

Analysis of Sub-synchronous Resonance on Different Load Ratings

Lakshmi Priya.L¹, Mahaboob Basha Qureshi²

P.G. Student, Department of Electrical and Electronics Engineering, MSAJCE, Egattur, Chennai, India¹

Associate Professor, Department of Electrical and Electronics Engineering, MSAJCE, Egattur, Chennai, India²

ABSTRACT: Series compensation (SC) is one of the important members of FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems. It can have various roles in the operation and control of power systems, such as scheduling power flow; providing voltage support; limiting short-circuit currents; damping the power oscillation and enhancing transient stability control of power systems, power factor improvement[1]. To increase the power limits, the series reactance of the transmission lines must be reduced. By inserting capacitors in series with the transmission lines reduces the overall Inductive reactance of the lines. This will introduce the phenomenon of Sub-synchronous Resonance (SSR) in turbine-generators, which can lead to electrical instability at sub-synchronous frequencies (below 60Hz) and potential turbine-generator shaft failures[2]. When the level of SC increased, effect of torque interaction can be magnified. To improve the power flow and to damp out the torque interaction (SSR), load can be connected at infinite bus. Real and reactive power flow under different load rating and no load can be noted and analysis in this paper. Power flows on different loads based on IEEE First Benchmark can also analysed with fault and without fault. The MATLAB software is used for simulating and observing the effects of SSR.

KEYWORDS: Series compensation, Sub-synchronous Resonance, FACTS

I. INTRODUCTION

Sub-synchronous oscillations in the range of 10-50Hz result from mechanical oscillations among individual turbine masses and the generator coupled into a long shaft, and these mechanical oscillations, electrically coupled with the electrical system via the generator. First experienced in 1970 resulting in shaft failure of units at Mohave Plant in Southern California Not until the second failure in 1971 was the real cause of failure recognized as SSR. Sub synchronous Resonance (SSR) was unheard of until the catastrophic damage to the turbine-generator at Southern California Edison's Mojave Power Plant in 1970[3]. SSR can be occurred at Nuclear power plant, Thermal or Steam power plant.

It has since been recognized that all high speed active controls of a power system such as HVDC, FACTS, excitation control, etc., have a potential of mitigating as well as causing damage or loss of life in large multi-machine generators. Even high speed reclosing after fault clearance has been recognized as having a potential of causing loss of life of turbine-generator shafts. Initiative to SSR, The use of series compensation may bring about some new problem to power system operation. One of the problems is possibility of Sub-Synchronous Resonance (SSR), which may lead to torsional oscillations of turbine generator shaft system and electrical oscillation with frequency below the sub synchronous frequency

II. DESIGN METHODOLOGY

Sub synchronous resonance (SSR) is the process which leads to the turbine generator shaft damage. This work addresses Contributions of synchronous generator rotor motion and induction generation to sustained sub synchronous oscillation. Series capacitor compensation has been widely used in the AC transmission systems as an economical

alternative for different purposes such as increasing power transfer capability through a particular interface, controlling load sharing among parallel lines, and enhances Steady state stability. However, the use of series compensation may bring about some new problem to power system operation. One of the problems is possibility of Sub-Synchronous Resonance (SSR), which may lead to torsional oscillations of turbine generator shaft system and electrical oscillation with frequency below the sub synchronous frequency. Turbine-generator shaft failure and electrical instability at oscillation frequencies lower than the normal system frequency result from SSR.

Turbine-generator electromechanical interaction with series capacitors has historically been known as the phenomena of "Sub synchronous Resonance" (SSR). The interactions between power controlling devices, such as HVDC converters, Static VAR systems, and power system stabilizers, and turbine-generators has led to a recognition of a broad range of turbine-generator torsional interactions which is nothing but the sub synchronous oscillations

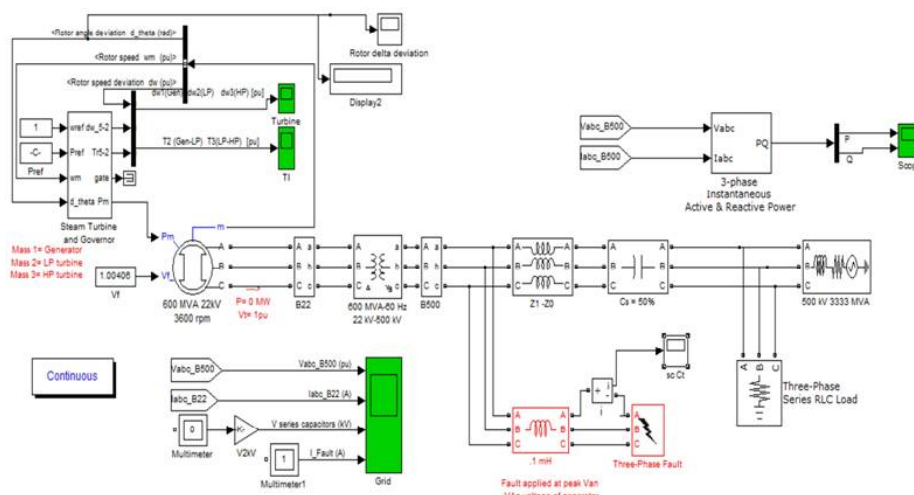


Fig.1(a) Block diagram of Analysis of Power Flow on Constant loads

The rotor of a turbo-generator is a very complex mechanical system. The generator rotor is connected to the last turbine of a group of turbines and the exciter is connected to the rotor at the end. The various sections are coupled together with the help of interconnecting shafts. The mechanical system comprises four masses, i.e. the HP, LP, GEN, and EXC, which are mechanically coupled on the same shaft.

From the structure of this model mass spring system, there exists three torsional modes (mode 1, mode 2, and mode 3) and one electromagnetic mode (mode 0) in the system. These four-modes are called SSR modes or torsional modes since their natural frequencies are all less than synchronous frequency or power frequency (60Hz).

III. SUBSYNCHRONOUS RESONANCE

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[4]. Due to the interaction between the electrical power system and turbo-generator mechanical system, the sub-synchronous oscillations can be sustained and amplified.

In general the series capacitor compensated transmission system is more complex and will result in many sub synchronous frequencies (f_{er}). Each of these frequencies is definable by an equation similar to the equation given above with the appropriate change in data.

$$f_r = f_0 \pm f_{er} \quad (1)$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

$$f_{er} = f_0 \sqrt{\frac{X_C}{X'' + X_E + X_T}} \quad (2)$$

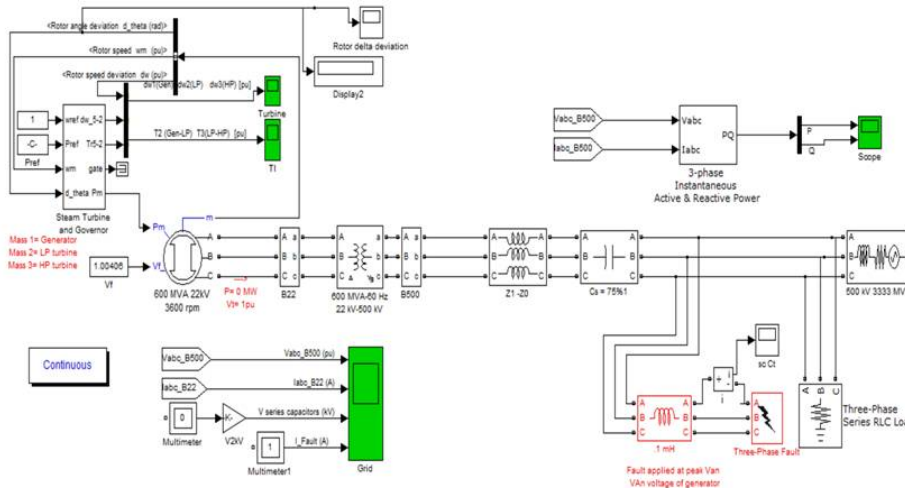


Fig.1(b) Block diagram of Analysis of Power Flow on Transient Loads

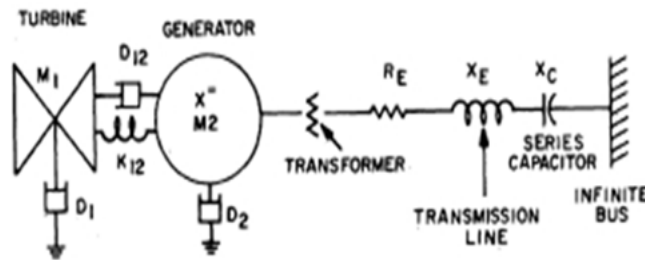


Fig.2 Turbine-Generator with compensated transmission

f_{er} =electrical system resonant frequency

f_0 = synchronous frequency

X'' = sub transient reactance of the generator

X_E = inductive reactance of transmission line

X_l =leakage reactance of transformer

f_r =induced rotor current frequency

Currents of resonant frequency (f_{er}) in the electrical system give rise to rotor current of frequency f_r as indicated in the equation given below.

$$f_r = f_0 \pm f_{er} \quad (3)$$

A balanced three phase set of armature currents at resonant frequency produces a rotating magnetic field in the synchronous machine. The time distribution of the phase currents together with the space distribution of the armature winding causes rotation at an angular frequency of $2\pi f_{er}$. The frequency of rotor body currents induced by this field is governed by the relative velocity between the armature field and the rotor. Positive sequence components of stator current produce rotor current at sub synchronous frequency $f_r = f_0 - f_{er}$. Negative sequence components of the stator current produce rotor current at super synchronous frequency $f_r = f_0 + f_{er}$. As the rotor magnetic field overtakes the more slowly rotating sub-synchronous mmf in the armature, it produces a sub-synchronous torque having a frequency which

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

is the difference between the electrical frequency corresponding rotor average speed (f_0) and the electrical sub-synchronous frequency (f_{er}). The sub-synchronous electrical frequency and sub-synchronous torque frequency (f_0-f_{er}) are said to be complimentary because they add to unity, when expressed in per unit synchronous frequency (f_0) exist, but are often separated for ease of analysis. Torsional interaction generally dominates when the sub-synchronous torque frequency (f_0-f_{er}) is close to one of the torsional modes. Induction generator effect generally dominates when the sub-synchronous torque frequency (f_0-f_{er}) is separated from the torsional frequency. There is no clear cut criterion to indicate which type of self-excitation dominates and, in fact, both effects may be significant.

IV. RESULTS

Series compensation (SC) will increase the Torque Interaction (TI). TI is nothing but SSR. Hence if SC increased to improve the power transfer thereby TI is also increased which leads to turbine generator damage. The intensification of SSR may be reduced by adding various higher ratings of loads. This can be done by connecting load at infinite bus side. For higher load ratings the effects of SSR may somewhat be reduced considerably so power transfer can be increased and also increases the voltage profile, and damping the oscillation.

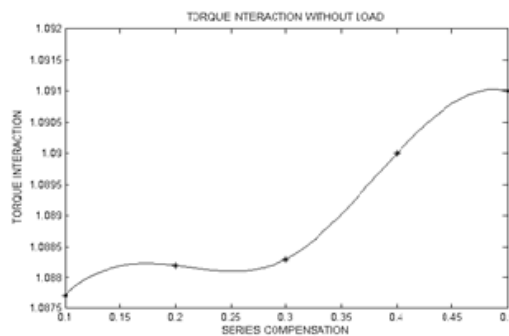


Fig.3 Torque Interaction without Load

Though SC will enhance the power flow, this will contribute Torque Interaction, which leads to turbine generator damage. The effects of SSR may be probably more without higher load ratings. As series compensation increases, torque interaction is also increased $TI=1.091$

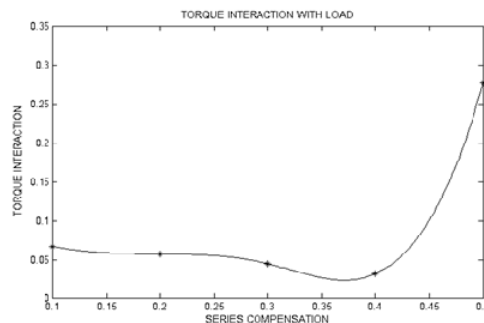


Fig.4 Torque Interaction with Load

During transient conditions the effects of SSR may be probably smaller, with higher load ratings. In presence of load, torque interaction will be $TI=0.2791$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

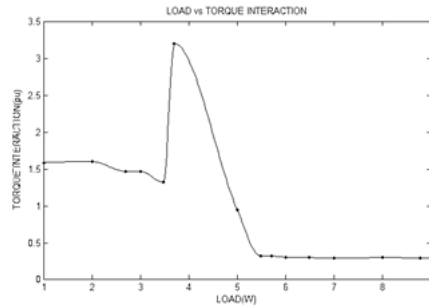


Fig.5 Torque Interaction at Constant Load

During transient condition, for various higher rating of load the effect of SSR may be probably reduced and here the load type is three phase RLC load(L=0;C=0).

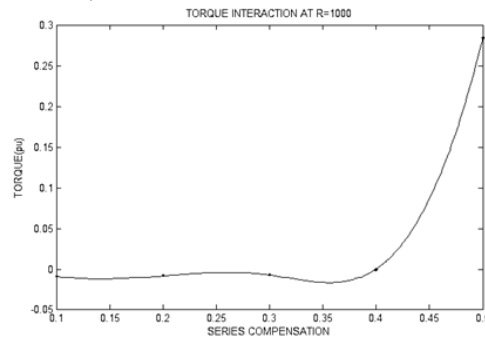


Fig.6 Torque Interaction at R=1000(ohm)

When the load resistance is about 1000(ohms) and more. At that condition three phase load will be act as three faults and there will be occurrence of sub synchronous resonance (TI). TI=0.28

V. MATLAB SIMULATION RESULTS

The lightly loaded system is likely to have less damping and higher voltage distortion. A heavily loaded system is likely to offer a better damping. In this paper a resistive load is connected in order to suppress sub-synchronous current. The resistive load has capability of limit the damping.

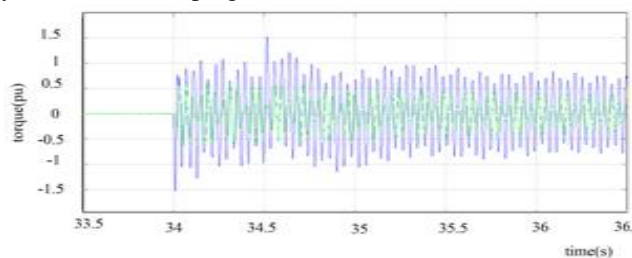


Fig.7 Torque Interaction without Load for SC=0.3(pu), TI=1.0883(pu), P=0.107, Q=-0.062(pu)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

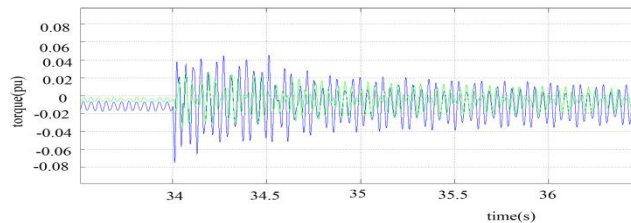


Fig.8 Torque interaction with load for SC=0.3, TI=0.0446(pu), P=0.982(pu), Q=0.68(pu)

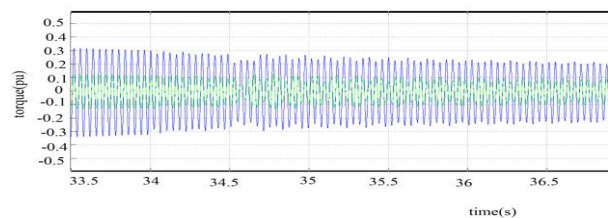


Fig.9 Torque Interaction at Constant Load for SC=50(%), TI=0.296(pu), P=0.105(pu), Q=0.57(pu), load=1e6

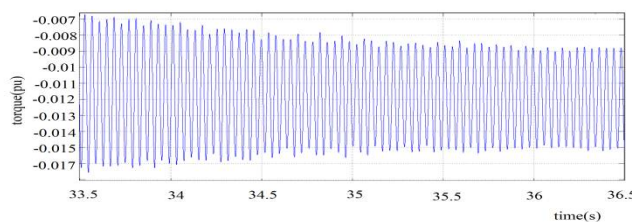


Fig.10 Torque interaction at R=5000(ohm), SC=0.3, TI=-7.1719e-3(pu), P=0.103(pu), Q=0.72(pu)

VI. CONCLUSION

The proposed work presented a comprehensive approach for sub-synchronous resonance (SSR). Thus with the help of IEEE First Benchmark Model we can analyse the Sub Synchronous Resonance (SSR) Phenomenon and observe its effects at different loads. This approach shows that by increasing the series compensation effect of torque interaction can be increased. Hence for heavily loaded system damping can be better and torque interaction will be reduced. The main cause of the Production of SSR is the Series Compensation. There are other sources responsible for excitations of SSR are Power System Stabilizer (PSS), HVDC Convertor, Static Var Compensator (SVC), Variable Speed Drive Convertor.

REFERENCES

- [1] N. H. Hingorani, "Flexible AC transmission systems," IEEE Spectrum p. 4045, Apr. 1993.
- [2] K. R. Padiyar, FACTS controllers in Power transmission and distribution, New AGE international publisher
- [3] J. Ballance and S. Goldberg, "Subsynchronous resonance in series compensated transmission lines," *Power Apparatus and Systems, IEEE Transactions on*, vol. PAS-92, no. 5, pp. 1649–1658, 1973
- [4] George Williams and Jacob Martin, "Resonance and Analysis of SSR", International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 7, July 2013
- [6] N. G. Hingorani and L. Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems", IEEE Press. New York, 1999.
- [7] R. M. Mathur and R.K. Varma, "Thyristor based FACTS Controllers for Electrical Transmission Systems", IEEE press, Piscataway 2002.
- [8] Hammons, T. J., "Effect of Three-phase Faults and Faulty Synerators", Rev. March 2015
- [9] Bernard Adkins, "The General Theory of Electrical Machines". London: Chapan & Hall Ltd., 957, pp. 101-124, pp.145-151, June 2014.
- [10] A.M.Kulkarni, K. R. Padiyar, "Damping of power swings using series facts controllers," *Electrical Power and Energy systems*, vol.21, pp.475-495, 1999.