Implementation of Phase Imbalance Scheme for Stabilizing Torsional Oscillations

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ABSTRACT

This paper implements the phase imbalance scheme for damping torsional oscillations of a series capacitor compensated power system. The IEEE Second Benchmark Model, system-1, wherein two turbine generator model and two system model connected to an infinite bus is employed as a standard system model to study the concept of subsynchronous resonance. The turbine generator models have a common torsional mode. The Electromagnetic Transients Program (EMTP) is employed to simulate the damping effects provided by the phase imbalance scheme. The simulation results also show that parallel phase imbalance scheme gives the better damping characteristics when compared to that of series phase imbalance scheme.

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1. INTRODUCTION

A number of control devices under the term Flexible AC Transmission System (FACTS) have been proposed and implemented to improve the stability of transmission system. The FACTS devices can be used for power flow control, loop flow control, load sharing among parallel corridors, voltage regulation, and enhancement of transient stability and mitigation of system oscillations. Depending on the device used it is known as series compensation and shunt compensation.

Series capacitor compensation of medium and long AC transmission lines has been recognized as a powerful tool for optimum and economical use of transmission lines. The potential inherent problem in series compensated transmission lines connected to turbo generators is subsynchronous resonance (SSR) leading to adverse torsional interactions [3]-[6] which results in shaft failure of mechanical system. Sub synchronous resonance (SSR) problems have been brought to general attention in particular in connection with the shaft damage events since the first shaft failure due to SSR occurred at the Mohave generating station in December 1970 and October 1971. After the shaft failure at Mohave generating station the first benchmark model for computer simulation of SSR was published in 1977. 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 was employed in the First Benchmark Model. But that would be rarely 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 [2].So as to avoid the shaft failure various countermeasures have been proposed. Phase imbalance scheme being one of them. Apart from implementation of the phase imbalance scheme, comparison of the scheme is also done in this paper. It is employed by using time domain simulations.

The idea of creating phase imbalance scheme in conjunction with the series capacitor banks was presented by Edris [10]. The basic idea of phase imbalance scheme is to reduce the energy exchange of turbine generator sets at subsynchronous oscillations by weakening the coupling between the electrical side and the mechanical side of the system. Such phase imbalance diminishes the capability of the three phase currents, which develop interacting electromagnetic torques.

In this paper, the phase imbalance scheme on damping SSR of the IEEE Second Benchmark Model has been implemented and analyzed. Section II introduces the studied system and configurations of the phase imbalance scheme. Section III compares the damping characteristics contributed by the phase imbalance scheme and finally section IV draws conclusions for this paper.

2. SYSTEM MODEL AND PHASE IMBALANCE SCHEME

A. The System Description

The first benchmark model for computer simulation of SSR was published in 1977. This provided the simplest possible model with a single turbine -generator connected to a single radial series compensated transmission line. The one line diagram of the IEEE Second Benchmark Model, system-1 is shown in Figure 1. The model comprises of four masses, i.e. the high pressure turbine (HP), the low pressure turbine (LP), the generator (GEN), and the exciter (EXC), which are mechanically coupled on the shaft. For this system there are three torsional modes (mode 1, 2 and mode 3) and one electromechanical mode (mode 0). These four modes are called SSR modes or torsional modes since their natural frequencies are all less than synchronous frequency or power frequency (60Hz).

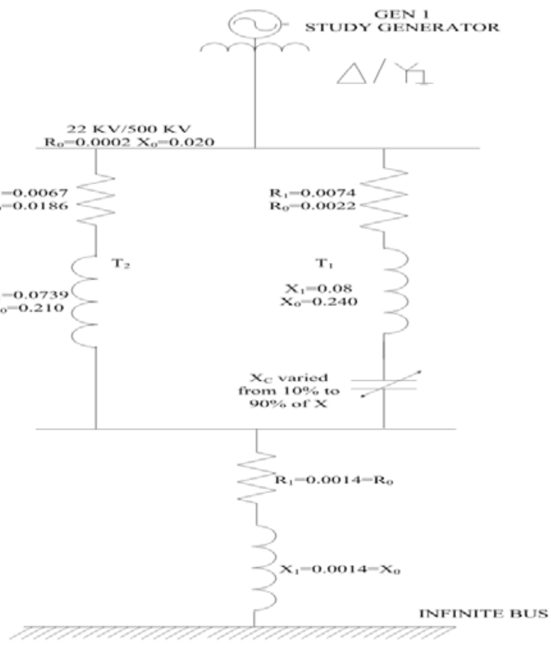

Figure 1. One line diagram of the IEEE Second Benchmark model

The inherent natural frequency for mode 0 is 1.35 Hz, mode 1 is 24.72 Hz, mode 2 is 32.39 Hz and mode 3 is 51.12 Hz respectively. The SSR mode i, i=0, 1, 2, 3 stands for the number of twists on the shaft. All turbine torques are proportional, with each contributing a fraction. The fractions for both HP and LP are equal to 50%. On the other hand, the electrical model of the studied system comprises of GEN connected to an infinite bus through a step up transformer and two parallel transmission lines, one of which is series-capacitor compensated. The values of X_c/X_l of the compensated line define the series compensation ratio [7]-[9]. The capacitive reactance X_c can be varied and X_c/X_l ranges from 10-90%. The mode frequencies are calculated with the help of inertia constants and spring constants which are shown in Table 1.

Table 1. Inertia constants and spring constants for IEEE Second benchmark model, system 1

Mass	Inertia(lbm-ft^2)	Shaft	Spring constant (lbf-ft/rad)
Exciter	0.00689	EXC-GEN	3.7403
Generator	0.87882	GEN-LP	83.472
LP	1.5497	LP-HP	42.702
HP	0.2489		

Using the above system parameters the mode frequencies are calculated with the help of MATLAB program and the mode frequencies are found to be Mode 0: 1.35 Hz, Mode 1: 24.65 Hz, Mode 2: 32.39 Hz and Mode 3: 51.10 Hz

The mode shapes corresponding to the mode frequency is shown in Figure 2:

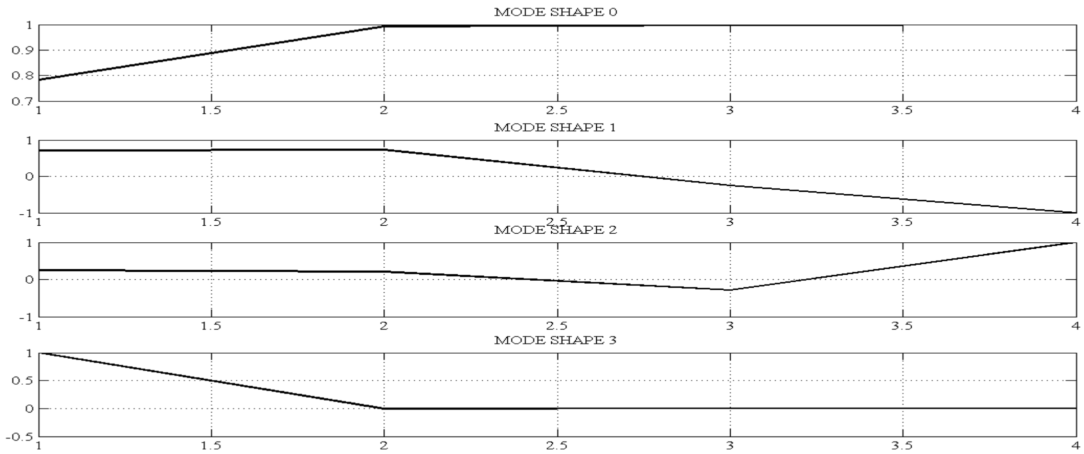

Figure 2. Mode shapes for IEEE Second Benchmark model

B. Phase Imbalance Scheme

The idea of creating phase imbalance scheme in conjunction with the series capacitor banks was presented by Edris. The phase imbalance scheme is created by introducing in one or more phases LC resonance circuits with a resonance frequency equal to the power frequency (60 Hz). With different values of L and C in each phase, these phase circuits will have unequal reactance at any frequency other than the power frequency. Basically there are two types of phase imbalance schemes: series resonance and parallel resonance whose configurations are shown in Figure 3 (a) and (b) respectively [1]. The values of L and C in parallel resonance scheme are decided by $\omega_0 = \sqrt{1/_{L_a C_a}}$. The degree of asymmetry, which uses parallel resonance between the three phases, can be controlled by tuning the two resonance circuits in parallel with their respective parts of the compensating capacitors.

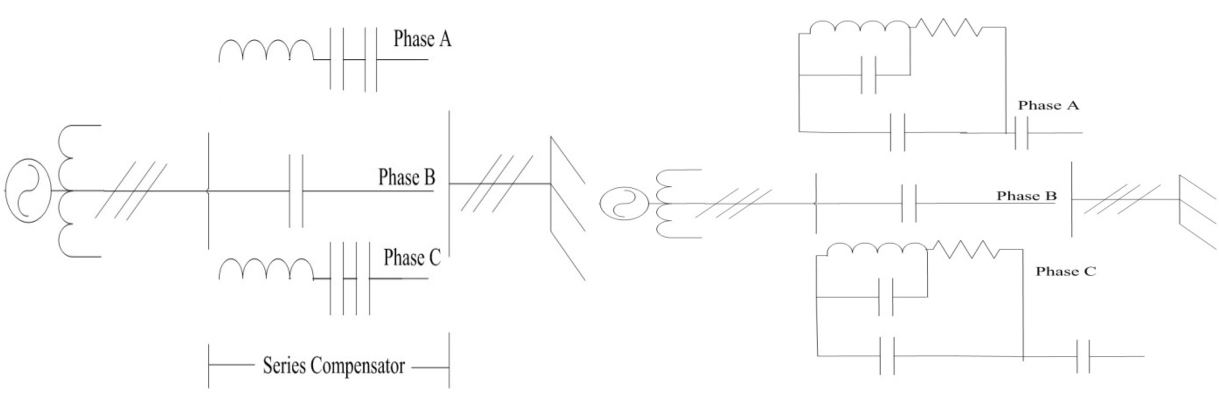

Figure 3. Configurations of phase imbalance scheme (a) Series Compensation (b) Parallel compensation

C. Sub Synchronous resonance

Sub synchronous resonance is an electrical power system condition where, electrical network exchanges energy with turbine generator at one or more natural frequency of the combined system, below the synchronous frequency of the system. For the IEEE first benchmark model the mode frequencies are calculated with the help of a MATLAB program. At these frequencies all rotating machinery system experience torsional oscillations to some degree during continuous or any disturbance operation in the power system. When the stress exceeds the endurance limit i.e. $45*10^7$ N/m^2, the shaft will be damaged. The stress is calculated as

$$Stress = \frac{\{(\delta_i - \delta_{i+1}) * G * R\}}{L}$$

where δ = twist angle
G =modulus of rigidity
R= Radius of shaft
L= Length of shaft

For the mode frequencies the stress exceeds the endurance limit of $45*10^7$ N/m^2. With the help of SSSC the stress at these frequencies can be reduced below the endurance limit.

3. RESULTS UNDER DISTURBANCE CONDITION

The IEEE first benchmark model, system 1 has been implemented with the phase imbalance scheme both series and parallel and the results are compared for different disturbance conditions

Three phase to ground fault

It is assumed that a three phase to ground fault, starting at t= 0.1 sec and lasting for 17ms, occurs at the high voltage side of the step up transformer. Figure 4 shows the dynamic response of torsional torque GEN-LP for the system with no damping scheme, series resonance scheme and parallel resonance scheme. Figure 5 shows the dynamic response of torsional stress GEN-LP for the system with no damping scheme, series resonance scheme and parallel resonance scheme. It is found that the system is unstable when no control schemes are in service. The result from the parallel resonance of phase imbalance scheme clearly indicates that GEN-LP torque comes to stable position in a much shorter span of time when compared to series. So parallel resonance scheme has better damping properties when compared to that of series resonance.

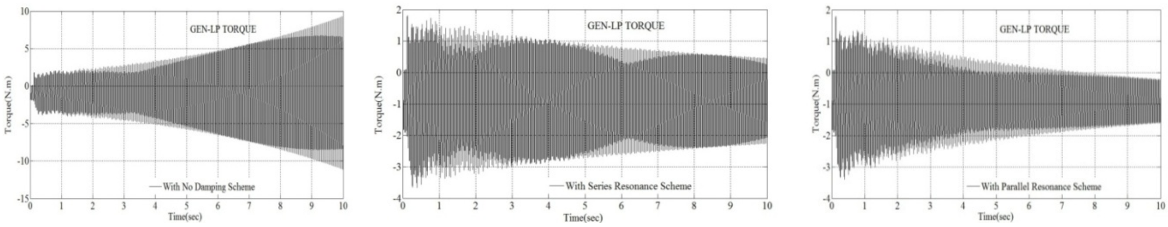

Figure 4. Dynamic response of GEN-LP Torque with no damping scheme, series resonance scheme and parallel resonance scheme

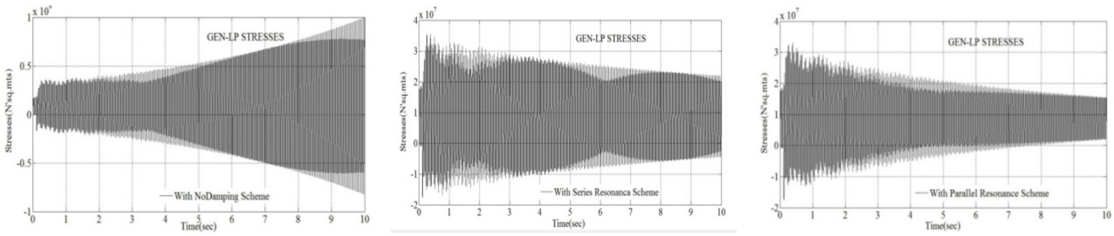

Figure 5. Dynamic response of GEN-LP stress with no damping scheme, series resonance scheme and parallel resonance scheme

Insertion of capacitor

The system is originally operated with one segment of series capacitor in service while the other capacitor is inserted at t=0.1 sec. Figure 6 shows the dynamic responses of torsional torque GEN-LP for the system with no damping schemes, prefiring NGH scheme, series resonance of phase imbalance and parallel resonance of phase imbalance scheme. Figure 7 shows the dynamic responses of torsional stress GEN-LP for the system with no damping schemes, prefiring NGH scheme, series resonance of phase imbalance and parallel resonance of phase imbalance scheme. With the insertion of capacitor the system becomes unstable in the absence of any control scheme. The result from the parallel resonance of phase imbalance scheme clearly indicates that GEN-LP torque comes to stable position in a much shorter span of time when compared to series. So parallel resonance scheme has better damping properties when compared to that of series resonance.

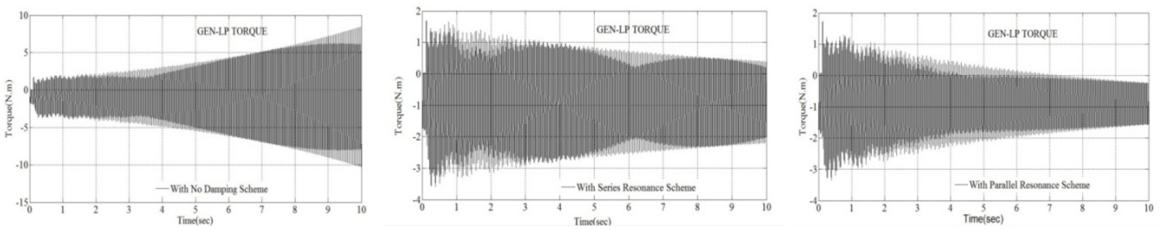

Figure 6. Dynamic response of GEN-LP torque with no damping scheme, series resonance scheme and parallel resonance scheme

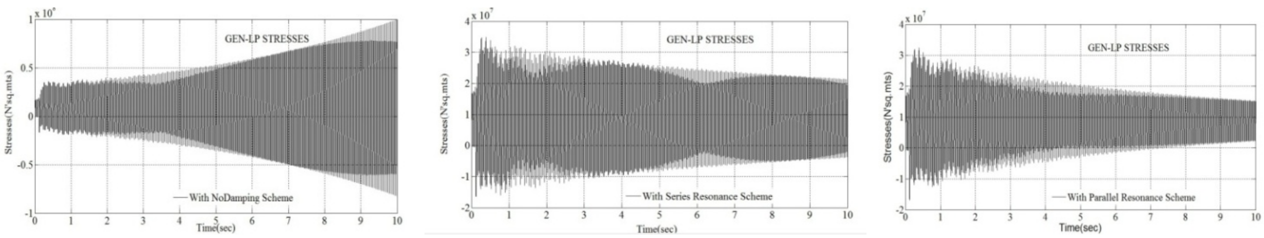

Figure 7. Dynamic response of GEN-LP stresses with no damping scheme, series resonance scheme and parallel resonance scheme

4. CONCLUSION

This paper presented the simulation results of a standard series capacitor compensated power system which uses phase imbalance scheme for stabilizing torsional oscillations. This paper studied the IEEE Second benchmark model, system 1when subjected to different disturbance conditions such as three phase to ground fault and insertion of capacitor. From the results it is found that the parallel resonance scheme has better damping characteristics when compared to series. The stress is also obtained below the endurance limit of $45*10^7$ N/m^2.

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