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Review and Mitigation of Sub-Synchronous Resonance using IEEE first benchmark model.

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Abstract-**In this paper dynamic performance of turbine-generator set connected to infinite bus bar is improved for the transmission network with and without series compensation. The FACTS device (Static Var Compensator) and optimal control theory are used for the improvement in dynamic performance and mitigation of sub-synchronous resonance (SSR). A well known technique i.e. Eigen value analysis is used for the analysis of SSR. The objective of the proposed frame work is to improve the dynamic performance and prevent the system from SSR phenomenon so that there is no damage to the generator rotor shaft**.

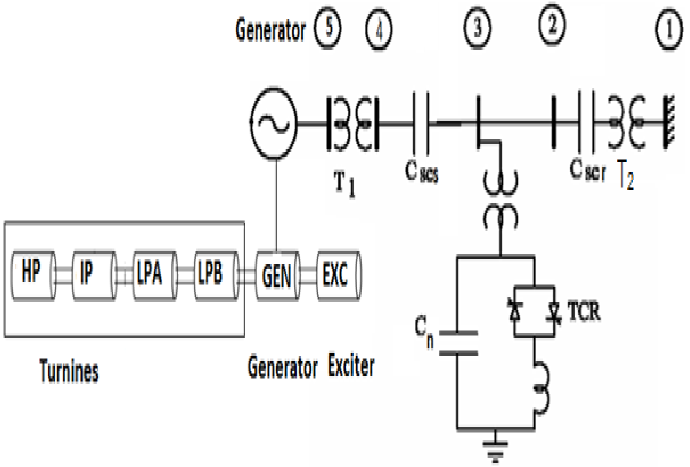
Keywords: **Sub-Synchronous Resonance (SSR), power system stabilizers (PSS), Electromagnetic Transients, Program (EMTP), particle swarm optimization(PSO)**

I.INTROUCTION

In India series compensated lines having capacitance C have a tendency to produce series resonance at frequencies lower than power frequencies. This is called sub synchronous resonance. If the star connected capacitor in 3 phase line i.e. shunt compensation and it is equivalent to delta connected capacitor then it may introduce the SSR.

1.1 Sub-Synchronous Resonance (SSR)

The phenomenon of sub-synchronous resonance occurs mainly in series capacitor compensated transmission systems. The first SSR problem was experienced in 1970 resulting in the failure of a turbine generator shaft at the Mohave plant in Southern California. It was not until a second shaft failure occurred in 1971 that the real cause of the failure was recognized as sub-synchronous resonance. Systems that experience SSR exhibit dynamic oscillations at frequencies below the normal system base frequency.



F i g .1.1 Study System

1.2 The formal definition of SSR is provided by the IEEE

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. The definition includes any system condition that provides the opportunity for an exchange of energy at a given sub synchronous frequency. This includes what might be considered "natural" modes of oscillation that are due to the inherent system characteristics, as well as "forced" modes of oscillation that are driven by a particular device or control system. The most common example of the natural mode of sub-synchronous oscillation is due to networks that include series capacitor compensated transmission lines. These lines, with their series LC combinations, have natural frequencies to that are defined by the equation (1.1)

$$\omega n = \sqrt{1/LC} = \omega 0/\sqrt{(\omega oL)(\omega oC)} = \omega 0\sqrt{XC/XL}\text{rad/sec}$$

$$\text{OR } fn = fo\sqrt{XC/XL}\text{ Hz}$$

or sub-synchronous resonant frequency of series compensated line is =fo√K ,where ωn is the natural frequency associated with a particular line L C product, ωo is the system base frequency, and XL and Xc are the inductive and capacitive reactance, respectively. These frequencies appear to the generator rotor as modulations of the base frequency giving both sub-synchronous and super synchronous rotor frequencies. It is the sub-synchronous frequency that may interact with one of the natural torsional modes of the turbine-generator shaft, thereby setting up the conditions for an exchange of energy at a subsynchronous frequency, with possible torsional fatigue damage to the turbine-generator shaft.

II. LITERATURE SURVEY

John W. Balance (1972) presented the concept of subsynchronous resonance in series compensated transmission lines.Contributions of synchronous generator rotor motion and induction generations to sustained subsynchronous oscillation are discussed. Computer simulation studies of a 500 kV transmission system are shown to closely correspond to actual system test data. Adverse effects of subsynchronous resonance on system components are described. Resonance in series compensated transmission lines coupled with the induction generator effects of a synchronous generator, and the effects of rotor motion near shaft resonant frequencies, has been shown to make possible sustained electrical system oscillations. Theoretical explanations have been shown to correlate very closely with actual system observations and computer simulation studies.[1]

K.R. Padiyar et.al.(1973) presented the general structure of a circuit model of a slip ring machine.The model is shown to be advantageous in many types of analysis of a machine when it is a part of a system. A specific circuit model of a synchronous machine (which was derived from Park's equations) has advantages in the stability analysis of multi machine power systems. The paper provides a more general and basic circuit model (applicable to any slip ring machine) utilizing the actual physical parameters of the machine. This is done with the view to extending the application of the circuit model to the study of asymmetrical faults or unbalanced operation.In such an analysis, the use of transformed aβ0 or dq0 components has no advantages. The advantages of this model in transient analysis over the existing models are shown to be the ease of formulation of the system equations, the elimination of the necessity to invert a timevarying inductance matrix and the ease of obtaining analytical solutions in a linear analysis.Further the model is also applicable to any slip ring machine with or without m.m.f. harmonics. If there are no m.m.f. harmonics in the air gap of the machine, it is possible to transform the model in αβo and dqo variables. Thus the relationship between the usual Park's model and the model given in this paper is shown. The analytical solutions for constant rotor speed can be derived using the standard state-space approach. The novel concept of dummy coils is shown to simplify the problems associated with dynamic saliency.[2]

D.N. Walker, et.al (1975) is the first fundamental paper presented on SSR. The results of the subsynchronous resonance test conducted on the turbine generator set at the Southern California Edison Company Mohave Generating Station are presented and discussed. Comparisons are made between measured and calculated torsional natural frequencies and mode shapes , and the damping associated with each torsional mode stimulated is presented at various loads. This test served to obtain a better understanding of the torsional dynamic characteristics of the turbine –generator, including the interactive effects of the electrical transmission system. These tests have laid the foundation for seeking a solution to the subsynchronous resonance problem in a systematic fashion. These tests results have given an optimistic view of designing the equipments to eliminate the concerned problem.[3]

R. G. Farmer et.al. (1977) suggested the number of equipments which can be used for SSR elimination .The history of subsynchronous resonance analysis by the Navajo Project leading to the selection of equipment to be applied at Navajo is presented. The analytical techniques used, potential problems discovered, solutions considered and solutions being applied are reviewed.This represents the first complete study of subsynchronous resonance problems on a particular system leading to selection of specific equipment to be applied as a solution to the problem. Although the Navajo Project is faced with the most severe SSR problems known, there is every indication that this problem can be solved by the installation of special equipment. For the Navajo Project the cost of eliminating series compensation by the addition of transmission circuits is much greater than the combined cost of series capacitors and special SSR equipment. From the number of equipments suggested in this paper but which equipment is better concerning the effectiveness, availability, and reliability is not mentioned.[4]

L. A. Kilgore et al (1977) An analysis of subsynchronous resonance problems requires a clear understanding of the physical relationships that produce the phenomenon. This paper presents these relationships and uses them to derive a number of useful formulas for studying the problems. The mathematical basis of these formulas is shown and the approximations required for their derivation are described. These formulas are most useful in planning a series capacitor compensated transmission system to avoid or minimize subsynchronous resonance problems, This application is the subject of a companion paper.[5]

A.A Fouad et.al (1978) proposed a new scheme of the damping of torsional oscillations through the use of stabilizing signals introduced at the input of the excitation system. The scheme is applied to the IEEE bench mark model for computer simulation, proposed by the IEEE Task Force on Subsynchronous Resonance. Subsynchronous resonance studies have confirmed the similarity between inertial oscillation, commonly observed under dynamic conditions, and the higher frequency modes observed when SSR occurs. Growing oscillations (that may be damagingly large) may occur under either condition. In situations where negative damping torques exist with inertial oscillations, power system stabilizers (PSS) have been used successfully to improve the system damping. In this investigation, an appropriate control signal is used to damp out the"troublesome" SSR modes .Design of the stabilizing control signal is given. The method is tested on the IEEE bench mark model, by an eigen value analysis and by analog computer simulation. Sub-synchronous oscillations can be successfully damped out using stabilizing control circuit (SCC) introduced at the input of the excitation system. The eigen value shown and the computer's recorded curves show that the control signal does not seem to have an appreciable effect on the system's normal operating conditions as far as the system inertial oscillation is concerned.[6]

R. G. Farmer (1985) proposed the second bench mark model for computer simulations. The first benchmark model for computer simulation of sub-synchronous resonance (SSR) was published in 1971. This provided the simplest possible model with a single turbine-generator connected to a single radial series compensated transmission line. The model has been used extensively for comparing study techniques and investigating different types of SSR countermeasures. The simple type of system employed in the First Benchmark Model, with its single series resonance would rarely be encountered in actual operation of a power system. Therefore, a more common type of system is presented in this Second Benchmark Model which deals with the so-called "parallel resonance" and interaction between turbine-generators with a common mode.[7]

Geza Joos (1987) presented the alternative of shunt capacitive compensation, since the electrical resonant frequencies in this case are usually considered to be super-synchronous. However, in heavily compensated or very long lines, at least one of the resonant frequencies may become sub-synchronous. This paper examines the torsional interactions between electrical resonant frequencies (which can be super-synchronous or subsynchronous) and the mechanical oscillations of a generator connected to a long transmission line.[8]

P.M.Anderson (1990)used the most common several analytical tools for the study of SSR. Frequency scanning .It is particularly effective in the study of induction generator effects. The frequency scan technique' computes the equivalent resistance and inductance, seen looking into the network from a point behind the stator winding of a particular generator, as a function of frequency (induction generator effect). The frequency scan method also provides information regarding possible problems with torsional interaction and transient torques. Eigen value analysis. Eigen value analysis provides additional information regarding the system Performance. This type of analysis is performed with the network and the generators modeled in one linear system of differential equations. The results give both the frequencies of oscillation as

well as the damping of each frequency. Eigen values are defined in terms of the system linear equations that are written in standard form. EMTP Analysis .The Electromagnetic Transients Program (EMTP) is a program for numerical integration of the system differential equations. Unlike a transient stability program, which usually models only positive sequence quantities representing a perfectly balanced system, EMTP is a full three phase model of the system with much more detailed models of transmission lines, cables, machines, and special devices such as series capacitors with complex bypass switching arrangements. Moreover, the EMTP permits nonlinear modeling of complex system components. It is, therefore, well suited for analyzing the transient torque SSR problems. EMTP adds important data on the magnitude of the oscillations as well as their damping. Frequency scanning method is fast and easy to use. Eigen analysis gives all of the frequencies of oscillation as well as the damping of each frequency. The method requires more modeling and data than frequency scanning and requires greater computer resources for the computation. EMTP requires still greater modeling effort and computer resources, but allows the full nonlinear modeling of the system machines and other devices, such as capacitor bypass schemes.[9]

K.R.Padiyar et.al (1990)In this paper a study of the improvement in system dynamic stability through effective use of auxiliary control of a static var system (SVS) is presented. The efficacy of different control signal for reactive power modulation of SVC is investigated with the objective of damping low frequency oscillations which are critical in limited power transfer. A new auxiliary signal designated as computed internal frequency (CIF) is proposed which synthesizes the frequency of the generator internal voltage from quantities available at SVS bus. It is concluded that this signal is far superior to other conventional auxiliary signals in that it allows full utilization of network transmission capacity. The efficacy of the signal is not critically dependent on the knowledge of the exact magnitude of the net reactance between the generators and SVS bus, thus making it very reliable in use.[10]

III. OVERCOMING PROBLEM

As SSR causes damage to the turbo-generator shaft or fatigue life of shaft so in the concerned heading we are going for analysis of SSR in series or shunt compensated line. Inpresent context IEEE first bench mark model has been considered. In the modeling the subsystems to be incorporated are Mechanical System, Rotor Circuit, Excitation system, SVS control System, and Transmission line with pre-specified assumption. The Eigen value analysis can be applied using editor window of MATLAB tool for SSR analysis. A controller based on application of optimal control theory can be used for increasing the stability of system as well as mitigation of SSR. The objective is to provide the cost effective, reliable, and user friendly method for the damping of SSR oscillations and increasing the stability of the overall system.

IV. PROPOSED METHODOLOGY

The FACTS device (Static Var Compensator) and optimal control theory are used for the improvement in dynamic performance and mitigation of sub-synchronous resonance (SSR).The results are shown by using the response curves through Matlab Power System Block set. A well known technique i.e. Eigen value analysis is used for the analysis of SSR. The objective is to provide the cost effective, reliable, and user friendly method for the damping of SSR oscillations and increasing the stability of the overall system. Results are shown with natural damping and without natural damping. The objective of the proposed frame work is to improve the dynamic performance and prevent the system from SSR phenomenon so that there is no damage to the generator rotor shaft toolbox of MATLAB will be used in my dissertation to implement the algorithm. MATLAB (Matrix Laboratory) was invented in late 1970s by Cleve Moler. It is a high-level language and its interactive environment helps us to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN. Another important feature of MATLAB is that it helps in modeling, simulating, and analyzing dynamic systems using SIMULINK, so it is widely used in applications that describe real-world phenomena. It supports linear and nonlinear systems, modeled in continuous time or sampled time.

V. CONCLUSION

SVS can supply controlled reactive power (lagging or leading) at the bus to which it is connected. The detail linearized model of SVS, mechanical system, excitation system, generator system and transmission line is presented for further applications. Mechanical system described is the multi-resonant mechanical model (all modes).All the torsional modes can be suitably studied using this model of mechanical system. Generalized system model for synchronous machine has been considered. The concept of dummy coils is shown to simplify the problems associated with dynamic saliency. The modeling of excitation system has been considered to see the effects of excitation control on the analysis of SSR study. Moreover power system stabilizer could easily be added to the model. The detail modelling of π – equivalent of along transmission line has been considered. The overall model is developed and found suitable for SSR study. The study is performed on the IEEE first bench mark model. The load flow study is carried out for calculating the operating point. The eigen value analysis is done for the system at Pg=600MW and Pg=420MW with and without series compensation at 0% and 8% respectively. The response curves and the time domain analysis for mechanical angle of generator, Torque between HP-IP turbine, SVS bus voltage, and SVS susceptance. As shown in curves, using optimal controller the steady state stability of compensated line is considerably enhanced. As the mode 0 is responsible for the dynamic interactions of generator and transmission line, the magnitude of the real part of the eigen values of this mode improves considerably on the application of optimal controller. With the step input of disturbance, system oscillations are greatly suppressed. This is verified by time domain analysis which shows fast restore of system states after the disturbance. The effect of optimal controller is more advantageous at higher level of compensation. The motive of increasing the power transfer capability at higher compensation level becomes feasible by using optimal controller. The control strategy is easily implementable as the controller works on the system states of the system.

The natural damping of the system is considered to be zero so that effect of controlling strategy can be examined effectively. Primarily it is seen that the oscillations are sustained and growing and the system is unstable. The mechanical damping coefficient of shaft system is positive and provides positive damping effect for the torsional oscillations.

Therefore excluding the effect of mechanical damping leads to most pessimistic operating condition w.r.t the stability of the torsional modes .Thus if the assigned countermeasure can provide the adequate damping for oscillations under worst condition, obviously they can damp the oscillations when the effect of mechanical damping is included in the system model. Thus dynamic analysis reveals that the SVC and optimal controller are able to limit the Eigen values in the stable region. Effective damping of all SSR modes is done.

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