTS Controllers but shunt capacitance of Transmission lines is increased to 1.5 times



CASE-7 Without FACTS Controllers but shunt capacitance of Transmission lines is increased to 3 times

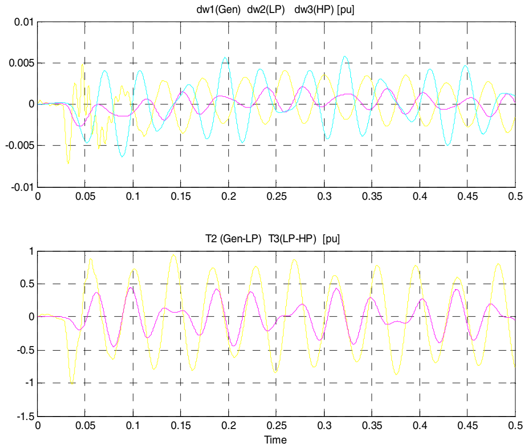


TABLE I

PEAK TORQUES OF ALL THE ABOVE SEVEN CASES

Case No.	Peak Torques (pu)				Speed Deviation %					
	Gen-LP		LP-HP		Generator		LP		HP	
1	0.885	-0.937	0.4227	-0.4305	4.777e-3	-6.82e-3	2.015e-3	-2.48e-3	5.544e-3	-6.005e-3
2	0.770	-0.896	0.366	-0.3795	3.793e-3	-6.74e-3	1.892e-3	-2.6e-3	4.95e-3	-5.7e-3
3	0.885	-0.931	0.42	-0.43	4.777e-3	-6.776e-3	2.036e-3	-2.467e-3	5.5743e-3	-6.02e-3
4	1.13	-1.105	0.494	-0.498	5.157e-3	-6.81e-3	2.383e-3	-2.465e-3	6.787e-3	-5.77e-3
5	0.864	-0.926	0.4125	-0.42	4.567e-3	-6.746e-3	1.995e-3	-2.46e-3	5.442e-3	-5.9e-3
6	0.9	-0.961	0.4282	-0.4365	4.815e-3	-6.96e-3	2.045e-3	-2.53e-3	5.615e-3	-6.1e-3
7	0.939	-1.02	0.445	-0.453	4.88e-3	-7.22e-3	2.115e-3	-2.67e-3	5.8e-3	-6.4e-3

IV. CONCLUSION

The paper presents a method to damp subsynchronous resonance (SSR) oscillations for large synchronous generators. In this paper, we have studied the characteristics of a transmission line compensated by series capacitor with the FACTS provided at the electrical center of the transmission line. These controllers are able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (i.e. voltage, impedance and phase angle). SSR phenomenon increase with the increase in shunt capacitance of transmission lines. Through analyzing the changes of system's electrical damping based on complex torque coefficient approach before and after running with SVC, it has indicated that SVC controller can mitigate SSR effective and robust. The following points emerge based on the results of the case study (Table-I).

1. UPFC and SVC are the most effective devices for SSR damping.
2. SSR Phenomenon increase with the increase in shunt capacitance of Transmission lines.
3. SSSC is the least effective device for SSR damping.
4. The inclusion of STATCOM does not change the SSR characteristics of the network significantly.

The cases investigated in this paper provide comparison between various FACTS Devices (i.e between UPFC, SVC, SSSC, and STATCOM). Our research is going on that what may be the optimum control parameters of UPFC for damping of SSR.

V. APPENDIX

AC System Parameters:

System Voltage: 500 kV
System frequency: 50 Hz
(a)Parameters of both the Transmission lines (3 phase):
Resistance/km : 0.02 ohm, Inductance/km : 0.9 H
Capacitance/km: 13 µF,
Length of Transmission Line: 200 km
Capacitive reactance: 30% of inductive reactance.
(b)Data of Synchronous Generator (3 phase, round rotor):
Nominal Power: 600MVA
L-L voltage: 22 kV
Reactances: $X_d = 1.65$, $X_d' = 0.25$, $X_d'' = 0.2$, $X_q = 1.59$, $X_q' = 0.46$, $X_q''=0.2$
d- axis time constant : open circuit
q- axis time constant : open circuit
Time Constant:
$T_{do}'= 4.5$ sec, $T_{do}''= 0.04$ sec, $T_{qo}'= 0.67$ sec, $T_{qo}''= 0.09$ sec
Stator resistance= 0.0045 pu
(c)Power Transformer (Delta/Star):
Nominal Power: 600 MVA(3 phase)
Rated voltage: 22kV/500kV (Line-Line)

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