Study of Sub Synchronous Resonance on IEEE second benchmark model and its mitigation Using Thyristor Controlled Series Capacitor (TCSC)

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Abstract-Series capacitive compensation in AC transmission system is used to enhance the power transfer capability of the lines. The central concept in series compensation is to cancel part of reactance of the line by means of series capacitors. However series capacitor compensation acts as a negative damping on torsional oscillations of nearby turbine-generator unit which leads to sub synchronous resonance condition. In this paper, SSR phenomenon is studied with IEEE second benchmark model and it is mitigated using TCSC. TCSC is one of the FACTS devices which can perform both series compensation and damping of SSR torques. Simulation is carried out in MATLAB/SIMULINK-2013 software.

Keywords–FACTS,TCSC, SSR, Torsional eraction

I. INTRODUCTION

Series capacitors introduce a capacitive reactance in series with the inherent inductive reactance of a transmission line, thereby reducing the effective inductive reactance. This significantly increase transient and steady state stability limit, in addition to reactive power and voltage control. Until 1971, it was generally believed that up to 70% series compensation could be used in any transmission line with little or no concern. However, in 1971 it was learned that series capacitors can create an adverse interaction between the series compensated electrical system and the spring-mass mechanical system of the turbine-generators. This effect is called sub synchronous resonance (SSR). It is studied using IEEE Second Benchmark system with booster transformer. Sub synchronous resonance, during fault conditions is encountered with the help of booster transformer which acts as a shunt compensation. This significantly decrease in magnitude of torsional oscillations caused by series compensation[1]. The series capacitors are provided with modern capacitor protection techniques Metal Oxide Varistors are connected across capacitors to protect them from high voltages that could be seen across their terminals when there is a faulty condition [2].

The major concern of SSR is Self Excitation and Transient Torque Amplification. If the size of the electrical network is small, Self Excitation may occur due to induction generator effect regardless of inertia ratio and mechanical damping. This effect caused by sub synchronous oscillation is prevented by increasing the length of transmission line or by increasing the transmission network resistance for the various level of series compensation [3]. Many countermeasures to sub synchronous resonance problem have been suggested [4]. Among them TCSC, one of the FACTS devices is utilized to damp SSR torques. SSR phenomenon is studied with IEEE second benchmark model in this paper shown in Fig.1.

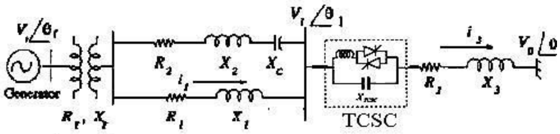

Fig.1 IEEE second benchmark model with TCSC

II. SSR PHENOMENON

An IEEE committee report (1985) has defined SSR as “sub synchronous resonance is an electric power system condition where the electric network exchanges energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system”.

A series capacitor-compensated transmission network can cause sustained or negatively damped sub synchronous oscillations by three distinctive mechanisms. 1) Self excitation due to induction generator effect. 2) Interactions with torsional oscillations. 3) Transient torque amplification.

The electrical resonance frequency f_{er} is given by

$$f_{er} = f_0 \sqrt{\frac{x_c}{x^{11}+x_t+x_e}} \qquad (1)$$

where x^{11} is sub transient reactance of the generator[7],

x_t is the leakage reactance of the transformer, x_c and x_e are the external reactances of the series connected capacitor and inductor respectively.

Torsional mode frequency f_m is given by

$$f_m = f_0 - f_{er} \qquad (2)$$

The state of self excitation of synchronous generator at sub synchronous frequency is defined as induction generator effect. The sub synchronous frequency current or voltage component will produce magnetic motive force (mmf) rotating at the angular speed that corresponds with the sub synchronous frequency. As rotor normally rotates at synchronous speed which is higher than the speed that corresponds with sub synchronous frequency, the machine will experience negative slip and hence induce sub synchronous component at the stator resulting into sustained sub synchronous currents and voltages at the generator. This effect can be detected by effective resistance seen by the machine as a combination of network, generator stator and rotor resistance. If this effective resistance is negative, the SSR problem is eminent as shown in Fig.2. [5].

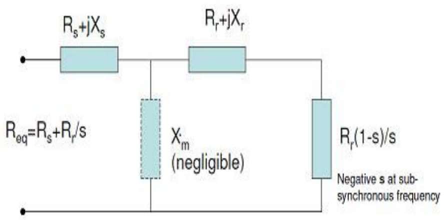

Fig.2 The equivalent resistance of the generator at sub synchronous frequency [5]

Torsional interaction occurs when sub synchronous component current produces induced sub synchronous torque. If the mechanical natural frequency of the generator shaft segments is close to the frequency of the produced sub synchronous torque, a torsional torque will occur resulting in a twisting force on the shaft segments of the generator causing fatigue and damage to the shaft [5].

Torque amplification is anticipated under system’s transient conditions that can occur due to disturbances such as short circuit faults and sudden change in network configuration near series compensated network [5] studied in this paper.

III. THYRISTOR CONTROLLED SERIES CAPACITOR

Thyristor controlled series capacitors can be effective in mitigating SSR. Thyristor valves of TCSC as shown in Fig.3 are gated to control the current through the capacitor, thereby affecting the dynamic characteristics of the series capacitor at the sub synchronous frequencies. If the control system is properly designed, TCSC can reduce the natural tendency of the series capacitor to resonate with the inductance of the transmission system and consequently reduce the detrimental impact of SSR on nearby turbine-generators.

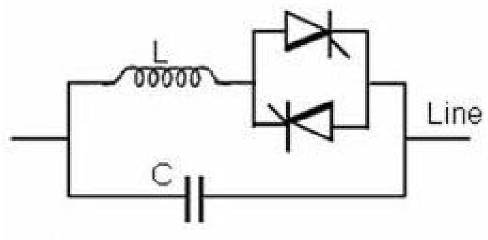

Fig.3 Simple model of TCSC

The equivalent impedance of TCSC is given by

$Z_{eq} = (j \frac{1}{\omega C}) \parallel (j\omega L) = -j (\frac{1}{\omega C - \frac{1}{\omega L}})$ (3)

If $\omega C - \frac{1}{\omega L} > 0$, reactance of the capacitor is less than that of parallel connected variable reactor. This corresponds to capacitive mode of TCSC operation.

If $\omega C - \frac{1}{\omega L} = 0$, resonance develops resulting in infinite capacitive impedance which is an unacceptable condition.

If $\omega C - \frac{1}{\omega L} < 0$, this corresponds to inductive mode of TCSC operation.

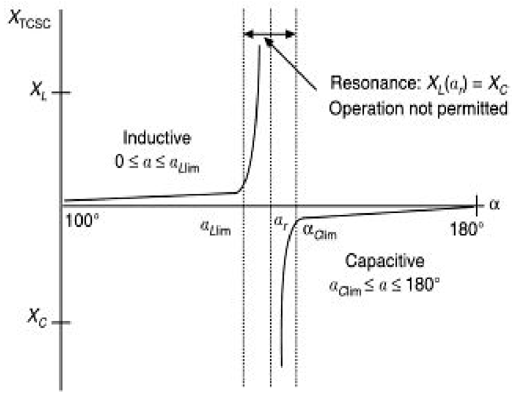

Fig.4. Variation of reactance of the TCSC with firing angle [6]

The expression for the reactance can be written as

$X_{TCSC} = [X_L(\alpha) X_C] / [X_L(\alpha) + X_C]$

Where

$X_L(\alpha) = X_L \{[\pi] / [2(\pi-\alpha) + \sin 2\alpha]\}$

IV. SIMULATION AND RESULTS

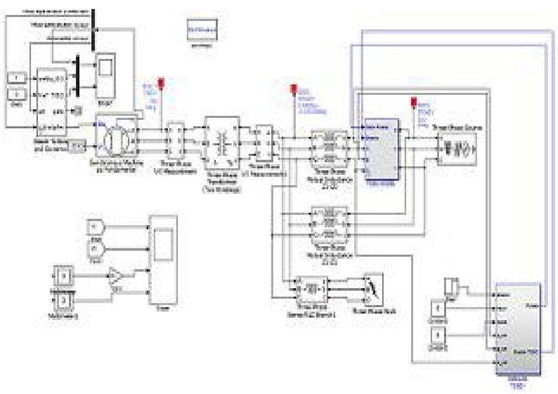

Fig.5. Simulation of three phase transmission network with TCSC

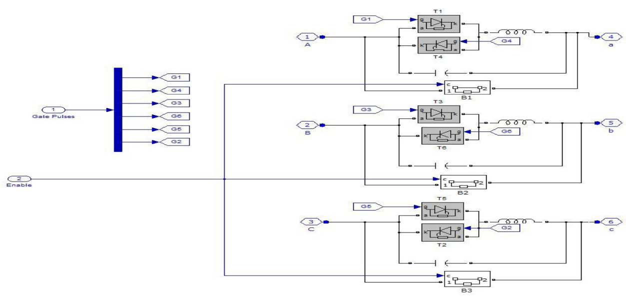

Fig.6. Model of TCSC developed in Simulink

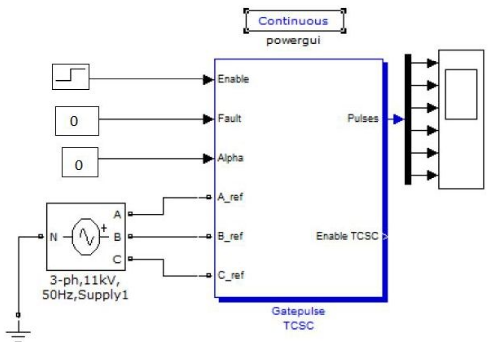

Fig.7. Gate pulse generation model of TCSC

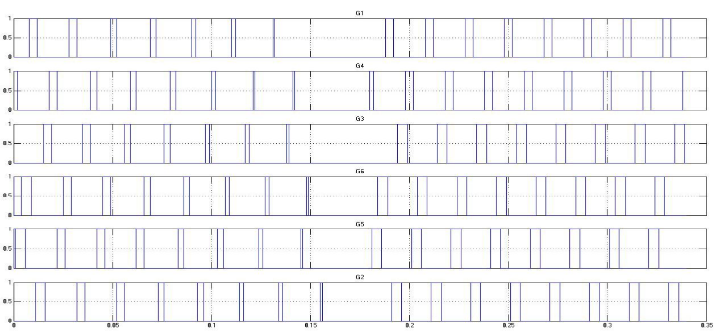

Fig.8 Gate pulses for TCSC

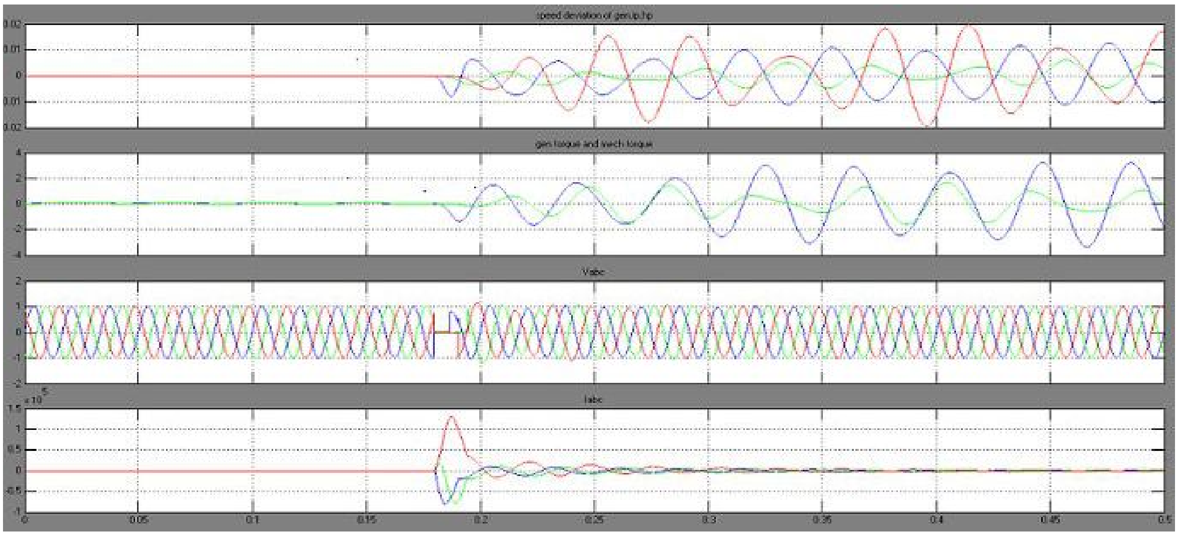

Fig.9 Speed deviation, torque amplification, voltage and current in a series compensated network without TCSC

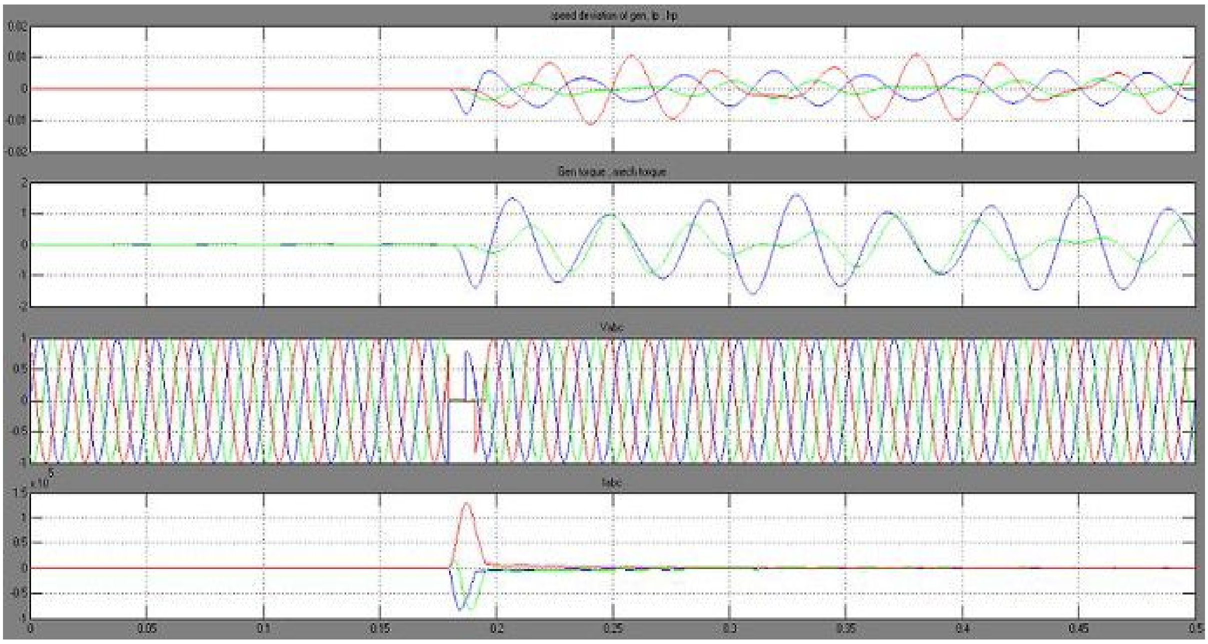

Fig.10 Speed deviation, torque amplification, voltage and current in TCSC compensated network.

V. RESULTS AND DISCUSSION

Simulation of Electro-mechanical system with TCSC is carried out in MATLAB/SIMULINK-2013as shown in fig.5. MATLAB model of TCSC and Gate pulse generation model of TCSC is shown in fig.6 and fig.7 respectively.

Fault condition is given at 0.18s which sets the firing angle to 90deg and pulse width is changed to maximum instantaneously. Fig.8 shows the results for both firing angle and fault condition.

Simulation results indicate clearly that in a series compensated network without TCSC at 0.18s fault time, the torque amplification is between 2 p.u to 4 p.u as shown in Fig.9., whereas, when TCSC is connected to the same network with same fault time, the torque amplification is reduced , between 1 p.u to 2 p.u as shown in Fig.10. Thus SSR torques of electro mechanical system have been analysed and damped by using TCSC. Methods for further improvements in the stability margin can be investigated using VSC based series FACTS devices.

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