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Study of SSR & its Mitigation Using a TCSC Based Subsynchronous Damping Controller

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Abstract - *It has been known since a long time that compensation with fixed capacitors in series, is a both cost and resource effective way of improving power flow compared to conventional construction of new lines. Until 1971 it was generally believed that 70% compensation can be used without any problem. In 1971 it was learnt that fixed series compensation can cause subsynchronous resonance (SSR). The objective of this paper is to study the use of thyristor controlled series capacitor (TCSC) as a substitute or addition to the fixed compensation. TCSC can potentially mitigate the SSR. The TCSC is a reactive power compensating FACTS devise with many benefits such as variable compensation and power control. A sub synchronous damping controller (SSDC) is designed, which is capable of SSR detection as soon as the manual switch is put on. SSDC observes this SSR phenomenon and directs an appropriate signal to the TCSC. Thyristor controlled series capacitor (TCSC) which improves transmission line capability, can also be used in damping out Sub synchronous resonance (SSR) efficiently.*

Key Words: Sub synchronous damping controller (SSDC), eigen value analysis, sub synchronous resonance(SSR), TCSC.

1. INTRODUCTION

Recent advancement of power electronics makes extensive use of Flexible AC Transmission System (FACTS) controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this unique feature of FACTS devices can be exploited to improve the stability of the power system. TCSC is composed of a capacitor for series compensation and it is shunted by a TCR shown in Figure1.

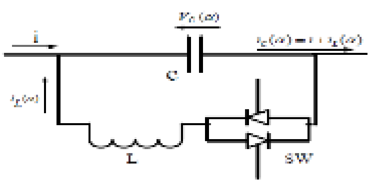

Fig -1: Basic TCSC Block

Vithayathil as well as others proposed the basic strategy of Thyristor controlled series capacitor (TCSC) in 1986 which acts for rapid adjustment of network impedance. The main theme of the TCSC approach can be to yield a continually varying capacitor by moderately negotiating the compensating capacitance with the assistance of a thyristor controlled reactor (TCR). The rotor speed deviation is used as input to SSDC.

TCSC allows wide application in power system. It can be used also for damping of active power oscillations, improve dynamic and voltage stability, eliminating SSR and other. It is one of the important members of FACTS family that is increasingly applied by the utilities in modern power systems with long transmission lines. It can have various roles in the operation and control of power systems, such as scheduling power flow, decreasing unsymmetrical components, reducing net loss, providing voltage support, limiting short-circuit currents, mitigating sub-synchronous resonance (SSR), damping the power Oscillation, and enhancing transient stability [4].

2. SSR PHENOMENON

SSR in simple is a kind of significant energy exchange between the electric system and a turbine-generator at one of the natural frequencies of the turbine-generator below the synchronous frequency f_0. When the electric system of Fig.2 is series compensated, there will be one subsynchronous natural frequency f_{er}.

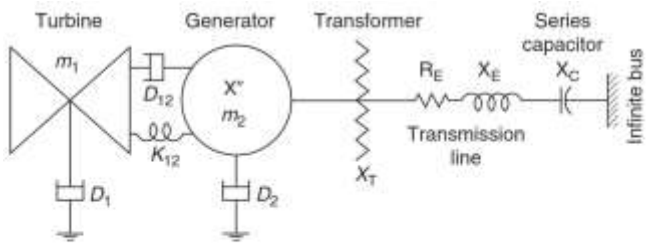

Fig -2: Turbine-generator with series compensated transmission line. (From IEEE Committee Report)

For any electric system disturbance, there will be armature current flow in the three phases of the generator at frequency f_{er}. The positive sequence component of these currents will produce a rotating magnetic field at an angular electrical speed of $2\pi f_{er}$. Currents are induced in the rotor winding due to the relative speed of the aforementioned rotating field and the speed of the rotor. The resulting rotor current will have a frequency $f_r = f_0 - f_{er}$. A subsynchronous rotor current creates induction generator effect. The armature magnetic field, rotating at an angular frequency of f_{er} interacts with the rotor's dc field, rotating at an angular frequency of f_0, to develop an electromagnetic torque component on the rotor at an angular frequency of $f_0 - f_{er}$. This torque component contributes to torsional interaction [3].

3. TYPES OF SSR PHENOMENA

There are three aspects of SSR which are best known as Induction Generator Effect, Torsional Interaction Effect and Transient Torque Effect.

3.1 Induction Generator Effect

Induction generator effect is only related with the electric system and the generator (except turbines). For an induction machine the effective rotor resistance as seen from the armature and external power system is given by the following equations:

$$R_r' = \frac{R_r}{s} \quad \text{.......................(1)}$$

$$s = \frac{f_{er} - f_0}{f_{er}} \quad \text{.......................(2)}$$

Where

R_r' → Total rotor resistance viewed from the armature

R_r → Rotor Resistance

s → Slip

f_{er} → Frequency of Subsynchronous component of current in armature

f_0 → Synchronous Frequency

Since $f_{er} < f_0$ (always due to subsynchronous nature). Therefore R_r' will always be a negative value. If this R_r' exceeds the positive Resistance (i.e. sum of armature and system resistance at resonant frequency f_{er}), the armature current will sustain or gradually grow. This is called Induction Generator Effect.

3.2 Torsional Interaction

Torsional interaction involves both the electrical and the mechanical systems. Both systems have one or more natural frequency. Generator rotor oscillations at a natural torsional frequency fn, induce armature voltage components of subsynchronous frequency given as below:

$$f_{er} = f_0 - f_n \text{.......................(3)}$$

When the frequency of the subsynchronous component of armature voltage, is near the electric system natural frequency fer, the resulting subsynchronous current flowing in the armature is phased to produce a rotor torque that reinforces the initial rotor torque at frequency fn. If the resultant torque exceeds the inherent damping torque of the turbine-generator for mode n, sustained or growing oscillations can occur. This is known as torsional interaction.

3.3 Torque Amplification

When there is a major disturbance in the electrical system, such as a short circuit, there are relatively large amounts of electrical energy stored in the transmission line inductance and series capacitances. When the disturbance is removed from the system, the stored energy will be released in the form of current flowing at the electrical system resonant frequency, f_{er}. If all, or a portion of the current, flows through a generator armature, the generator rotor will experience a subsynchronous torque at a frequency $f_0 - f_{er}$. If the frequency of this torque corresponds to one of the torsional modes of the turbine-generator spring-mass system, the spring-mass system will be excited at that natural torsional frequency and cyclic shaft torque can grow to the endurance limit in a few cycles. This is referred to as torque amplification[3].

4. IEEE FIRST BENCHMARK MODEL FOR SSR STUDY

The IEEE First Benchmark Model (FBM) was created by the IEEE Working Group on Subsynchronous Resonance in 1977 for use in "computer program comparison and development."

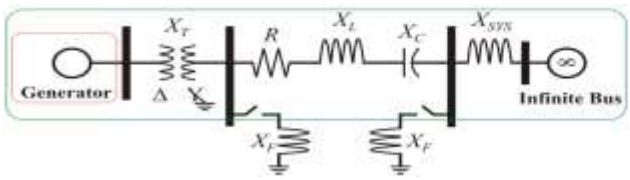

Fig -3: IEEE FBM Proposed by SSR Task Force Work Group

IEEE FBM [1] is proposed by subsynchronous resonance task force of the dynamic system performance working group power system engineering committee of IEEE which is further modified to include TCSC for the study of SSR in this paper [4]. The single-line diagram shown in Fig.4 represents a three-phase, 60 Hz, 735 kV power system transmitting power from a power plant consisting of six 350 MVA generators to an equivalent system through a 600 km transmission line. The transmission line is split into two 300 km lines connected between buses B1, B2, and B3. A 100 MW series R-L-C load is connected between generator and transformer. To increase the transmission capacity, each line is series compensated by capacitors representing 55% of the line reactance.

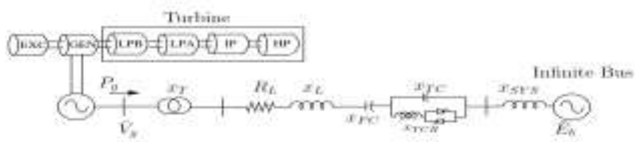

Fig -4: The modified IEEE first benchmark model with a TCSC.

5. CASE STUDY USING MATLAB SIMULATION

A detailed MATLAB SIMULINK system is modeled for the study and mitigation of SSR using simulation is shown in fig (5). Torsional SSR and Torque amplification are related to energy exchange between electrical and mechanical system. This system is designed to focus more on these electromechanical phenomena rather than a purely electrical phenomena i.e. Induction generator effect [14].

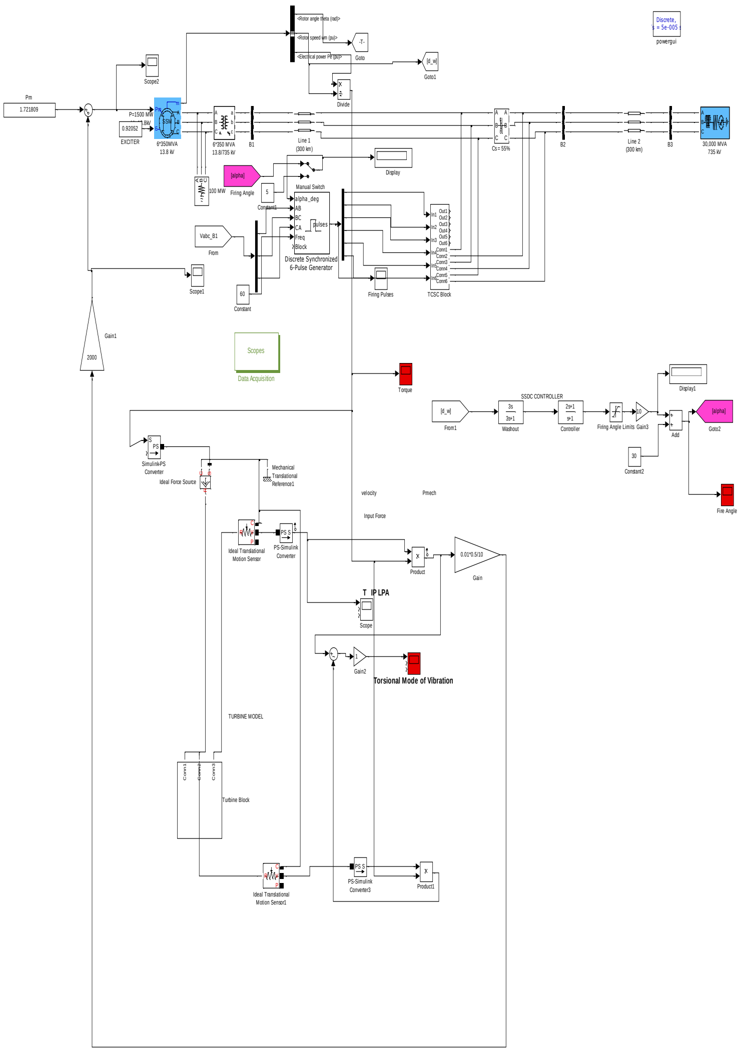

Fig -5: MATLAB SIMULINK model for study and mitigation of SSR

5.1 Torsional Interaction

The above MATLAB system model has been designed to work both with and without subsynchronous damping controller. A manual switch is provided and as soon as it is put on, the SSDC is electrically inserted in the system. When switch is off, the default value of TCSC firing angle α is set as 5 degrees (arbitrarily). As soon as the SSDC is inserted, the damping controller takes roror speed deviation as feedback and as per that the value of α starts changing automatically. Post SSDC insertion, the value of changing firing angle can also be seen in the display block of the system. Ref fig (6).

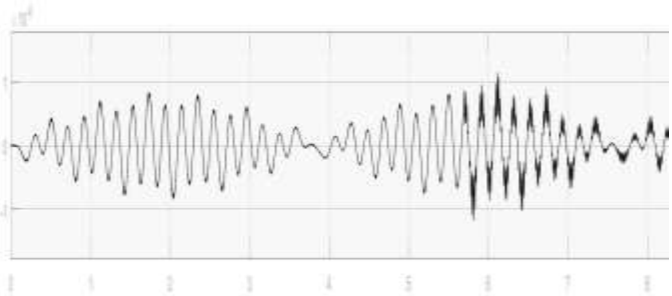

Fig -6: Torsional Interaction SSR with and without SSDC

5.2 Torque Amplification

Torque amplification SSR study can also be done and the graph is plotted using MATLAB. At the mid of the Simulation, the SSDC is inserted in the circuit. Post SSDC introduction the torque amplification envelope can be seen shrinking up to a larger extent, leaving a very small scope for rotor instability. Vice versa is also true. Ref fig (7).

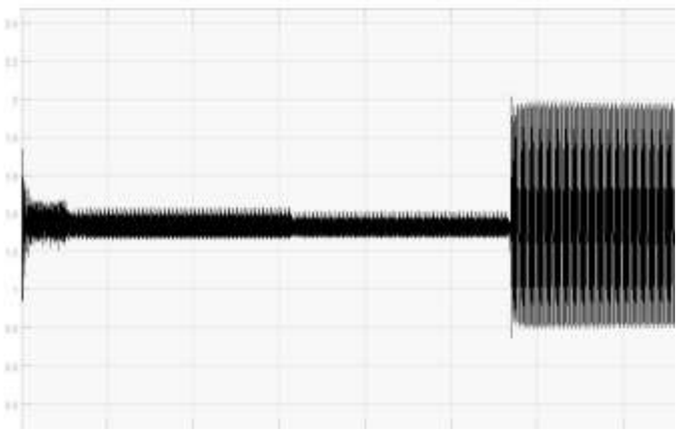

Fig -6: Torque Amplification SSR with and without SSDC

6. RESULT & CONCLUSION

As seen in the figs (6) and (7), a reverse switching action can also be done and graphs can be plotted for better observation and results can be obtained. After the disconnection of Subsynchronous Damping Controller, an expanded envelope of Torque amplification and highly pronounced Torsional interaction can be observed. It proves that the presence of SSDC in the system provides a more stable ecosystem in which more power can be transmitted, keeping the oscillatory stability intact.

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Biography

Gyan prakash Rai is persuing M.Tech in Integrated Power System from Abha Gaikwad College of Engg., affiliated to RTM Nagpur University. He also works as a Lecturer in another Institute affiliated to the same University.