

NEURAL NETWORK APPROACH TO IDENTIFICATION AND CONTROL OF SUB-SYNCHRONOUS RESONANCE IN SERIES COMPENSATED SYSTEMS

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Abstract - The development of a precise mathematical model for SSR is a complicated process, especially, in systems involving multiple generators and series compensated transmission lines. Further, the analysis of the SSR phenomenon for the entire operating range is computationally intensive. In view of these situations, it is envisaged that Neural Networks can be effectively employed to design SSR countermeasures. This paper presents such a contribution. Examples on systems with thyristor controlled shunt reactor are used to illustrate the benefit gained from this approach.

1. Introduction

SSR situations arise, basically, due to the interaction of unstable ElectroMechanical (EM) modes of oscillations of the Turbine Generator (TG) shaft with the electrical natural frequency of the transmission network. Some of the important countermeasures for SSR are the supplementary control for thyristor controlled shunt reactor, co-ordinated SVC controllers with Sub-synchronous Damping Controllers of HVDC rectifier in case of AC/DC systems, etc.,. In all these countermeasures, the hardware component used to suppress the sub-synchronous oscillation is some variant of an SVC which is switched by means of fast acting thyristors.

The development of a precise mathematical model for SSR is a complicated process, especially, in systems involving multiple generators and series compensated transmission lines. Further, the analysis of the SSR phenomenon for the entire operating range is computationally intensive. In view of these situations, it is envisaged that Neural Networks can be effectively employed to design SSR countermeasures. This paper presents such a contribution.

2. Neural Network Approach

To characterise the phenomena of SSR in series compensated systems, a parametric study is conducted on the First Benchmark Model (FBM) test system that was proposed by IEEE SSR Task Force [1]. The studies conducted, confirmed the existence of unstable EM modes of oscillations and their

interactions with the electrical natural frequency. Multi-Layered Perceptron (MLP) is used to design two NN-based systems, namely, the SSR detector and SSR estimator which can detect the presence of unstable EM modes of oscillation and estimate the associated instabilities. A comparison between the results from the parametric studies conducted using Eigen-Value (EV) analysis and the results obtained from NN based SSR detector has validated the NN model [2-3]. The generator rotor is represented by its small signal equivalent circuit.

2.1 Generation of Training Patterns

Since the power, power factor, series compensation levels and the damping coefficients may lead to EM oscillations, these parameters constitute the input vector for the ANN.

The real parts of the EVs corresponding to the electromechanical modes of oscillations which are indicative of the stability of the respective modes shall form useful outputs of the neural network. The fundamental information required as the output of the ANN is that whether the electromechanical modes of the system are stable against a prevailing input condition. This information can be provided in the binary form where a logical one indicates stability of a mode and a logical zero indicates instability. A second information that is required is the extent of instability which is provided by the magnitude of the real part of the respective EVs which are continuous values. In order to designate all outputs to be binary, the magnitudes of the real part of EVs of the required modes of oscillations are quantised and represented by binary value of three bit length. Thus the minimum value of the real parts of the EVs corresponds to 000 and the maximum corresponds to 111. Further, the EM modes of oscillation are unstable only in a small range of the series compensation. At other points, they are characterised by negative real part of the corresponding EVs. To cater these situations, all negative values are given the binary value 000. In this way, two different training sets are generated which are later used to train two separate neural networks which are called the SSR detector and SSR estimator. Considering the entire operating range and normally encountered range for the series compensation levels, 350

input situations are synthesised and the output vectors for each of these input situations are computed using EV analysis

2.2 ANN Architecture and Testing

The most widely used supervised, Error Back Propagation learning algorithm with Multi-layered Perceptron (MLP) is employed to implement both the SSR detector and SSR estimator.

The input vectors for the SSR detector and SSR estimator are identical and consists of generated power, power factor, series compensation and the damping co-efficients d_1 and d_2 , which are all continuous values. Accordingly, we have five sensory neurons constituting the input layer. The output vector of SSR detector is a binary string of length 5 each bit of which is indicative of the stability or instability of different EM modes of oscillations. On the other hand, the output vector of the SSR estimator is again a binary string of 9-bit length (D0-D8). D0-D2 represents the quantised level of the real part of the EV corresponding to mode 1. Similarly, D3-D5 and D6-D8 represent the quantised level of the real parts of the EVs corresponding to mode 3 and mode 4, respectively.

The optimal number of neurons in the hidden layers of the SSR detector and SSR estimator is found to be 15 and 40, respectively. The set of input vectors with power generation of 0.9 pu is used for testing and this has not been seen by the NN before, that is it is not a part of the training set. The results show that the network has attained good generalisation.

2.3 Design of an ANN based SSR Countermeasure

Most of the published research works in the area of SSR countermeasures have considered either the prime mover speeds or the modal speeds as the feedback signals and have employed state variable feedback technique. The gain values and time constants are determined based on the desired performance of the system at a single operating point without any consideration for robustness of the controller. To overcome this problem it is necessary to evolve a control strategy which gracefully honours the variation of the feedback signals with the changes in the operating points.

The information obtained from this SSR detector in terms of the stability behaviour of different modes of oscillations can be effectively employed as Feedback (FB) signals to modulate the reactive power absorbed by a shunt reactor connected to the low voltage winding of the generator transformer. In this way, the application of ANN to detect SSR can be extended to implement an SSR countermeasure.

As a first step, a PI controller is designed by employing the

state variable technique, wherein the deviations in the angular velocities associated with different modes of oscillations are used as FB signals. The gain and time constant of the controller are determined using the Eigen structure assignment technique. Dedicated controllers are designed for each of the unstable modes of oscillations and hence the controller is called a Multiple Proportional Integral (MPI) controller. The second step involves a reinforcement of this MPI controller with an ANN based SSR detector. A logic 1 in a particular bit position is an indicative of the instability associated with a particular mode and a logic 0 indicates stability. Depending upon these logical levels, the corresponding controller of the MPI controller is either triggered or not triggered. This reinforcement on conventional PI controller, fundamentally, obviates the need for the measurement of velocities which involve complex instrumentation, implements a non-invasive control action across different modes of oscillations and exercises the controllers in an optimal fashion thus increasing their life. The proposed ANN based countermeasure requires the operating condition as the input which consists of the active and reactive power, damping associated with

different sections of the TG and the series compensation levels.

3. Results

The test system is shown in Figure 1. The numerical values of the system parameters are given in [1-3].

3.1 Analysis of the test system

The variations of the real parts of the Eigen values corresponding to different electromechanical modes of oscillation with respect to the series compensation levels at different operating points are determined to characterise the oscillatory behaviour of the system. Figure 2 shows the variation of the real parts of the EVs as a function of series compensation at different generation levels. These plots clearly establish the performance enhancement which can be achieved by just connecting a shunt reactor to the low voltage side of the generator transformer. However, an observation of these plots reveals that shunt reactor alone is not sufficient to relieve the system completely of the possibility of SSR occurrence. Hence, the shunt reactor controller is required to be augmented to damp these electromechanical modes of oscillations which, otherwise, may lead to SSR at strategic operating conditions and compensation levels.

The input signals to the Single-Input-Multiple-Output (SIMO) type of controller are the speed deviations and the angle deviations of those sections of the turbine which correspond to unstable modes (modes 0,1,3 and 4). The poles corresponding to unstable modes of oscillation are arbitrarily

placed in the Left Half Plane in accordance with the expectations of the damping of these modes. The FB gains are computed based on the arbitrarily assigned locations for the poles. In this way, the design could be very conservative leading to non-optimised control efforts.

An ANN is employed at the input section of the MPI so that the dependency of the controller on precise measurement of speed deviations is removed. The ANN outputs a binary string whose length is equal to the number of oscillatory modes of the system and each bit position of the binary string corresponds to one mode of oscillation. A logic 1 in a bit position is indicative of the instability of that mode and a 0 in that bit position is indicative of the adequacy of the damping for that particular mode. In this way, the controllers constituting the MPI controller are configured dynamically depending on the mode/s of oscillation which require damping.

3.2 Dynamic Response of FBM with Shunt Reactor Controller (SCR)

To assess the performance of the ANN based SSR countermeasure, simulation of the FBM test system equipped with this countermeasure, is conducted. For this purpose, series compensation level is maintained at 50% and the generation at 0.8 pu and 1.0 pu. The system is subjected to a pulsed torque disturbance of 10% for 0.1 sec. For the sake of comparison, the response of the system with the ANN based

SSR countermeasure and an identical system with a fixed shunt reactor is presented in Figure 3 for the shaft oscillation. A significant improvement in the dynamic response of the system is observed with the present approach.

4. Conclusions

In this paper, the design and implementation details of an ANN based SSR countermeasure are presented. Basically, a thyristor controlled shunt reactor connected to the low voltage side of the generator transformer is used as the controlling element. Results show that the present approach can get good results.

5. References

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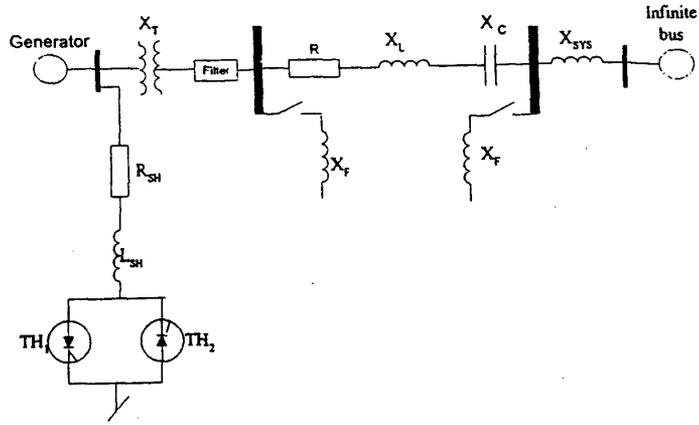
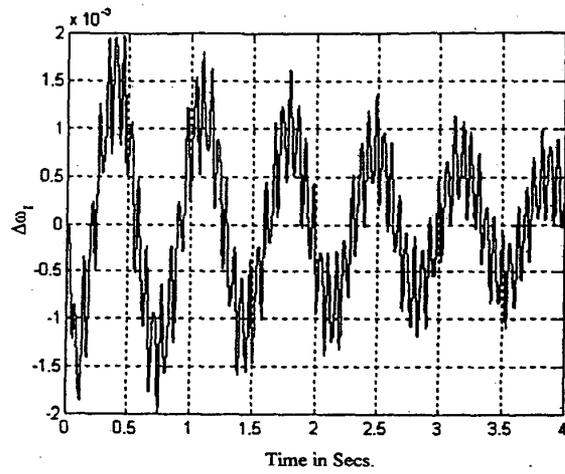
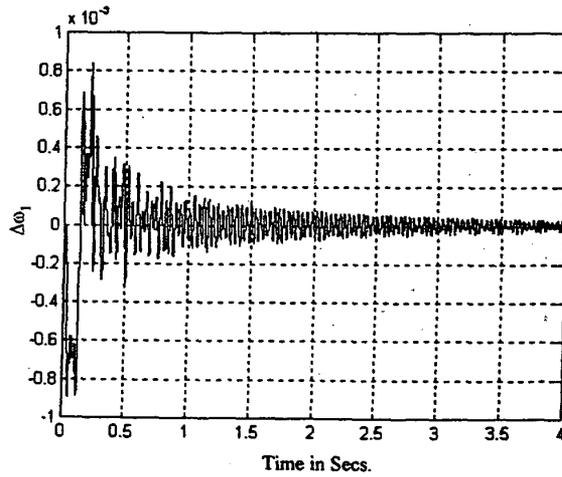


Figure 1 Single Line diagram of the test system with shunt reactor



With Fixed shunt reactor



With ANN based SSR countermeasure

Figure 3 Dynamic response of FBM with NN based SSR countermeasure

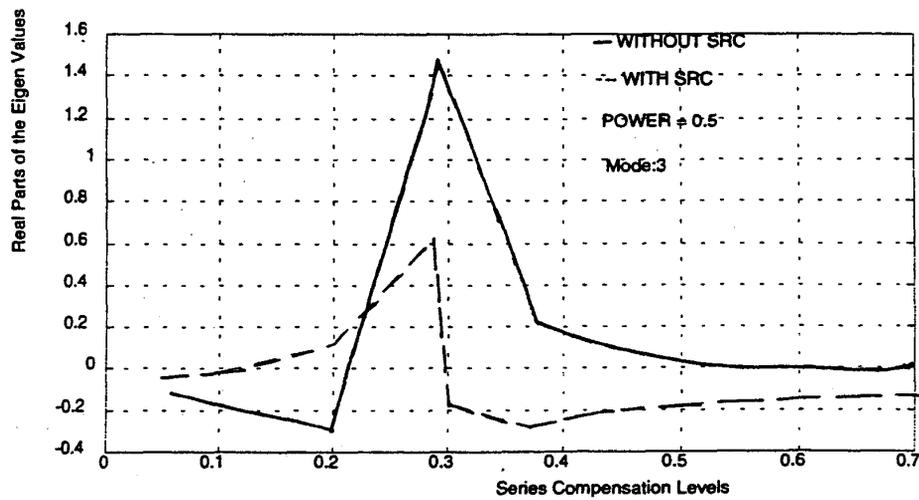
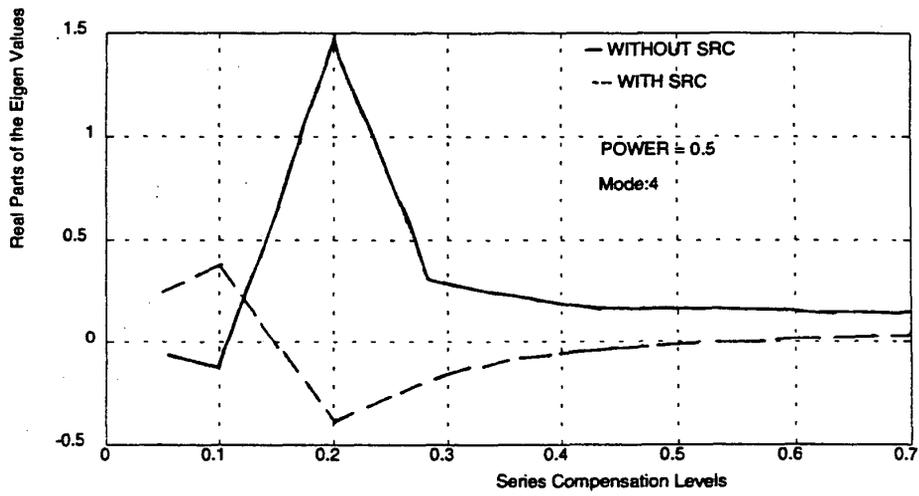
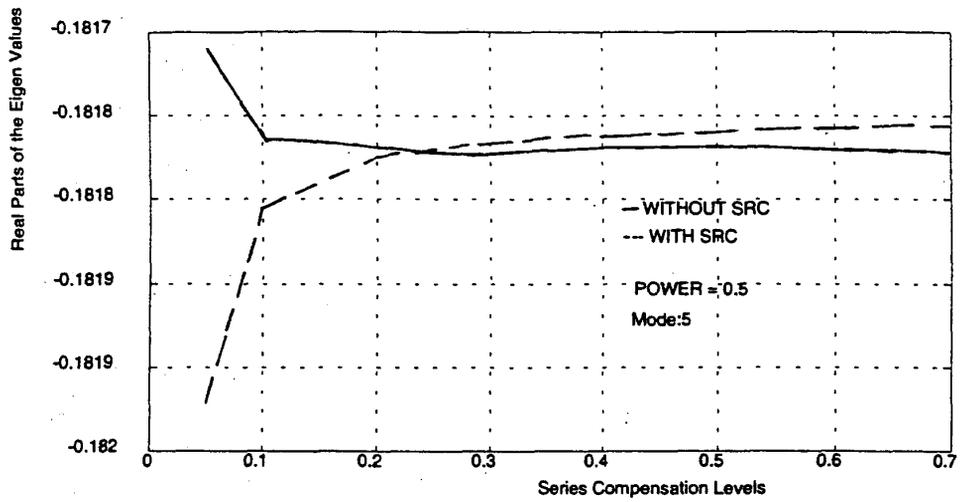


Figure 2 Real parts of Eigenvalue .vs. series compensation levels