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Damping of Subsynchronous Resonance in an Series Compensated System using PSCAD

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Abstract-Series capacitor compensation in AC transmission systems may cause sub synchronous resonance that can lend to turbine generator shaft failure. Series capacities also have a tendency to amplify the shaft stress during major network transient events. When the level of series compensation is increased subsynchronous Resonance will be more. The mode of oscillation between the electrical and mechanical system will be high. The major concern of sub synchronous resonance is self excitation and Transient Toque Amplification. This paper is based on IEEE first Bench mark model and provides an overview of sub synchronous resonance for the various level of series compensation. The paper also provides method for mitigating sub synchronous Resonance problems. Simulation is carried out in PSCAD Software.

Keywords- IEEE first Benchmark Model, Self-Excitation, Series Capacitors, Subsynchronous Resonance, Transient Torque Amplification

I. INTRODUCTION

The applications of series capacitors to compensate the inductive reactance of long transmission lines for improved stability[1]. Series capacities compensation in AC transmission systems is an economical means to increase load carrying capability, control load sharing among parallel lines and enhance transient stability which is widely used is Chinese power grid to unbalanced resource location [2]. However capacitors in series with transmission lines may cause SSR that can lead to turbine generator shaft failure. Sub synchronous Resonance is an electrical power system condition where the electrical network exchanges energy with turbine generator at one or more of the natural frequency of the combined below the sub synchronous frequency. A numbers of mechanical masses of the turbine generator shaft oscillate at some frequencies known torsional oscillations which are characterized by their mechanical properties like spring constants and mass inertia. The frequencies of these oscillator range from 10Hz to 55Hz for 50Hz systems [3]. The major concern of SSR is the Self Excitation and transient torque Amplification. The mitigation of Self-Excitation effect is done by increasing the network resistance of the transmission line. Further damping SSR oscillation is done through dissipating the energy during resonance in resistor banks[4].

II. OVERVIEW OF SUBSYNCHRONOUS RESONANCE

Subsynchronous oscillations is used as collective term for tensional oscillations, electrical oscillations or a combination of the two at frequencies below the fundamental. Torsional interaction between the mechanical system and active system component such as excitation controls, speed governors and HVDC controls [5]. For the discussion of SSO a simple system, consisting of turbine generator connected to a single series compensated transmission line is considered. The turbine generator has only two masses connected by a shaft acting as a torsional spring. Eigen value analysis is done for analysis the SSR phenomenon [6].

A. SSR in series compensated system

Series capacitors in combination with inductive transmission networks components such as machine, transformers and transmission lines constitute an electric resonance circuit. For a simple radial system the resonance frequency is calculated as

$$f_{er} = f_o\sqrt{\frac{X_C}{X_L}} \qquad (1)$$

Where f_o is the nominal system frequency, X_C is the capacitive reactance and X_L is the inductive reactance. As series compensation level is high SSR will be high. Hydro generator are prone less risk of SSR than thermal generator based on Generator to turbine inertia ratio[7].

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B. Self Excitation

In a power system employing series capacitor compensated transmission line, electrical subsynchronous terminal voltage components. These voltages components may sustain the currents to produce the effect that is called self excitation.In the reference frame of the subsynchronous mode, the rotor act as an induction machine rotor running above synchronous speed with a negative damping element between the two masses and each mass has a damping element. The electrical system has single resonant frequency and the mechanical spring mass system has a single natural frequency. The electrical system may be complex grid with many series compensated lines resulting numerous resonance frequencies f_{er1}, f_{er2}, f_{er3} etc. likewise the turbine generator may have several masses connected by shafts resoling in several natural tensional frequencies f_{n1}, f_{n2}, f_{n3} etc.. For any electrical system disturbance, there will be armature current flow in the three phases of the generator at frequency fer. Turbine and generators unit of thermal is connected to series compensated system as shown in Fig.1

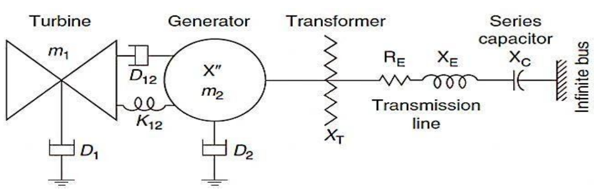

Fig.1.Turbine and generators unit of thermal is connected to series compensated system.

The positive sequence component of these current will produce a rotating magnetic field at an angular electrical speed of $2f_{er}$ currents are induced in the rotor winding due to the relative speed of this rotating filed and the speed of the rotor. The armature magnetic field rotating at an angular frequency of f_{er} integrals with the rotor dc field rotating at an angular frequency of f_o to develop and electromagnetic tongue component on the generator rotor at an angular frequency of f_o-f_{er}.This torque component contributes to torsional interaction.

$$S = \frac{f_{er} - f_o}{f_{er}} < 0 \qquad (2)$$

The effective resistance of the machine seen from the stator terminals can be negative and possibly exceed the external network resistance in magnitude. In such case SSR will grow. Therefore when viewed from the generator terminals the rotor offers negative resistance. When this negative resistance is equal to or greater than positive network resistance at the resonant frequency the currents are sustained and will grow in magnitude Torosional interaction occurs due to the induced sub synchronous torque in the generator is close to one of the tensional natural modes of the turbine generator shaft. Generator rotor oscillations will build up and this motion will induce armature voltage components at both sub synchronous and supper synchronous frequency. The armature voltage components are related to the torsional mode frequency by their Equation

$$f_{en}^{\pm} = f_o - f_n \qquad (3)$$

If resonance frequency is close to a natural frequency of the electrical system. The sub synchronous current component produces an osculating component of air gap toque in phase with the rotor speed elevation where as the tongue associate with the super synchronous current is anti-phase with the rotor speed deviation. SSR interaction with power system controls such as HVDC controls and governors[8].

C. Transient Torque Amplification

A sudden change of the subsynchronous frequency current in a series compensate system will produce transient current at the natural frequency of the system. If the complement of this natural frequency is close to the torosional mode frequency of a connected machine, the shaft torque a system fault will reach levels which are larger than they would be in uncompensated systems. This phenomenon is known as transients torque Amplification.System disturbances cause would changes in the network, resulting in sodden change in currents that will tend to oscillate at the natural frequencies of the network.

III. NETWORK MODEL

A series capacitor compensated transmission line may be represented by the RLC circuit. Torosional interaction
and electrical damping of the synchronous machine are given in [9] Consider an simple radial series compensated system as shown in Fig.2

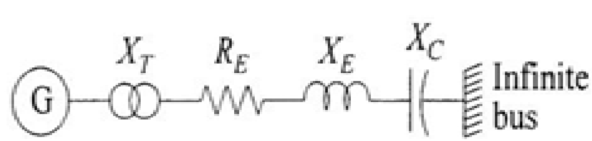

Fig.2. Simple radial series compensated system

The capacitive and inductance reactance is given by

$$X_L = \omega_1 L = 2\pi f_1 L \quad (4)$$

$$X_C = \frac{1}{\omega_1 C} = \frac{1}{2\pi f_1 C} \quad (5)$$

$$v(t) = \sqrt{2} V \sin(\omega_1 t + \theta) \quad (6)$$

$$Z(j\omega_1) = R + j\omega_1 L + (j\omega_1 C)^{-1} \quad (7)$$

Applying the Laplace transform to the voltage and impedance

$$V(s) = \sqrt{2} V . \frac{S \sin\theta + \omega_1 \cos\theta}{S^2 + \omega_1^2} \quad (8)$$

$$Z(s) = R + sL + \frac{1}{sC} \quad (9)$$

The current in the branch is given by

$$I(s) = \frac{V(s)}{Z(s)} = \frac{\frac{sV(s)}{L}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{\frac{sV(s)}{L}}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{\frac{sV(s)}{L}}{(s-a)^2 + \omega_2^2} \quad (10)$$

Where,

Undamped natural frequency is given by $\omega_n = \sqrt{\frac{1}{LC}}$

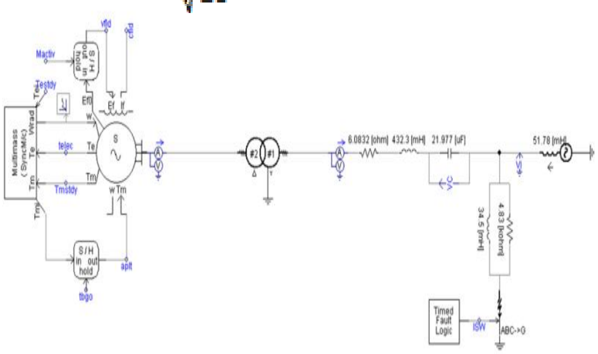

Fig.3. Simulation of thermal unit carried out for various level of series compensation

Damping ratio is given by $\zeta = \frac{R}{2}\sqrt{\frac{C}{L}}$

Damping rate is given by $a = -\zeta \omega_n$

Damping frequency is given by $\omega_2 = \omega_n \sqrt{1 - \zeta^2}$

The Inverse Laplace transform of the current is given by

$$i(t) = K[A \sin(\omega_1 t + \Psi_1) + Be^{-\zeta\omega_2 t} \sin(\omega_2 t + \Psi_2)] \quad (11)$$

These kind of currents flow in the stator windings of the generator. The physical process in which they are reflected into the generator rotor can be described mathematically by thePark's transformation. The base frequency of the machine is given by

$$\theta = \omega_1 t + \delta + \frac{\pi}{2} \quad (12)$$

$$\cos\theta \sin\omega_2 t = \frac{1}{2}[\sin(\theta + \omega_2 t) - \sin(\theta - \omega_2 t)]$$

$$-\frac{1}{2}[\cos[(\omega_1 + \omega_2)t + \delta] - \cos[(\omega_1 - \omega_2)t + \delta]] \quad (13)$$

Current of frequency are transformed into currents of frequencies containing both the sum and difference of the two frequencies.

IV. MITIGATION OF SUBSYNCHRONOUS RESONANCE

SSR can cause severe damage to the system which causes shaft damage. In order to overcome this oscillation by adding damper winding (or) increasing the network transmission resistance. Several proven methods exist for mitigating the effects of SSR are SSR blocking filters, supplemental exciter damping controls [10].

A. Damper winding

Amorissuer windings on the pole faces of the generator are been dampened. and Damping is the process of

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restricting the oscillation in a system. By increasing the damper winding of the generator the synchronous current induces in the generator is reduced there by the SSO presented between the masses of the turbine generator is reduced.

B. Increasing the Network Resistance

The stability criterion is determined by the total effective resistance of the electrical circuit at the resonance frequency. Transmission line is long enough to prevent self excitation even if the complement of the electrical resonance would coincide with the torsional mode frequency. The overall network resistance is increased and hence self excitation effect is decreased.

V. SIMULATION AND RESULTS

Simulation of thermal unit to on series compensated system is carried out in PSCAD. Simulation is carried out for various level of series compensation. The series compensation value can be varied through slider. By using timed fault logican fault is occurred and the system is analyzed. The simulation of thermal unit is carried out for various level of series compensation shown in the Fig .3. For 50% percentage of series compensation of line the resistance of the transmission line is 6.0832 ohm the oscillation at the output voltage of the system is increased. A fault has occurred at time 1.5 sec the oscillation at the output voltage is further increased is shown in the Fig.4.

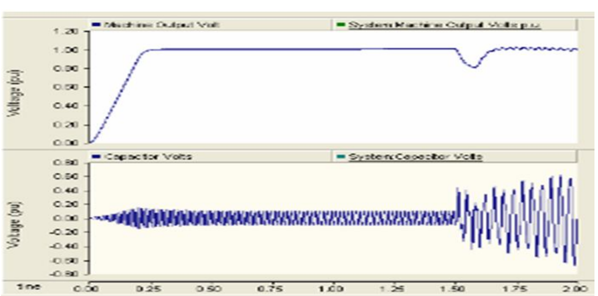

Fig.4.Oscillation at the output and capacitor voltage is increased at resistance 6.0832 Ω.

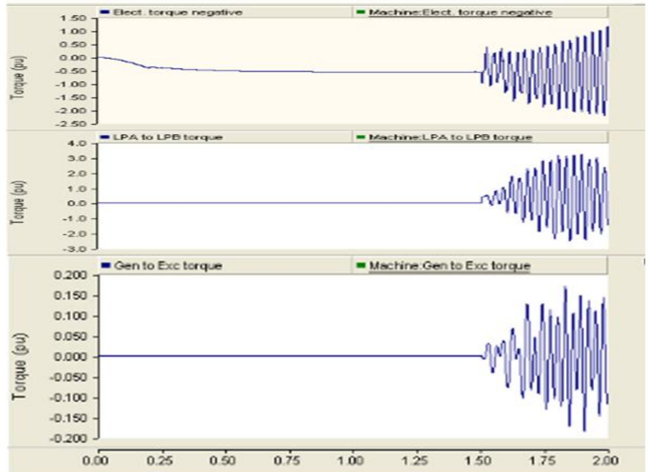

Fig.5. Oscillation at Generator to exciter torque is increased at resistance 6.0832Ω.

For 50% percentage of series compensation of line the resistance of the transmission line is 6.0832 ohm the phases of generator and exciter will be at the oscillating mode during the fault condition occurred at 1.5 sec is shown in Fig.5. For 50% percentage of series compensation of line the resistance of the transmission line is being increased to 95 ohm, then oscillation at the output voltage is decreased and ever during the fault condition the oscillation is further reduced is shown in the Fig.6.

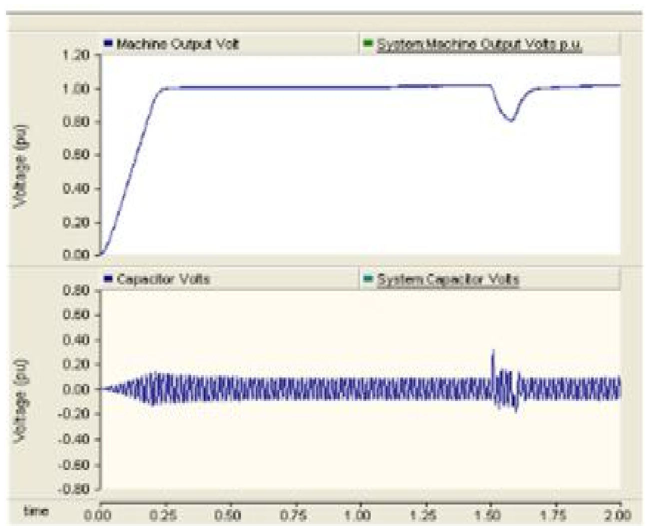

Fig.6. Oscillation at the output and capacitor voltage is decreased at resistance 95Ω.

For 50% percentage of series compensation of line the resistance of the transmission line is being increased to 95 ohm. The masses of the generator and exciter will be the oscillating mode during the fault condition occurred at 1.5 sec is decreased by increase network resistance is shown in Fig.7.

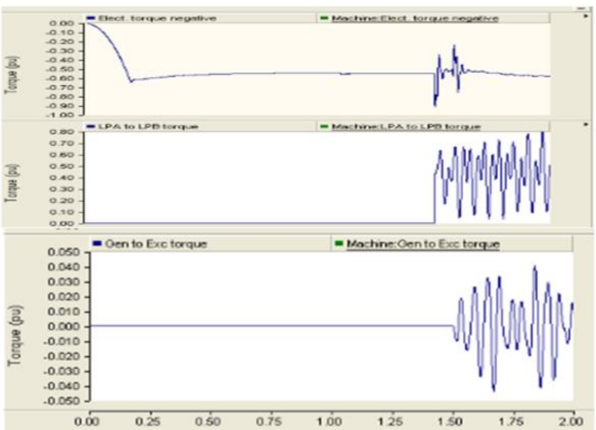

Fig.7. Oscillation at Generator to exciter torque is decreased at resistance 95Ω.

VI. CONCLUSION

The results presented in this paper support the prevailing view that the thermal unit is more predominant to sub synchronous resonance as the masses of the thermal unit are larger. However, if the size of the electrical network is small, self-excitation may occur due to the induction generator effect regardless of the inertia ratio and the mechanical damping. This stability criterion is determined by the total effective resistance of the electrical circuit at the resonance frequency. Self Excitation effect caused by Subsynchronous oscillation is prevented by increasing the length of the transmission line or by increasing the transmission network resistance for the various level of series compensation. Further in future the tensional interaction between the system and power system controllers such as HVDC system will be analyzed and torsional relay will be designed using PSCAD software to reduce Subsynchronous resonance in the system.

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BIOGRAPHY

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