Electrical Power and Energy Systems 63 (2014) 132–139

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

An integrated approach for optimal placement and tuning of power system stabilizer in multi-machine systems

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ARTICLE INFO

Article history:
Received 4 August 2013
Received in revised form 23 May 2014
Accepted 27 May 2014
Available online 26 June 2014

Keywords:
Power system stabilizer
Tuning and placement of PSS
PSO algorithm
Fuzzy logic
Multi-machine system

ABSTRACT

In this paper, a hybrid approach for tuning and placement of power system stabilizers (PSS) in multi-machine power systems is provided with the aim of reducing low-frequency oscillations (LFO) and improving power system dynamic stability with wide range of changes in system parameters and operating point of the system. PSS parameters are adjusted using Particle Swarm Optimization algorithm (PSO), and using Takagi–Sugeno (TS) fuzzy, optimal location for the PSS is determined. The employed fuzzy system has two inputs, the real part and the damping coefficient of network eigenvalues. The results of test on a grid four machine-two area sample, show optimal performance of the proposed method in improving system stability and reducing low-frequency oscillations of local and inter-area modes.

1. Introduction

The power system is a complex and nonlinear system. Mechanical nature of the power systems produces low-frequency oscillations (LFO) in the system, which will negatively affect the stability and performance of the system and will restrict the capacity of the transmission line [1]. In order to solve this problem, a supplementary controller is employed in the excitation system of the generators. This supplementary controller, known as PSS, is widely used to reduce the LFO and improve system stability [2]. Many new intelligent methods such as neural networks [3] and fuzzy logic [4,5] have been used in PSS design. Modern control methods such as adaptive control have also been used in PSS design [6]. In [7], an approach based on state feedback control is presented for tuning PSS parameters. Pole placement has also been employed to design PSS for multi-machine power systems in coordination with FACTS devices [8]. In [9], PSO was used to tune PSS for interconnected power systems. In [10], the use of adaptive neuro-fuzzy inference was proposed for PSS design to enhance the damping issue of the conventional PSSs. Bacterial swarm optimization is the other approach used for the design of PSS in coordination with thyristor controlled series capacitor (TCSC) for multi-machine power systems [11]. A fuzzy PI Takagi–Sugeno stabilizer is presented in [12]. An optimal power system stabilizer (OPSS) based on second-order linear regulator with conventional lead-lag compensation structure is also proposed in [13]. The modified particle optimization (MPSO) is the other method proposed to adjust the stabilizer parameters [14].

In [15] presented a method to determine the optimal location and the number of multi-machine power system stabilizers (PSSs) using participation factor (PF) and genetic algorithm (GA). A type-2 fuzzy logic power system stabilizer with differential evolution algorithm presented in [16]. In [17], the design of a conventional power system stabilizer (CPSS) is carried out using the bat algorithm (BA). In [18] presents an enhanced indirect adaptive fuzzy sliding mode based power system stabilizer for damping local and inter-area modes of oscillations for multi-machine power systems. In [19] presented a new technique named cultural algorithms (CAs) to tune the PSS parameters. In [20] present the design and implementation of Power System Stabilizers in a multi-machine power system based on innovative evolutionary algorithm overtly as Breeder Genetic Algorithm with Adaptive Mutation.

This paper presents a hybrid approach to tune and place PSSs in multi-machine systems. PSS parameters are adjusted using PSO algorithm, according to the operating point of the network. The optimal location for PSS installation is then determined by fuzzy Takagi–Sugeno (TS) system. The fuzzy system has two inputs, the real part and the damping coefficient of network eigenvalues.

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http://dx.doi.org/10.1016/j.ijepes.2014.05.072
0142-0615/

Network eigenvalues are obtained by the linearization of differential–algebraic equations of the power system. The experimental results on a four machine-two area network show the good performance of the proposed method improving system stability and reducing low frequency oscillations of local and inter-area modes.

Power system modeling equations are presented in section ‘Power system modelling’ and the algorithm used for tuning and placement of PSSs is given in section ‘PSS tuning and placement’. Simulation results and conclusions are described in sections ‘Experimental results and Conclusion’, respectively.

Power system modelling

In order to analyze the power system, linearization of Differential–Algebraic Equations (DAE) around the operating point is used [21].

Generator equations

For each generator, the following fourth-order model has been considered:

$$\frac{d\delta_i}{dt} = \omega_i - \omega_s \tag{1}$$

$$\frac{d\omega_i}{dt} = \frac{T_{Mi}}{M_i} - \frac{(E'_{qi} - X'_{di} I_{di}) I_{qi}}{M_i} - \frac{(E'_{di} + X'_{qi} I_{qi}) I_{di}}{M_i} - \frac{D_i(\omega_i - \omega_s)}{M_i} \tag{2}$$

$$\frac{dE'_{qi}}{dt} = -\frac{E'_{qi}}{T'_{doi}} - \frac{(X_{di} - X'_{di}) I_{di}}{T'_{doi}} + \frac{E_{fdi}}{T'_{doi}} \tag{3}$$

$$\frac{dE'_{di}}{dt} = -\frac{E'_{di}}{T'_{qoi_i}} + \frac{I_{qi}}{T'_{qoi_i}} (X_{qi} - X'_{qi}) \tag{4}$$

Exciter equation

Exciter equation is:

$$\frac{dE_{fdi}}{dt} = -\frac{E_{fdi}}{T'_{doi}} - \frac{(X_{di} - X'_{di})}{T'_{doi}} I_{di} + \frac{E_{fdi}}{T'_{doi}} \tag{5}$$

A detailed description of all symbols and quantities can be found in [21]. By the linearization of the power system equation, explained in [21], and by the addition of PSS equations, the power system model is:

$$\Delta\dot{x} = Ax + Bu \tag{6}$$

$$\Delta y = Cx + Du \tag{7}$$

where A is the state variables matrix, B is the input matrix, C is the output matrix, D is the feed-forward matrix, x is the vector of state variables, u is the vector of control inputs, and y is the output. Here, the gole of PSS design is to place the eigenvalues of matrix A in the left half of the complex plane. Eigenvalues of the system can be evaluated from matrix A:

$$\lambda_i = \sigma_i \pm j\omega_i \tag{8}$$

where $i = 1, 2, 3, \ldots, n$ and n denotes the total number of eigenvalues. The eigenvalues may be real or complex. The imaginary part of the complex eigenvalue (ω) is the radian frequency of the oscillations and the real part (σ) is the decrement rate. Then, the damping ratio (ξ_j) of the jth eigenvalue is defined with the following equation:

$$\xi_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \tag{9}$$

PSS structure

The PSSs used here possess a conventional lead-lag structure and have speed deviation input [22–24]. The Gain of stabilizer (K_{PSS}) determines the amount of damping created by PSS. Like a high-pass filter with time constant T_w, the Filtering block (washout) passes the cross speed deviations and blocks steady-state values of the speed. The two-level compensation blocks provide an appropriate lead characteristic, in order to compensate the lag characteristic between the input excitation control and the electrical torque of the generator. Five parameters of PSS, including T_1–T_4 (time constant) and K_{PSS}, are optimized by PSO algorithm and T_w is considered to be constant. Fig. 1 shows the PSS structure.

PSS tuning and placement

The classical PSS tuning methods are usually used for specific frequency and operating point, and hence, any change in system operating point degrades the performance of PSS. In this paper, Particle Swarm Optimization algorithm (PSO) is used to adjust PSS parameters.

Particle Swarm Optimization (PSO) algorithm

PSO is an evolutionary computation algorithm, inspired from the nature and based on repetition [25]. The PSO algorithm is composed of fixed number of particles taking random initial values. Two values are assigned to each particle, position (X_i^k) and velocity (V_i^k). These particles repetitively move in the n-dimensional space (corresponding to the number of parameters) to look for new possible answer choices by calculating the optimality of each particle based on the objective function. At each step, the best position of each particle ($pbest_i^k$) and the best position among all particles ($gbest_i^k$) are stored. New speed (V_i^{k+1}) and new position (X_i^{k+1}) of each particle will be updated using following equations [26]:

$$V_i^{k+1} = w \times V_i^k + c_1 \times r_1 \times \left(pbest_i^k - X_i^k\right) + c_2 \times r_2 \times \left(gbest_i^k - X_i^k\right) \tag{10}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{11}$$

where c_1 and c_2 are positive numbers illustrating the weight of the acceleration of each term, guiding each particle toward the best individual (p_{best}) and the best swarm (g_{best}) positions, r_1 and r_2 are two random number in the range [0 1], and w is the inertia calculated by the following equation [26]:

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{k_{\max}}\right) \times k \tag{12}$$

where w_{max} and w_{min} are the maximum and minimum values of w, k_{max} is the maximum number of iterations and k is the current iteration number.

Objective function

The Stability of a power system can be determined based on its eigenvalues. Eigenvalues with large negative real parts ensure system stability. the overshoot and oscillations values are determined

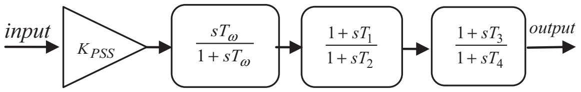

Fig. 1. Structure of power system stabilizer.