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Design of a New IPFC-Based Damping Neurocontrol for Enhancing Stability of a Power System Using Particle Swarm Optimization

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Abstract

The interline power flow controller (IPFC) is a concept of the FACTS controller for series compensation which can inject a voltage with controllable magnitude and phase angle among multi lines. This paper proposes a novel IPFC-Based Damping Neuro-control scheme using PSO for damping oscillations in a power system to improve power system stability. The addition of a supplementary controller to the IPFC main control can provide effective damping to the low frequency oscillation on the heavily loaded tie lines of interconnected power systems. However, the conventional controller designed based on a linearized model cannot provide satisfactory performance over a wide range of operation point and under large disturbances.

Keywords: interline power flow controller; power system stability; neurocontrol.

1. Introduction

Today's Reported Studies in the literatures have shown the FACTS are the known devices as a potentially attractive solution for the problems of power systems such as power flow limits, transient and dynamic stability [1-3]. Improving the system stability by superimposing damping controllers at FACTS devices is very attractive subject for researchers and the high amount of research papers and studies for the system stability has been carried out through this technique in the past decade and has presented optimal performance of FACTS based damping controllers in multiple operation points [4-7]. But improving the overall stability of system in a wide range of operating conditions by applying damping controllers is closely related to the performance of these controllers. Thus many optimized control schemes for the optimization of the performance of these controllers have been suggested such as a supplementary optimized lead-lag controller and output feedback controller using PSO algorithm for UPFC in [8, 9]. Since these damping controllers are designed through a linear model at a given operating point and an off-line procedure, they are not globally optimal, because of highly nonlinear operation of power system. Neural networks (NN) have been widely used to solve co-mplex problems of pattern recognition and they can recognize patterns very fast after they have already been trained. There are two types of training which are used in neural networks. These are supervised and unsupervised training of which supervised is the most common. In supervised training, the neural

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network assembles a training data set. This data set contains examples of input patterns together with the corresponding output results, and the network learns to infer the relationship between input patterns and output results through training. The training process requires a training algorithm, which uses the training data set to adjust the network's weights and bias so as to minimize an error function, such as the mean squared error function (MSE), and try to classify all patterns in the training data set. After training, the NN will have a set of weights and biases that will be used to recognize the new patterns. In general, training NN with a larger training data set can reduce the recognizing error rate, but there are some problems that we have to consider. Recently neural networks because of ability to approximate a wide range of nonlinear functions to any desired degree of accuracy under certain conditions are used to overcome system uncertainties to enhance the system damping performance [10, 11]. By using the conventional training method to train the damping neuro-controller, it does not adapt to high changes in system operation conditions and configuration, thus a novel improved training algorithm can be used to conquest the above mentioned problem of damping controller. Particle Swarm Optimization (PSO) is an evolutionary computation technique developed by Kennedy and Eberhart in 1995 and has been applied successfully to various optimization problems. The PSO idea is inspired by natural concepts such as fish schooling, bird flocking and human social relations. It combines local search (by self experience) and global search (by neighboring experience), possessing high search efficiency. Back propagation (BP) is generally used for neural network training. It is very important to choose a proper algorithm for training a neural network.

In this paper, in order to make the neuro-controller more robust to parametric variations, a new train method, using particle swarm optimization (PSO) has been proposed for designing the neuro-controller. The neuro-controller, designed by using the proposed method, is robust to operation uncertain uncertainties and has adaptive performance for enhancing dynamical stability in power systems. In this paper, a nonlinear model of single machine infinite-bus power system installed with an IPFC proposed in [12] is applied to test performance of the damping neuro-controller to enhance stability of power system. The contents of this paper are as follows. In first section, the configuration of the system with an IPFC is described. In next sections a short introduction of PSO algorithm is given. Then the proposed control scheme is described and the efficacy of the proposed control technique is demonstrated through detailed simulation. The performance of the proposed neuro-controller is also compared with the conventional phase compensation controller.

2. Proposing neuro-controller structure

Fig.1 shows the proposed structure of damping neuro-controller. In order to implement the simplified control, the author has studied out a single neuron controller with a PSO based training algorithm. Objective of neuro-controller is to reduce rotor speed deviation to zero. Therefore, Δω is the primary input to all these blocks.

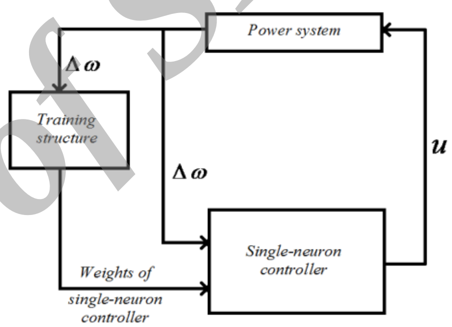

Fig. 1. Proposed controller structure

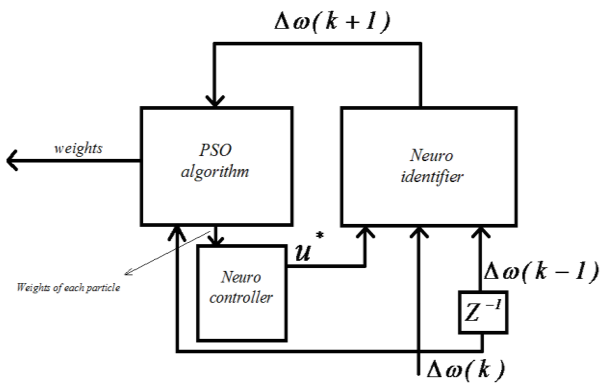

Fig. 2. Ttraining structure block

Controller design consists of two separate neural networks, namely the neuro-controller and the neuro-identifier. The neuro-identifier is used in training structure block is shown in Fig. 2. The neuro-identifier is a model of power system that is trained offline using a suitably selected training data set collected from two sets of training. The first set is called forced training, in which the plant is perturbed by a step load perturbation in mechanical power. The second set is called natural

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training, in which the plant is stable. Training algorithm used for the neuro-identifier training is a well known Back Propagation. Neuro-identifier is used to identify the input–output dynamics of the plant.

The structure of used neuro-identifier in this paper is shown Fig. 3 that is a three-layer feed forward network with 10 hidden neurons and 5 input neurons. The gains K1, K2 are used to normalization of input and output of controller. Neuro-identifier has three inputs. One input is supplementary signal (i.e. each δ1, δ2, m1, m2). Other two inputs are derived from rotor speed using one unit delays.

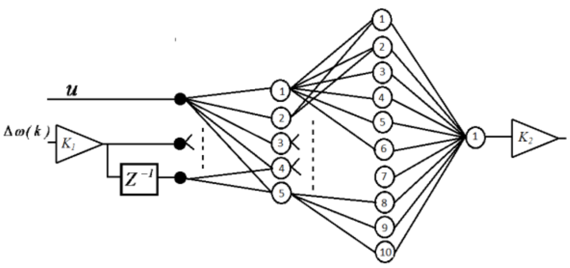

Fig. 3. The structure of neuro-identifier

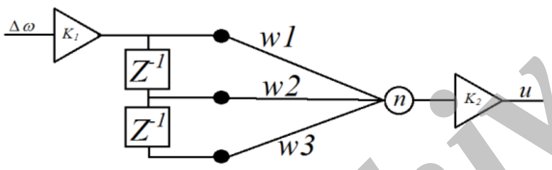

Fig. 4. The structure of neuro-controller

These two phases are for the training of neuro-identifier and the neuro-controller. At first phase neuro-identifier is trained and after training has been completed, at second phase trained neuro-identifier is used at process of online training of neuro-controller and damping oscillations in a power system.

PSO learning method is employed to speed up the convergence of online training along with neuro-controller to enhance the dynamic performance of power systems. The aim of training procedure with PSO is, reduce rotor speed deviation to zero, thus a fitness function for PSO is given by:

$$f = \frac{1}{\alpha(\Delta\omega(k+1) - \Delta\omega(k))^2 + \beta(\Delta\omega(k+1))^2 + \gamma(u^*)^2}$$

where α, β and γ are scale parameters. u* is a supplementary signal derived from each particle when is used as weights of single-neuron controller in training process.

And (Δω(k+1)-Δω(k))2 and (Δω(k+1))2 is used to reduce rotor speed deviation to zero but (u*)2 is used to reduce cost of control signal. In this procedure, the position of each particle is given by S, where S is a vector of single neuron weights. The structure of neuro-controller is shown in Fig. 4. The gains K1, K2 are used to normalization of input and output of controller. Neuro-controller has three inputs. One input is supplementary signal (i.e. each δ1, δ2, m1, m2). Other two inputs are derived from rotor speed using two unit delays. Two time delays are applied for rotor speed because a third order model is used, which has been shown to be sufficient for study of transient stability [10]. The following describes the incorporation of PSO algorithm for online training the neuro-control of dynamic stability.

Step1: Initialize the swarm using the randomly, in this paper the swarm consist of 5 particle that $S = [\, w_1, w_2, w_3 \,]$

Step2: the neuro-weights of each particle is used as neuro-controller in training structure to Evaluate supplementary signal derived from each particle and by using neuro-identifier the rotor speed deviation is calculated at next step time of iteration. By using arrived data, the fitness (e.q.3) is calculated for each particle.

Step3: the Pbest of each particle and gbest is calculated

Step4: the velocity and position of each particle is updated.

Step5: if the iteration of algorithm isn't arrived to maximum number of iterations, go to step2 otherwise end of iterations.

After any step of online training, by using the neuro-weights of gbest the output of neuro-controller is calculated which is used as supplementary signal (i.e. each δ1, δ2, m1, m2)?

3. Controllability measure

To measure the controllability of the EM mode of test system from each of the four inputs: δ1, δ2, m1, m2, the SVD is estimated in [12] so that The EM mode is more controllable with m1, m2 than with either δ1, δ2.

4. Simulation results

To verify the efficiency of the PSO-neuro controller a practical single-machine infinite-bus power system was tested. Parameters of the example system have been shown in Fig. 1, are given in [12].

In order to examine the dynamic behaviours and The performance of designed damping neural

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network controller, is compared with performance of a controller (lead-lag controller) that the phase compensation method is used to set its parameters and two scenarios is used:

1) Changing of system loading: The oscillation is started to carry out a step load perturbation in mechanical power (i.e.,.) $\Delta P_m = 0.1 \quad p.u.$

2) Fault: A three-phase to earth short circuit is occur on the end of transmission line in the example power system at 1.0 s of the simulation and is cleared after 100 ms.

For these scenarios, the applied supplementary signal for both controllers is u = m1 and also we assumed that Master voltage source converter (VSC-M) injects active power to its line and Slave voltage source converter (VSC-S) absorbs active power from its line at nominal operating condition. And it is used MATLAB/Simulink software package for simulation. Two damping controller is examined at operating condition, were shown below:

a) Vto = 1.0 p.u., Vbo = 1.0 p.u., Peo = 0.3 p.u.

b) Vto = 1.0 p.u., Vbo = 1.0 p.u., Peo= 1.2 p.u.

where Peo is electrical output power at operating condition, Vbo is voltage of infinite bus at operating condition and Vto is voltage of IPFC bus at operating condition.

The parameters of designed controller with phase compensation and neuro controller and neuro-identifier are shown in Table. 1. A structure of IPFC based damping designed controller with phase compensation method is:

$$H(s) = k_{dc}\left(\frac{s.T_\omega}{1+s.T_\omega}\right)\left(\frac{1+s.T_1}{1+s.T_2}\right)$$

Table.1
The controller's parameters

Controller	Parameters
Designed controller with phase compensation method	kdc = 19.55, T1 = 0.08756s, T2 = 0.08763s
neuro-controller	k1=1, k2=100
neuro-identifier	k1=100, k2=0.01

Damping controller with phase compensation method is designed at (Vto = 1.0 p.u., Vbo = 1.0 p.u., Peo = 0.1 p.u.). This operation point is chosen as best operation point among multiple operation points for design of damping controller with the proposed method of Sanchezgasca et al.

Figs. 5–12 show numerical results of nonlinear simulation with damping controller at where

1: respective response at operating condition without damping controller.

2: respective response at operating condition with designed damping controller with phase compensation method.

3: respective response at operating condition with designed damping neural network controller.

From figures it can be seen that neural controller is effective for damping dynamic oscillations respect to lead-lag controller.

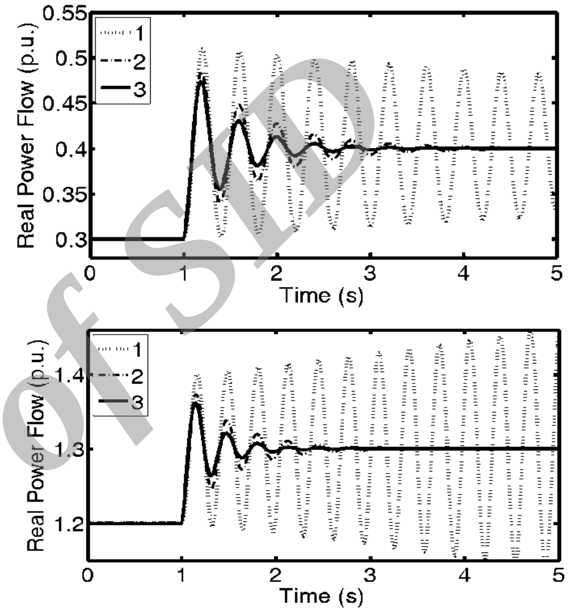
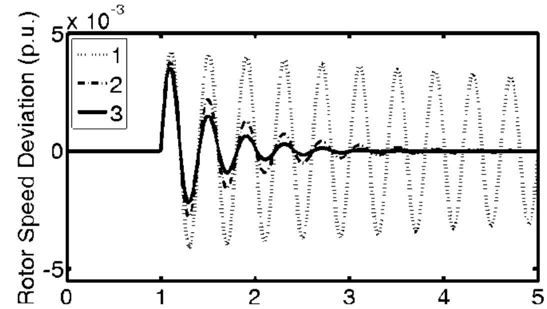
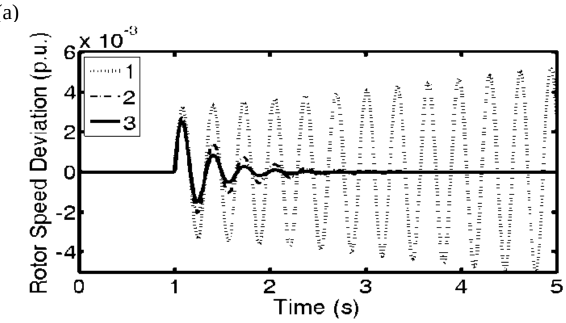


Fig. 5. Power flow response for ΔP_m =0.1 pu at operating conditions a and b

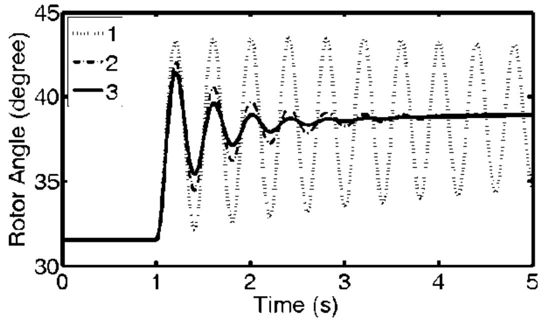


(a)

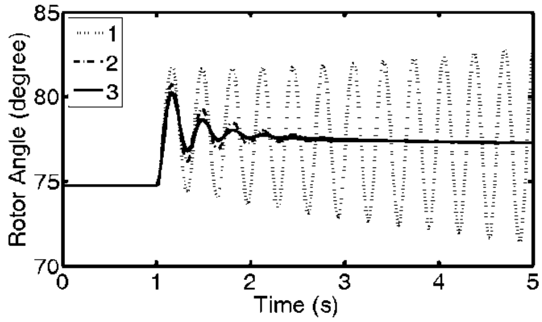


(b)

Fig. 6. Rotor speed response for ΔP_m =0.1 pu at operating conditions a and b



(a)



(b)

Fig. 7. Rotor angle response for ΔPm =0.1 p.u. at operating conditions: a, b

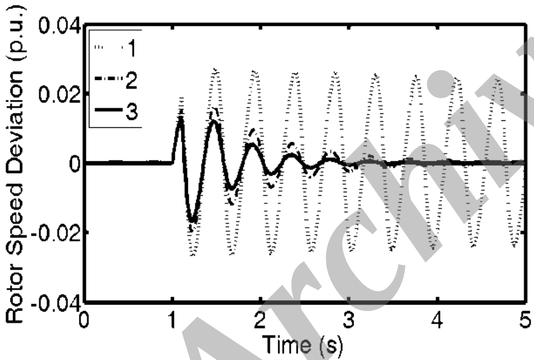


Fig. 8. . Rotor speed response for a three-phase to earth short circuit at operating conditions: (a)

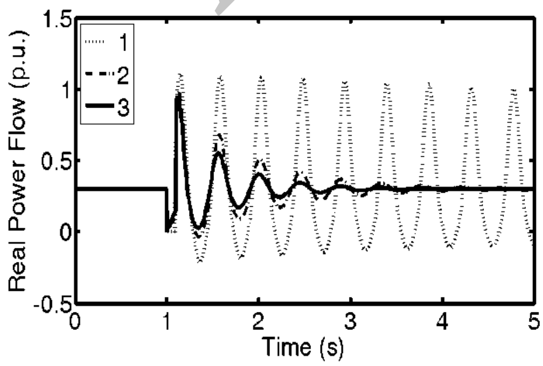


Fig. 9. Power flow response for a three-phase to earth short circuit at operating conditions (b)

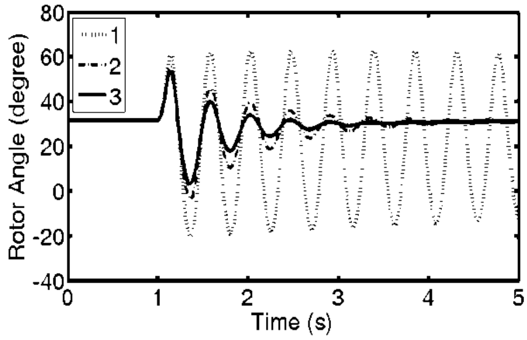


Fig. 10. Rotor angle response for a three-phase to earth short circuit at operating conditions: b

5. Conclusion

This paper presents a novel design method for determining the IPFC-Based Damping neuro controller using the PSO method and its performance is compared with performance of the IPFC controller with phase compensation method. The simulation results show that using the neuro controller at system operating conditions provides the almost steady damping respect to phase compensation method and neuro controller is the adaptive controller for changing at the system operating conditions.

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