Analysis of Damper Parameters Effect on Sub Synchronous Resonance Stability

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Abstract: This paper presents effective and economic approach to reduce probability of sub synchronous resonance (SSR) occurrence. In order to highlight the importance of dampers parameters effect, eigenvalue analysis method is used. The effectiveness of the theory is shown by using the IEEE First SSR Benchmark Model (FBM).

1- Introduction

Series capacitor compensation in AC transmission systems is an economical and effective means to shorten electrical distance of transmission lines, to increase power transfer capability, to control load sharing among parallel lines and to enhance transient stability [1]. However, one major drawback of such capacitor compensation is that such systems are prone to SSR.

SSR is an electromechanical power system instability in which transmission lines compensated with series capacitors interact with torsional modes of generator shafts [2]. This instability can break generator shafts and must be studied and prevented when series compensation is used [3].

The first experience of shaft damage which caused by SSR occurred at Mohave substation in 1970. Since then, several countermeasures for damping of SSR, such as use of excitation control [4], NGH scheme [5], Static Synchronous Compensator (STATCOM) [6], Thyristor-controlled series capacitor (TCSC) [7] etc., have been suggested in the literatures.

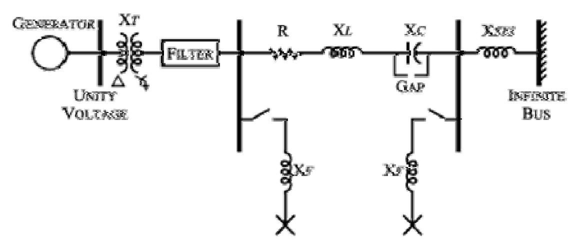
Some of the shortcomings of these devices are expensiveness and harmonics injection problems. Therefore by good design of system parameters, using the proposed method, probability of SSR occurrence decrease by reasonable cost. The procedure of the proposed method is given and a mathematical discussion is provided on [10] to prove the validity of the proposed method.

2- Power System Study Model

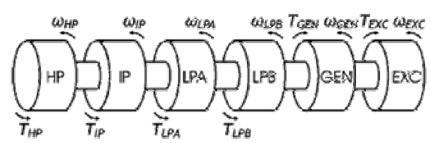
In order to study and analysis SSR, the First IEEE Benchmark Model [8], shown in Fig. 1, is applied. This model contains an 892.4 MVA synchronous generator which is connected to an infinite bus via a highly compensated 500 kV transmission line. The mechanical system consists of a four stage steam turbine, the generator and a rotating exciter.

The electrical and mechanical systems were modeled. Two damper windings were provided in the q axis while in the d axis one damper and a field winding were considered.

The mechanical system was represented by a multi mass spring dashpot system, with six lumped masses coupled by shaft sections of known torsional elasticity. Mechanical damping was assumed to be zero in all the analyzed cases, to represent the worst damping conditions.



1-a- IEEE FBM



1-b- 6 mass spring model

Fig. 1, a- IEEE first benchmark system, b- mass spring model of turbine-generator

2-1- Generator Model

Fundamental equations of synchronous machine were derived by Park. These equations have the simplest form and are most well known. The equations are lineared as below:

$$\frac{1}{w_b}\left(-x_{mq}\Delta\dot{i}_q + x_{mq}\Delta\dot{i}_Q + x_s\Delta\dot{i}_s\right) = -r_s\Delta i_s \tag{1}$$

$$\frac{1}{w_b}\left(-x_{mq}\Delta\dot{i}_q + x_Q\Delta\dot{i}_Q + x_{mq}\Delta\dot{i}_s\right) = -r_Q\Delta i_Q \tag{2}$$

$$\frac{1}{w_b}\left(-x_{md}\Delta\dot{i}_d + x_{md}\Delta\dot{i}_F + x_D\Delta\dot{i}_D\right) = -r_D\Delta i_D \qquad (3)$$

$$\frac{1}{w_b}\left(-x_{md}\Delta\dot{i}_d + x_F\Delta\dot{i}_F + x_{md}\Delta\dot{i}_D\right) = -r_F\Delta i_F + \Delta v_F \qquad (4)$$

$$\frac{1}{w_b}\left(-x_d\Delta\dot{i}_d + x_{md}\Delta\dot{i}_F + x_{md}\Delta\dot{i}_D\right) = -x_q\Delta i_q + x_{mq}\Delta i_Q + x_{mq}\Delta i_s + y_{q0}\Delta w + r_a\Delta i_d + \Delta v_d \qquad (5)$$

$$\frac{1}{w_b}\left(-x_q\Delta\dot{i}_q + x_{mq}\Delta\dot{i}_Q + x_{mq}\Delta\dot{i}_s\right) = x_d\Delta i_d - x_{md}\Delta i_F - x_{md}\Delta i_D - y_{d0}\Delta w + r_a\Delta i_q + \Delta v_q \qquad (6)$$

Where, D, Q and S are damper windings. Since analysis of dampers parameters is the goal of this paper and only equations of generator are presented.

The other parts of the system are modeled which can be fined in [9]. When these equations are linearized, state space equations are obtained which can be written as below:

$$\dot{X} = AX + BU$$
$$Y = CX \qquad (6)$$

Which X is the state vector, Y is the output vector and U is input vector.

3- Analytical Simulation

Eigenvalue techniques are based on the mathematical model of the system using its set of linearized differential equations. They are used to examine the effect of different series compensation levels and system configurations on the damping of torsional modes. Also the salient feature of the eigenvalue analysis method is that it provides an intuitive explanation and physical understanding of the phenomenon. Therefore in this paper eigenvalue analysis method is used for description of damper parameters affect.

At first system matrix (A) is calculated that is 27 order matrix. Since the mass spring model of turbine-generator has 6 lumped mass then it has 5 torsional modes which can be unstable. Fig. 2 shows the real part of eigenvalue of these torsional modes when percentage of series compensation is varied from 0 to 100%.

Therefore the unstable modes, in normal range of series compensation, are 3 and 4 which must be stable.

3-1- Effect of Q damper parameters

Parameters in Q damper are x_Q and r_Q, coefficient of Eq.2, which can change the real part of torsional modes.

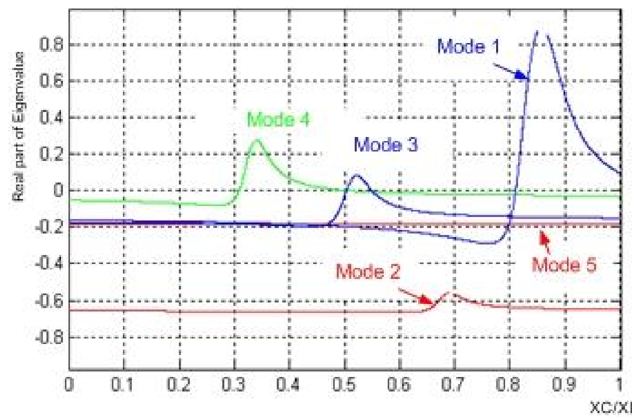


Fig. 2 Real parts of torsional mode as a function of XC/XL

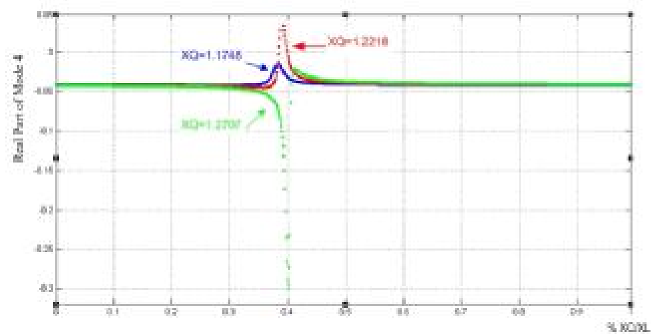


Fig. 3 Real part of mode 4 for some value of x_Q

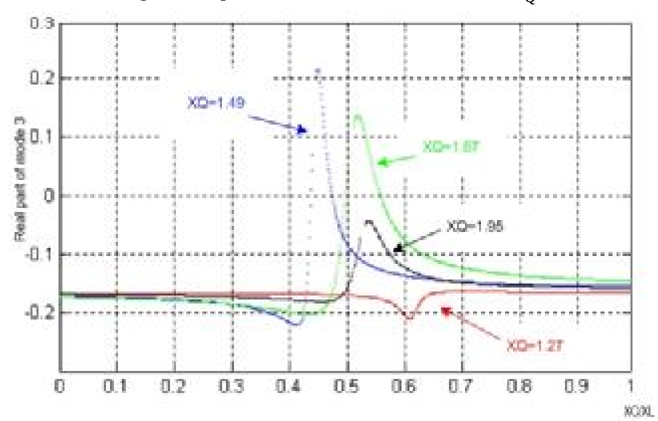


Fig. 4 Real part of mode 3 for some value of x_Q

Fig. 3 and 4 shows real part of mode 4 and 3 for some value of x_Q when percentage of series compensation is varied from 0 to 100%.

It is well known that negative real part in an eigenvalue indicates modal stability. It can thus be concluded that this mode become stable or unstable for very small change in x_Q value so this parameter is very important.

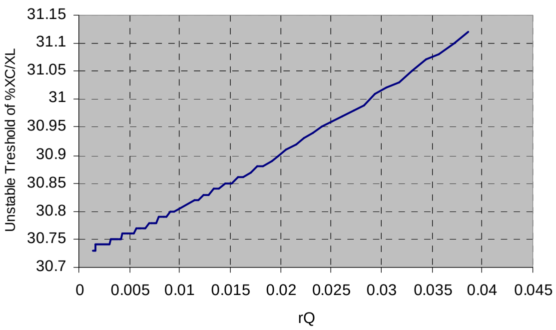


Fig.5 Unstable threshold of mode 4 for different value of r_Q

It has been observed from Fig. 5 that stable series compensation max for mode 4 has small change (about 0.4%) for different value of r_Q. So this parameter has not critical role in stability.

3-2- - Effect of D damper parameters

Parameters in D damper are x_D and r_D that this part evaluates the effect of them on stability. They are coefficient of Eq.3

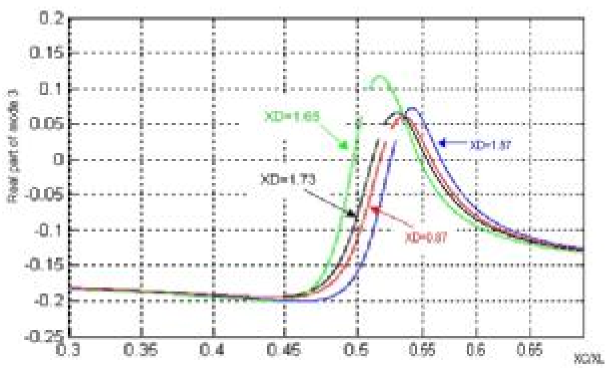


Fig. 6 Real part of mode 3 for some value of x_D

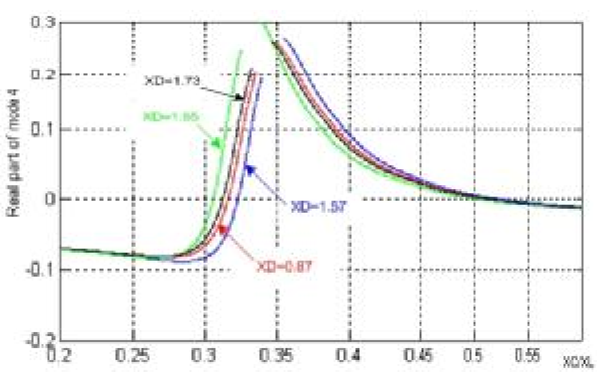


Fig. 7 Real part of mode 4 for some value of x_D

Fig. 6 and 7 show effect of x_D on mode 3 and 4 respectively. It can be understudied from these figures that this parameter only can change the threshold of instability about 2 percentage for variation from 0.25 to 10 times of rated value. The effect of r_D on mode 4 is shown in Fig.8. Also it has affected nearly 0.8 percentages for wide range of variation in r_D. It has similar effect on mode 3 therefore it is not shown. So parameters of D damper are not vital parameters for stability.

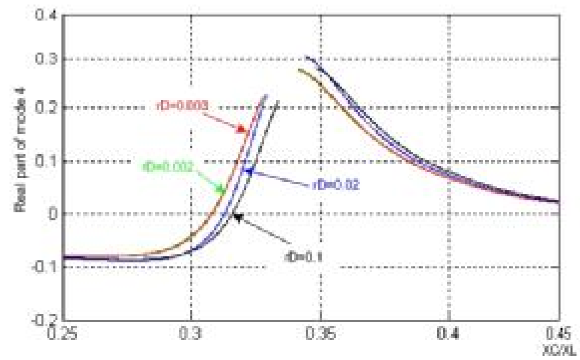


Fig. 8 Real part of mode 4 for some value of r_D

3-3- 3-2- - Effect of S damper parameters

Parameters in S damper, coefficient of Eq.1, are x_S and r_S. This part evaluates the effect of them on stability.

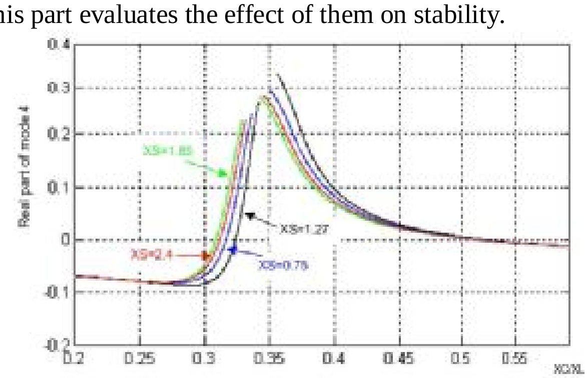


Fig. 9 Real part of mode 4 for some value of X_S

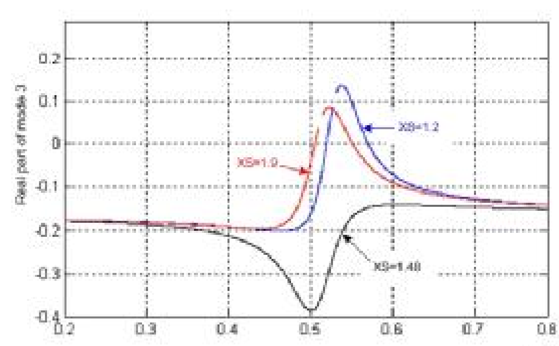


Fig. 10 Real part of mode 3 for some value of X_S

The effect of X_S on mode 4 is shown in Fig.9 which it has small effect on threshold of stability but the affect of X_S on mode 3 which shown in Fig.10 is vital for stability because this mode become stable and unstable for narrow range of variation in this parameter. Fig.11 shows affect of r_S on mode 3. It has important role in stability of this mode but it has not significantly influence on mode 4.

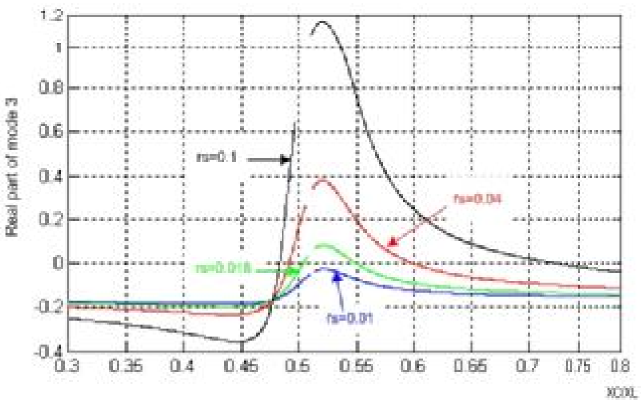


Fig. 11 Real part of mode 3 for some value of r_S

Thus the effective parameters for mode 3 are x_Q, r_S, x_S and x_Q is for mode 4. Therefore by suitable design for x_Q the system can be stable. Fig.12 shows the flow chart of algorithm for obtain range of each parameters for stability. Stability thresholds of mode 3 and 4 are drawn in Fig.13. As can be seen in the figure, it can be concluded that by choosing X_Q=0.9 stability is obtained for 100 percentage of compensation. Whereas the discussion is presented in [10] which proved the destabilize effect of damper windings on SSR phenomenon, this paper shows all of torsional modes for 100 percentage series compensation are stable. And this claim is proved by deep theoretical mathematical proof ness which is shown in Fig.14. Additionally the theory and proposed method are calculated and obtained based on FBM. Consequently, this paper confirms the significant role of damper winding especially damper winding Q on stability of the SSR phenomenon obviously.

The proposed method operates as follows:

1) Firstly, models all of the system components.

2) Secondly, determines amount of deferent modes instability.

3) Thirdly, determines the essential parameters.

4) Finally, calculates the amounts interval of parameters in which threshold of torsional instability they could occur by increasing the compensated percentage.

Finally, in order to proof, the evident of the proposed method the eignvalue of torsional modes for varies of series compensated range are listed in table 1. As can be seen in the table eignvalues are shown for both the original system component and proposed design component which some of the original system eignvalue are unstable but all are stable in new design.

Authors try to design new synchronous generator with proper value of dampers parameters in order to stabilized torsional modes for each individual power systems. Another work will has been obtained the value of dampers parameters precisely for optimization of all generator characteristics.

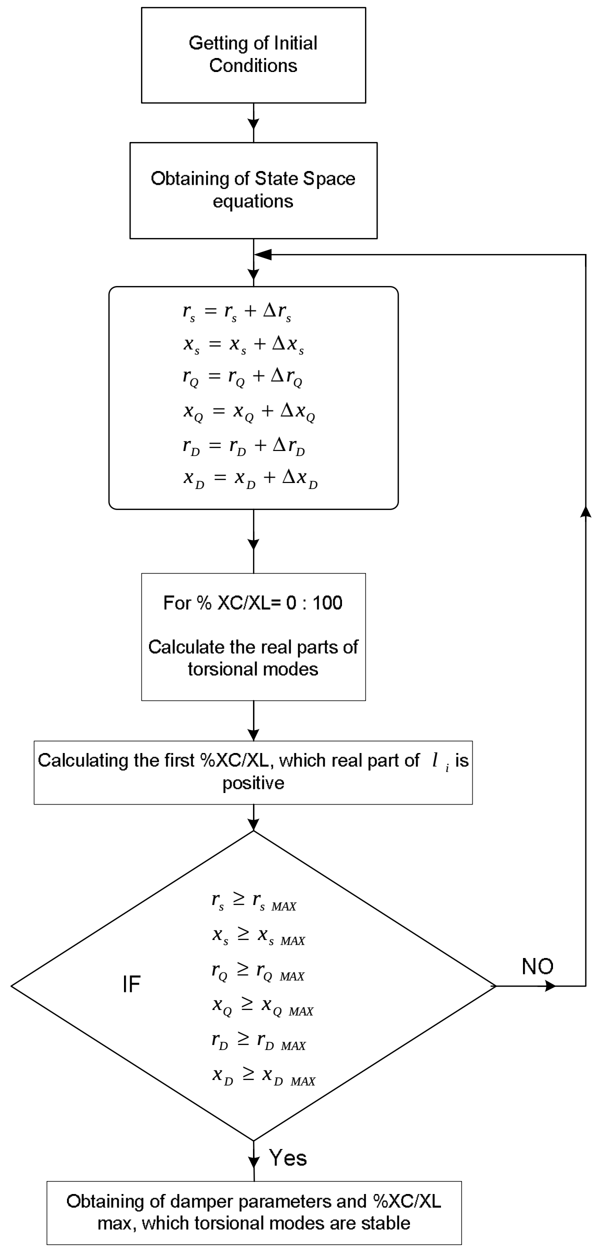


Fig.12 flow chart for obtain parameters of dampers for stability

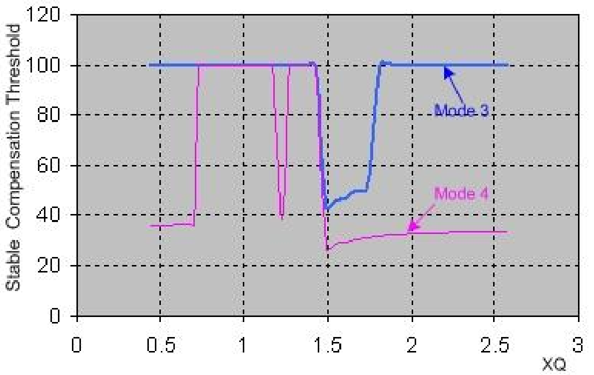


Fig. 13 Threshold of stable compensation for mode 3 and 4 when XQ changes

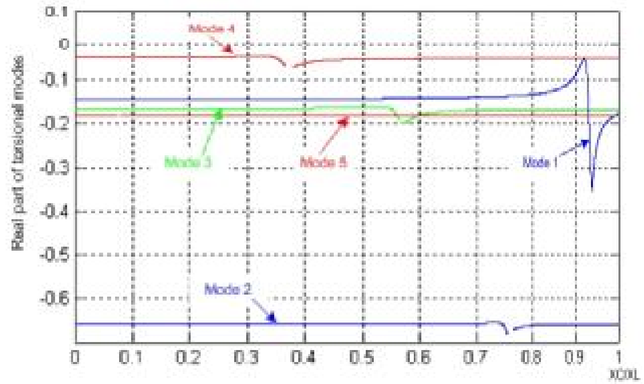


Fig. 14 Real parts of torsional mode as a function of XC/XL after new design

Table 1 eignvalue of torsional modes for different compensated percentage

	Original design			This paper		
Modes	%XC/XL=35	%XC/XL=55	%XC/XL=85	%XC/XL=35	%XC/XL=55	%XC/XL=85
Mode 5	-0.18±298i	-0.18±298i	-0.18±298i	-0.18±298i	-0.18±298i	-0.18±298i
Mode 4	+0.25±202i	-0.00±202i	-0.02±202i	-0.04±202i	-0.04±202i	-0.04±202i
Mode 3	-0.19±160i	+0.1±160i	-0.15±160i	-0.17±160i	-0.17±160i	-0.17±160i
Mode 2	-0.66±127i	-0.66±127i	-0.64±127i	-0.66±127i	-0.66±127i	-0.66±127i
Mode 1	-0.18±99i	-0.2±99i	+0.87±99i	-0.15±99i	-0.14±99i	-0.12±99i

4- Conclusion

In competitive environments such as power market transmission lines are equipped with series capacitors to enhance amount of power transmission in other to achieve more benefits. But implementation of these series capacitors, synchronous generators may undergo torsional oscillations. Therefore, to overcome this problem and secure generator shaft, damping winding came to consideration as a solution because transmission lines and power plant are belong different companies. Consequently, in this paper the effect of dampers parameters were analyzed by eignvalue method then a proper design of damper winding's parameters was proposed. By this method all of torsional modes were stabled without any extra device such as FACTS devices. So this method is cost efficient.

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