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A Comparative Study on Damping of SSR Using TCSC and UPFC

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Abstract: ***Series capacitive compensation of AC transmission system provides most economical way to increase power transfer capability of existing transmission lines, control of load sharing of parallel lines & enhance transient stability. When series compensated transmission system is connected to a steam Turbine-Generator Set, it may lead to Subsynchronous Resonance (SSR) which may damage the machine shaft. FACTS controllers are gaining importance for controlling SSR. This paper presents an analysis of impact of TCSC & UPFC on Subsynchronous Oscillation problem. IEEE Second Benchmark Model is used to evaluate the effectiveness of TCSC & UPFC on SSR. The simulation results obtained using MATLAB are then compared to study the effect of two systems without FACTS device and with above mentioned FACTS device.***

Keywords: Subsynchronous Resonance, series compensated transmission line, FACTS device, TCSC, UPFC, MATLAB.

1. Introduction

Series capacitive compensation is an economical attractive and excellent method to increase power transfer capability, to improve voltage profile of transmission lines, to enhance steady state stability of system and to control the load sharing among parallel lines. However, use of series compensation technique may lead to some new problem in power system operation. When this technique is applied to steam turbine-generator, due to interaction between an electrical mode of series compensated network and a mechanical shaft mode of a turbine-generator group, it may result subsynchronous resonance phenomenon. This phenomenon causes the failure of T-G shaft and electrical instability at oscillation frequency below synchronous frequency of the system.

Two incidents of shafts failure occurred in December 1970 & October 1971 at the Mohave Generating Station in Southern Nevada (USA). These incidents alerted the power engineering community about the dangers of SSR. Since then many researches & developmental efforts have been done for developing the effective methods for SSR mitigation.

IEEE Definition of SSR: " Subsynchronous oscillation is an electric power system condition where electric network exchanges significant energy with a turbine-generator at one or more of natural frequencies of the combined system blow the synchronous frequency of the system following a disturbance from equilibrium."

This definition includes both "natural modes" of oscillation that are due to inherent system characteristics and "forced modes" of oscillation that are driven by a particular device or control system. SSR is categorized into three types depending on the type of the disturbance. Induction generator effect & Torsional interaction are caused by steady state disturbance whereas Torque amplification is excited by transient disturbance. To overcome this problem, many techniques have been used and proposed by the researchers.
Use of FACTS device for damping SSR is one of the measures. Since FACTS devices are best compensating device as these have the flexibility of controlling both active & reactive power in the system. In this paper, two FACTS device TCSC & UPFC have been used for damping torsional oscillations in series capacitive compensated system. For the analysis of SSR, IEEE Second Benchmark Model is used. The simulation results of these devices are obtained from MATLAB software by considering two systems, first without FACTS device and second with FACTS devices. These results are then compared to know the effectiveness of TCSC & UPFC on damping of subsynchronous oscillations.

2. Power System Study Model

To analyze subsynchronous resonance phenomenon on a series compensated power system, IEEE Second Benchmark Model[1] is used. It consists of a synchronous generator (600MVA/22Kv/60Hz/3600rpm) supplying power to an infinite bus via two parallel transmission lines. One of the transmission lines is 55% compensated by a series capacitor. The mechanical system consists of a high pressure turbine (HP), low pressure turbine (LP), the generator (GEN) and rotating exciters (EXC). When a disturbance occurred and cleared in transmission system, compensation capacitor introduces subsynchronous mode. This excites the oscillatory torsional mode of multimass shaft system. With growing rotor oscillations, induced voltages and currents will grow, resulting in excessive mechanical shaft torques.

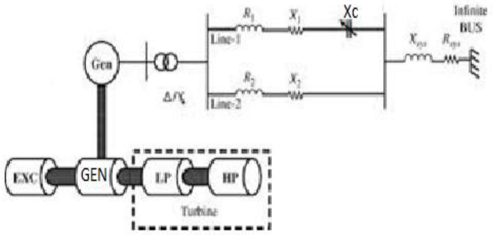

Figure 1: IEEE Second Benchmark Model

3. Thyristors Controlled Series Compensator (TCSC)

A TCSC is a series cotrolled capacitive reactance. It comprises of a series compensating capacitor shunted by a thyristor controlled reactor (TCR) shown in Fig.2.

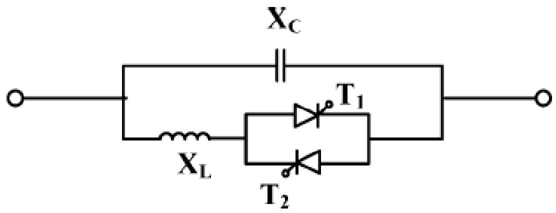

Figure 2: Basic structure of TCSC

TCSC can be used for several power system performance improvements, namely, enhancing system stability, damping of power oscillations, compensating transmission line reactance, increasing or controlling power transfer. Due to its flexible control, it becomes an effective device for damping the electromechanical and subsynchronous oscillations. TCSC can operate in capacitive or inductive mode. To change the operating mode of TCSC, firing angle of thyristors is controlled, although capacitive mode can be considered to be main control mode.

Many theoretical analysis & field tests of [2], rotor speed signals were used to modulate firing angle of TCSC to excite a torsional oscillation mode. This modulation on firing angle has some influence on SSR. It was shown in [2] that when conduction angle of thyristors is approximately wide, TCSC is almost SSR neutral. SSR does not occur for moderate generator damping. But for narrow conduction angle, it shows large negative damping. So in such case of insufficient generator damping, firing angle of TCSC must be modulated. Therefore with some modulation in firing angle of TCSC, there is significant effect on SSR. With frequency scanning method in [3], it was shown that between frequency range 5Hz-47Hz, TCSC is inductive. Beyond this frequency range, TCSC then passes through parallel resonance & become capacitive. This means that in SSR frequency range and with proper firing angle of order of 169^0-170^0, TCSC operating under impedance control is potentially effective to avoid torsional interactions. Thus it is cleared that TCSC can damp SSR if its firing angle is modulated with rotor angle variation.
The TCSC impedance is purely capacitive at a nominal synchronous frequency. It can be raised above the rated capacitance of the series capacitor by a factor of2.5-3 through the appropriate firing angle control. However, at subsynchronous frequencies, the TCSC under constant reactance control presents a very different impedance characteristic. This can greatly helps in damping the subsynchronous oscillations.

4. Unified Power Flow Controller (UPFC)

UPFC is the most versatile FACTS controller capable of controlling voltage, power angle & transfer impedance. It consists of shunt connected voltage source converter (VSC1) and series connected voltage source converter (VSC2) as shown in Fig.3. injection of series reactive voltage by VSC2 provides active series compensation while injection of shunt reactive current by VSC1 regulates the voltage at bus where VSC1 is connected. The capacitor voltage is regulated at the specified value by dc voltage controller to maintain power balance shunt & series branches.

In this paper UPFC is realized by two three level 12 pulse VSCs. As there is not much published work on analysis of SSR with UPFC, it becomes essential to establish validity of models used. It was concluded in [4] that UPFC without supplementary damping controller cannot be able to damp the oscillations of SSR phenomenon. So ANFIS controller was suggested for UPFC to mitigate the SSR. The aim of this paper is also to investigate the detailed SSR characteristics of UPFC by considering IEEE Second Benchmark Model.

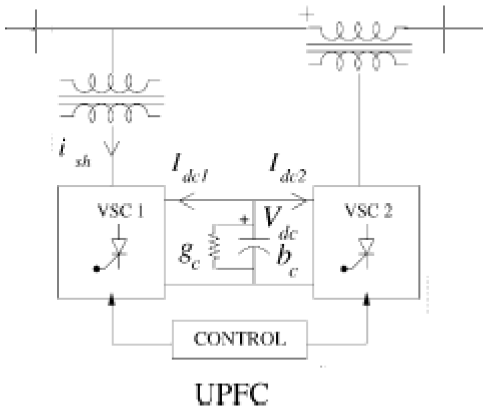

Figure 3: Basic structure of UPFC

5. Simulation Implementation

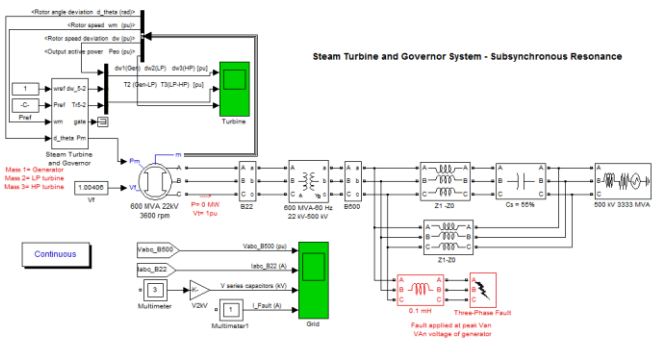

Figure 4: Simulink model of IEEE Second Benchmark System

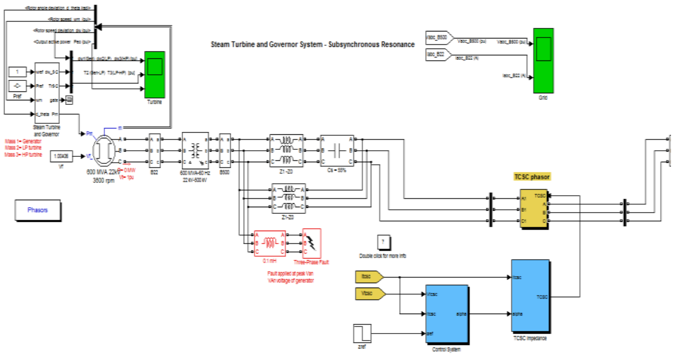

Figure 5: Simulink modelling TCSC

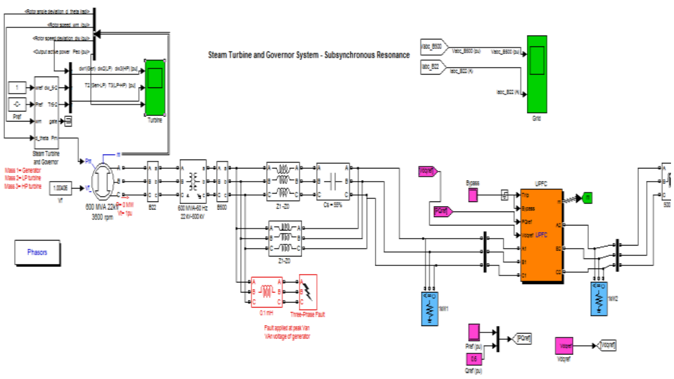

Figure 6: Simulink modelling UPFC

6. Simulation Results

The MATLAB simulation is carried using three specifications (1) System without FACTS device (2) System with TCSC (3) System with UPFC. Without FACTS device the system become more unstable for three phase fault at infinite bus. When FACTS device is connected to the series compensated line, it stabilizes the common mode oscillations.

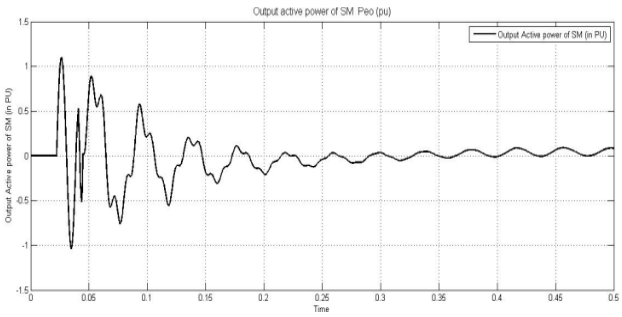

Figure 7: Variation of power without TCSC & UPFC

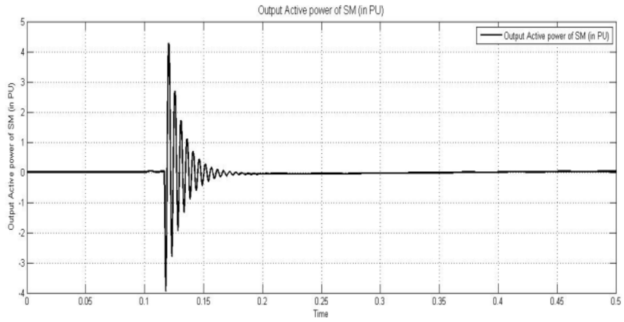

Figure 8: Variation of power with TCSC

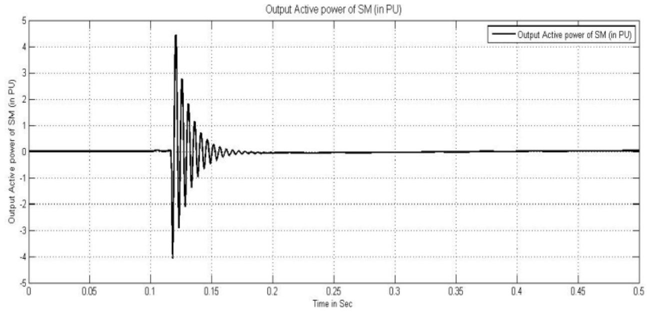

Figure 9: Variation of power with UPFC

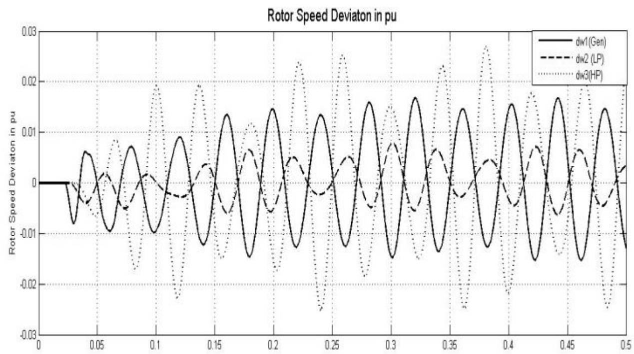

Figure 10: Variation of rotor speed without TCSC & UPFC

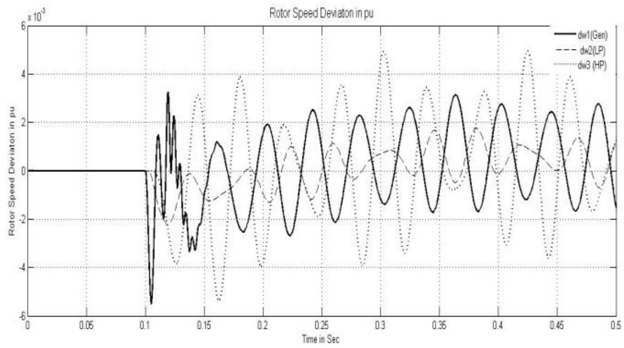

Figure 11: Variation of rotor speed with TCSC

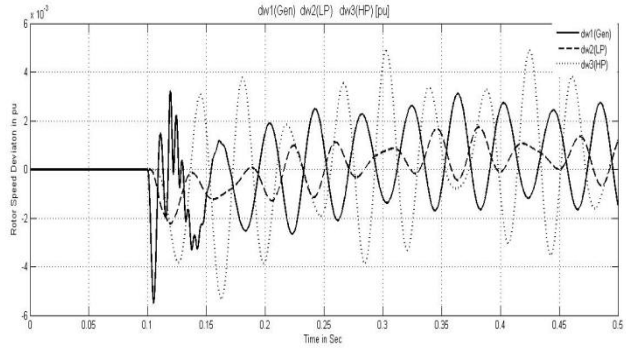

Figure 12: Variation of rotor speed with UPFC

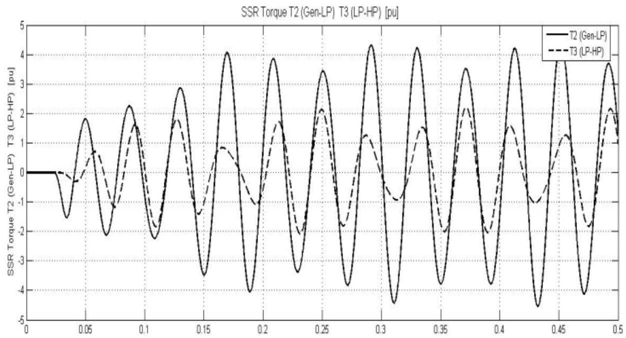

Figure 13: Variation of SSR torques without TCSC & UPFC

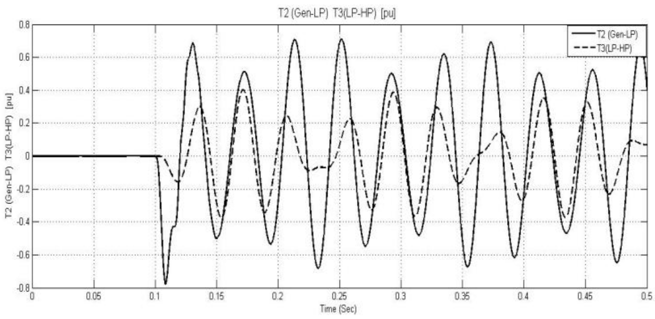

Figure 14: Variation of SSR torques with TCSC

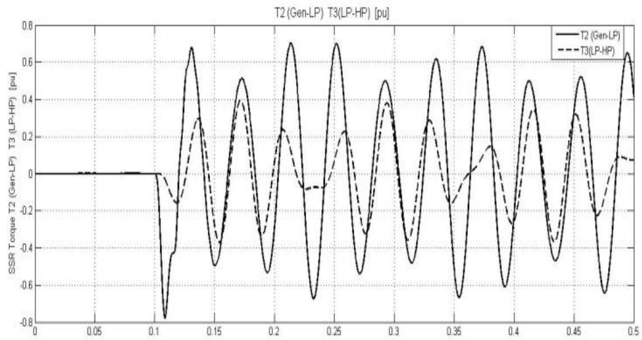

Figure 15: Variation of SSR torques with UPFC

7. Conclusion

In this paper IEEE Second Benchmark Model is used to study the subsynchronous resonance effect. The simulation results of two systems without FACTS device and with FACTS device like TCSC and UPFC are compared. From simulation results we can conclude that by placing TCSC & UPFC on a series compensated transmission line, there is a cons+iderable variation in power flow, rotor speed and SSR torques. Hence the proposed FACTS controllers can effectively damp the subsynchronous oscillations present in the power system. So these devices can be employed successfully to mitigate the SSR.

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