

Sub Synchronous Resonance Mitigation in Series Compensated Wind Farm Using Facts Device

Janki Panchasara¹, Hitesh Khunt²,

^{1,2}Department Of Electrical Engineering Aits ,Rajkot

¹jankipanchasara@gmail.com

²hrkhunt@aits.edu.in

Abstract— Series capacitor compensation is used for increasing power transfer capability of the existing transmission line. But due to series capacitor compensation sub synchronous resonance is introduced. The Sub-synchronous resonance (SSR) is the phenomenon which is caused by the series capacitor. Due to SSR two shaft failures was occurred at Mohave unit in 1970 and 1971. To mitigate SSR phenomenon many FACTS controllers is used to mitigate SSR effects. Among all facts controllers GCSC is used. The gate-controlled series capacitor (GCSC) is a FACTS device proposed initially for series compensation of transmission line to control power flow. The simulation is done in matlab software using simulink and sim power system toolbox. Here the IEEE SBM model is used to analyze the SSR.

Keywords— Flexible ac transmission systems (FACTS), Self-excited induction generator (SEIG), series compensation, Gate controlled series capacitor, sub synchronous resonance (SSR), wind power systems.

I. INTRODUCTION

Environmental pollution and shortage of conventional fossil fuel are the two major concerns which have led to the global emergence of wind energy as an effective means of power production^[2]. Wind generating capacities have increased from negligible levels in the early 1990s to more than 50 GW today. This shift to wind energy will inevitably lead to large wind turbine generators (WTGs) being integrated into electric power grids. It will be further necessary to transmit the generated power through transmission networks that can sustain large power flows. It is well known that series compensation is an effective means of increasing power transfer capability of an existing transmission network. However, series compensation is shown to cause a highly detrimental phenomenon called sub synchronous resonance in electrical networks.^[5]

The oscillation covers a wide frequency range approximately from 0.001 Hz to 50 MHz. Due to transient disturbance, generator speeds up causing rotor angle to increase resulting in the development of varying torque. This varying torque develops the varying stresses on the T-G shaft, which leads to damage of the shaft and may reduce life of T-G set. Some techniques to mitigate SSR with FACTS devices can be found in the literature. These techniques can provide

controllable series compensation and reduce or even eliminate the effects of the SSR

Flexible ac transmission systems (FACTS) can provide an effective solution to alleviate SSR and thyristor-based FACTS controllers have been employed in the field for this purpose. Wind turbines are subject to mechanical modes of vibrations related to turbine blades, shaft, gear train, tower, etc. In the case of wind turbine generators operating radially on the end of a series-compensated transmission line, there is the potential for induction-machine self-excitation SSR.^[1]

The main motivation behind this work is to utilize thyristor-based FACTS devices for mitigation of SSR. The FACTS devices may be already installed for achieving other objectives and SSR damping function can be additionally included, or the FACTS devices can be exclusively connected for mitigating SSR.

In this paper gate controlled series capacitor is used as mitigation device. The gate-controlled series capacitor (GCSC) is a FACTS device proposed initially for series compensation of transmission line to control power flow. The benefits and the advantages presented by the GCSC in the control of power flow in a transmission system have already been presented. On the other hand, it has the key advantage of being a much simpler device.^[6]

The main objective of this work is to present a more detailed investigation on the capability of the GCSC to mitigate SSR and electromechanical oscillation. This investigation was done based on the IEEE Second Benchmark Model.

II. SUB SYNCHRONOUS 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.^[9] 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 (fer). Each of these frequencies are definable by an equation similar to the equation given above with the appropriate change in data,

$$f_{er} = f_0 \sqrt{\frac{X_C}{X_E + X_T}}$$

$$f_r = f_0 \mp f_{er}$$

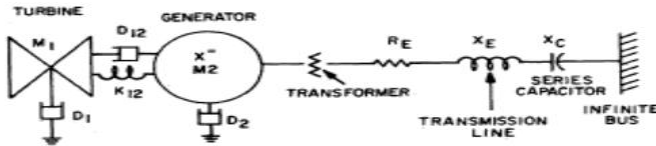


Fig. 1 Turbine Generator Compensated System

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_T = 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.

$$f_r = f_0 \pm f_{er}$$

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 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).

A. Self Excitation

In a power system employing series capacitor compensated transmission line, the electrical sub-synchronous currents entering the generator terminals produces sub-synchronous terminal voltage components. These voltage components may sustain the currents to produce the effect that is called self excitation. There are two types of self excitation: one involving electrical dynamics and the other involving both electrical and mechanical turbine generator dynamics,

accordingly to resonance phenomena can be classified into two categories:

1) Induction Generator Effect

Self excitation of a series capacitor compensated electrical system alone, assuming constant rotor speed, is caused by induction generator effect. Since the rotor circuits are turning faster than the rotating magnetic field produced by the sub synchronous armature currents, the rotor resistance to sub synchronous currents viewed from the armature terminals are negative. When this negative resistance exceeds the sum of the armature and network resistances, the electrical system is self excited. Such self excitation would be expected to result in excessive voltages and currents.^[2]

2) Torsional Interaction

Mode shape: The rotor system of a turbine generator is vibrate in a particular way which is known as mode shape. Mechanical system is a multimode system which has a more than one torsional natural frequency.^[2]

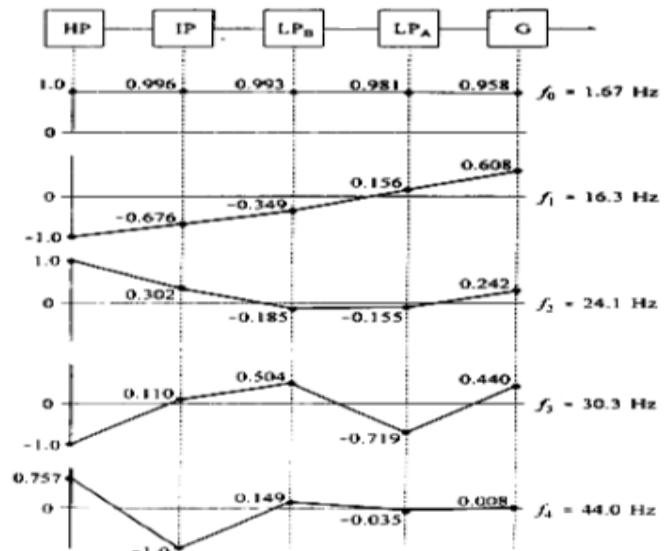


Fig 2 Torsional Natural Frequencies and Shapes of Modes for Turbine Generator

Torsional interaction is the interplay between the mechanical system (turbine-generator) and a series capacitor compensated electrical network. Small signal disturbances in a power system result in simultaneous excitation of all natural modes of the electrical and mechanical systems.

The turbine-generator shaft system responds to disturbances with oscillations at its torsional natural frequencies. Just as the electrical system, the real mechanical system is multimodal and will have more than one natural frequency.

$$F_n = \sqrt{\frac{K_{12}(M_1 + M_2)}{M_1 M_2}}$$

Oscillations of the generator rotor at this frequency result in modulation of the generator voltage. The sub synchronous frequency voltage component is at frequency $f_{en} = f_o - f_{er}$

When this frequency is close to a system natural frequency f_{er} , the resulting armature currents produce a magnetic field which is phased to produce a torque which reinforces the aforementioned generator rotor oscillations. This can result in sustained or growing oscillations. This phenomenon is referred to as torsional interaction.

3) Shaft Torque Amplification

When the transmission system contains series capacitor, it is possible that the complement of the electrical network natural frequency may align closely with one of the torsional natural frequencies. If this is the case, torques may be induced in the shafts following a system disturbance which are much larger than those developed as a result of three phase fault in an uncompensated system. This is due to the resonance effect and the fact that the torsional mode damping in a turbine generator rotor system has been observed to be extremely low. This effect is again referred to as shaft torque amplification.

Most often, the shaft response is not sinusoidal with a single frequency component, but contains contributions from the same peak torque level the torsional fatigue life. Consumption will be significantly lower for a multimode response in comparison to a single mode response.

III. SUB SYNCHRONOUS RESONANCE MITIGATION TECHNIQUE^[10]

Line filter
Parallel filter
Dynamic filter
Facts devices

There is a variety of facts devices are available. Among all facts devices GCSC is used for sub synchronous resonance mitigation in series compensated wind farm. Basic circuit is used for the sub synchronous resonance mitigation technique is shown in fig.

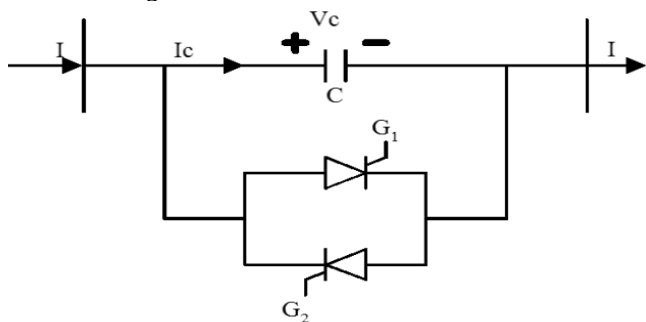


Figure 3 Basic GCSC Circuit^[6]

Fig. 3 shows a transmission line with series compensation using GCSC. The GCSC consisting of a capacitor and two reverse blocking semiconductor

switches (e. g. GTO, IGCT) connected in anti-parallel. The principle of operation of the GCSC is based on the variation of the turn-off angle (γ) of the controlled switches. Controlling the turn-off angle the voltage of the capacitor is controlled, consequently controlling the series compensation level of the transmission level.

When GTO valve is closed, the voltage across the capacitor is zero and when the valve is open, the voltage is maximum. For controlling this voltage, the closing and opening of the valve is carried out in each half cycle in synchronism with ac system frequency. The GTO valve is stipulated to close automatically through control action whenever the capacitor voltage crosses zero. However, the turn-off instant of the valve in each half cycle is controlled by a delay angle γ with respect to peak of the line current.

At the fundamental frequency, the GCSC is equivalent to a continuously variable series capacitor, where its reactance varies from its maximum value for $\gamma = 90$ to zero for $\gamma = 180$.

IV. SIMULATIONS AND RESULTS

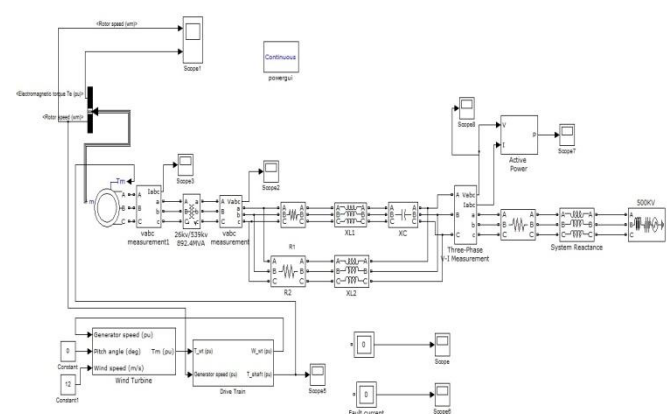


Fig. 4 Simulation of SBM Without Faults

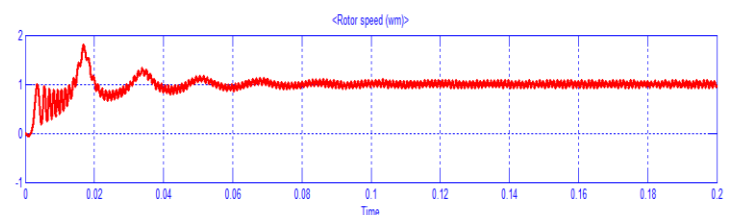


Fig. 5 Rotor Speed

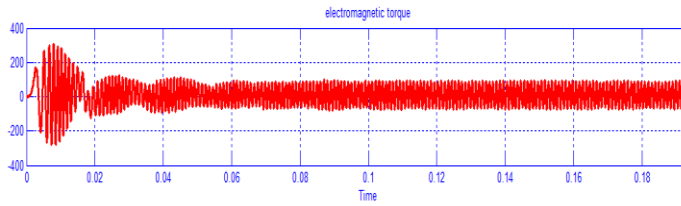


Fig. 6 Electromagnetic Torque

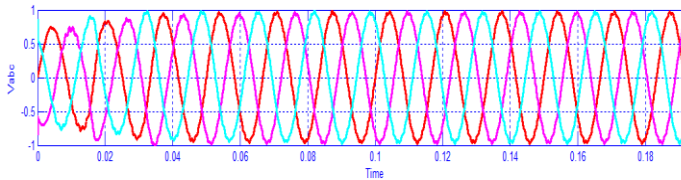


Figure 7 Source Voltage

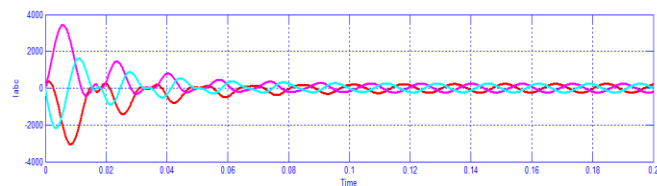


Fig. 8 Source Current

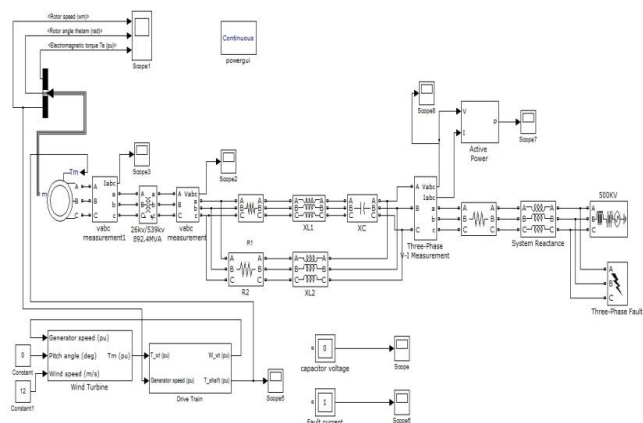


Fig. 9 Simulation of SBM With Faults

1) Series compensation for 30%

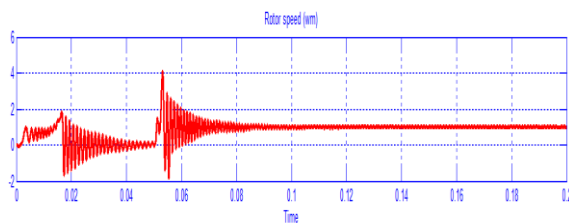


Figure 10 Rotor speed

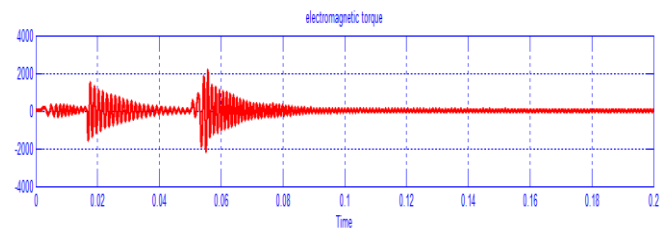


Figure 11 Electromagnetic Torque

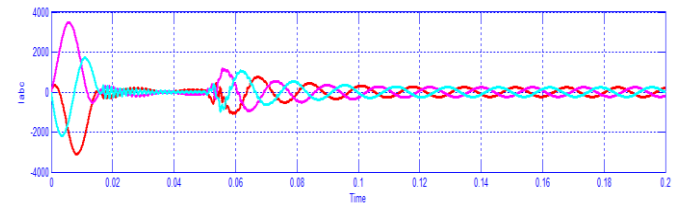


Figure 12 Source Current

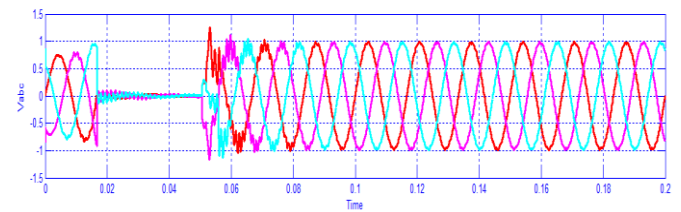


Figure 13 Source Voltage

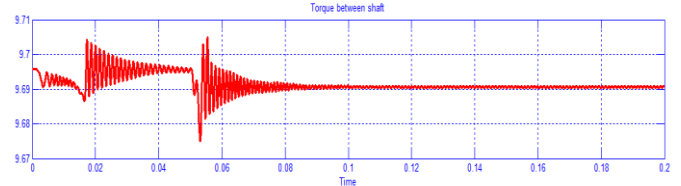


Figure 14 Torque Between Shaft

1) Series compensation for 50%

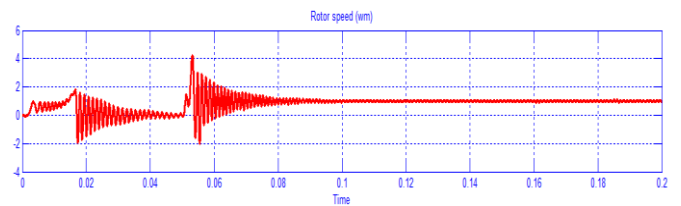


Figure 15 Rotor Speed

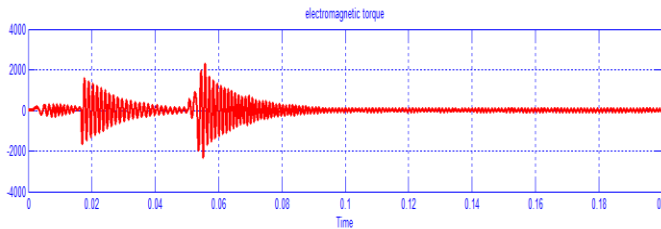


Figure 16 Electromagnetic Torque

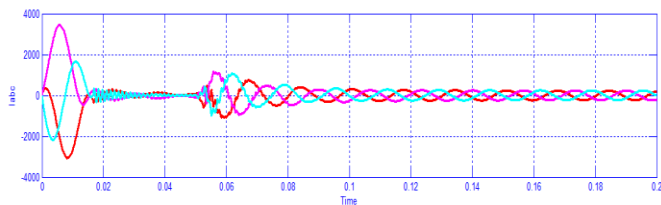


Figure 17 Source Current

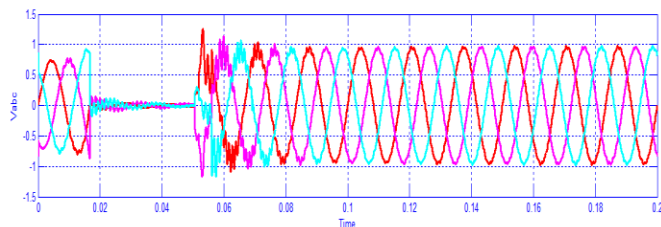


Figure 18 Source Voltage

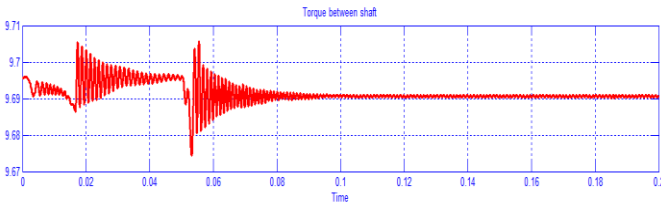


Figure 19 Torque Between Shaft

V. CONCLUSIONS

It is required to increase the power transfer capability of existing transmission line. When load demand is increased by using series capacitor compensation the power transfer capability of transmission line can be increased. But simulation results it shows that series capacitor compensation introduce the sub synchronous resonance in the power system.

REFERENCES

- [1] Sub synchronous Resonance Working Group of the System Dynamic Performance Subcommittee, "Reader's Guide To Sub synchronous Resonance IEEE Committee Report", IEEE transaction, Vol. 7, No. 1, February 1992
- [2] Andres E. Leon, And Jorge A. Solsona, "Sub-synchronous Interaction Damping Control For DFIG Wind Turbines", IEEE Transactions, February 2010

- [3] R. Griinbaum, P.Halvarsson, P.Joseph, "Series Capacitor Compensation For Increased Power Transmission Capacity"
- [4] Rajiv K.Varma, Soubhik Auddy, And Ysni Semsedini, "Mitigation Of Sub synchronous Resonance In A Series-compensated Wind Farm Using Facts Controllers" , IEEE Transactions, Vol. 23, No. 3, July 2008
- [5] D. H. R. Suriyaarachchi, U. D. Annakkage, C. Karawita, And D. A. Jacobson, "A Procedure To Study Sub-synchronous Interactions In Wind Integrated Power Systems", IEEE Transactions, Vol. 28, No. 1, February 2013.
- [6] Fábio Domingues de Jesus, Edson Hirokazu Watanabe, Luiz Felipe Willcox de Souza, and José Eduardo R. Alves, Jr, "SSR and Power Oscillation Damping Using Gate-Controlled Series Capacitors (GCSC)" IEEE Transactions on Power Delivery, Vol. 22, No. 3, July 2007
- [7] IEEE sub synchronous resonance working group of the system dynamic performance subcommittee power system engineering committee, "Terms, Definitions And Symbols For [8] Sub Synchronous Oscillations", IEEE transactions on power apparatus and systems, vol 6,june 1985
- [9] B. S. Umre, J. B. Helonde, J. P. Modak, Sonali Renkey (Rangari) 4"Application of Gate-Controlled Series Capacitors (GCSC) for Reducing Stresses due to Sub-Synchronous Resonance in Turbine-Generator Shaft" IEEE 2010
- [10] Hussein Ali Mohammad pour, MD Moinul Islam, David Coats, Enrico Santi Yong June Shin "Sub-Synchronous Resonance Mitigation in Wind Farms Using Gate-Controlled Series Capacitor", IEEE transactions 2009 M.H. Nehrir ,M.K. Doanelly, R. Adapa,