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Robust design of multimachine power system stabilizers using fuzzy gravitational search algorithm

Ali Ghasemi [a,*], Hossein Shayeghi [b], Hasan Alkhatib [c]

[a] Young Researcher Club, Islamic Azad University, Ardabil Branch, Ardabil, Iran
[b] Technical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran
[c] Electromagnetic Compatibility Laboratory of Marseille, Paul Cézanne University (Aix-Marseille III), France

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ABSTRACT

This paper presents a novel Fuzzy Gravitational Search Algorithm (FGSA) for optimal design of multimachine power system stabilizers (PSSs). The FGSA technique is characterized as simple, robust and capable to solve difficult combinatorial optimization problems. For achieving optimal tuning of PSS parameters, the problem is formulated as an optimization problem with the time domain-based objective function over a wide range of operating conditions and is solved by the proposed FGSA technique. The performance of the proposed FGSA based-PSS design is validated for two multimachine systems: a 3-machine 9-bus system and a 10-machine 39-bus. The effectiveness and robustness of proposed method is demonstrated using many performance indices. The results prove that the proposed FGSA assures a well damping to the electromechanical modes of oscillations for a wide range of system operation conditions. The superiority of the proposed method is proved compared to different optimization methods.

1. Introduction

Low frequency oscillations are detrimental to the goals of maximum power transfer and optimal power system security. Three different oscillations have been observed in large interconnected power systems: Inter-unit Oscillations (1–3 Hz), Local Mode Oscillations (0.7–2 Hz), and Inter-area Oscillations (0.5 Hz) [1]. These low frequency oscillations may result in serious consequences such as tripping the generator from the grid, or even participating to major system blackouts. The stability of power system is the core of power system security protection which is one of the most important problems researched by electrical engineers [2]. The fast-acting static excitation systems, used to improve transient stability limits, contribute strongly to the diminution of low frequency oscillation damping. Power system stabilizers (PSSs) have been widely used to damp low frequency oscillation and enhance power system stability.

The earlier stabilizer designs were based on concepts derived from classical control theory [3]. Many such designs have been physically realized and widely used in actual systems. These controllers act through the excitation systems to introduce suitable stabilizing signals derived from the power, speed or frequency of the related generator either alone or in various combination as input signals so as to generate an additional rotor torque to damp out the low frequency oscillations [4,5]. The stabilizers' gain and the required phase lead-lag are mostly tuned by using appropriate mathematical models. The main drawback of the above controllers is their inherent lack of robustness [6].

Several metaheuristic optimization methods have evolved in the last decades. Population-based optimization methods inspired by Nature may be classed in two important categories that are evolutionary algorithms and swarm intelligence. Various algorithms based on these methods such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Tabu Search (TS), Chaotic Optimization Algorithm (COA), Strength Pareto Evolutionary Algorithm (SPEA) and others have been widely applied to the problem of multimachine PSSs design [7–10]. These methods seem to be good approaches for the solution of the PSS parameter optimization problem. However, when the objective function of the optimization problem is epistatic, (i.e. where parameters being optimized are highly correlated), and when the number of parameters to be optimized is large, then these methods have degraded effectiveness to obtain the global optimum solution.

Artificial Neural Network (ANN) is an intelligent method which is used for PSS tuning [11]. This technique has its own advantages and disadvantages. The performance of power system is improved by ANN based controller but, the main problem of these controllers are the long training time and selecting the number of layers and the number of neurons in each layer [12]. To overcome the drawbacks of the above methods, a Fuzzy Gravitational Search Algorithm (FGSA) is proposed to implement optimization in this study.

* Corresponding author. Tel.: +98 939 4614576.
E-mail address: ghasemi.agm@gmail.com (A. Ghasemi).

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Gravitational Search Algorithm (GSA) that is used in this paper is a new algorithm that attempts to establish a new population-based search algorithm based on gravity rules. It uses the Newton's laws of gravity and motion for a collection of masses. One important advantage of GSA is its ability to find the global optimum in a small period of time in comparison with other optimization algorithms. Furthermore, GSA has high effectiveness to obtain the global optimum solution when the number of parameters to be optimized is large. However, the high speed of the algorithm risk to shrink dramatically when we get closer to the answer in the search space. Therefore, the fuzzy logical is used to speed up the final stages of the process and find the accurate answer in a shorter time, even for very large problems.

The proposed Fuzzy Gravitational Search Algorithm (FGSA) based-PSS design is applied to two multimachine power systems: the 3-machine 9-bus WSCC system and the 10-machine 39-bus New England system, with various configurations and loading conditions. To illustrate the effectiveness of the proposed method, the system performance is evaluated and compared to that of other approaches based on CPSS, SPEA and PSO techniques. Result interpretation shows that the proposed method is effective as it retains the simplicity of the conventional PSS and still guarantees a robust acceptable performance over a wide range of operating and system conditions. The simulation results showed that the proposed FGSA can provide better and faster solutions to the PSS than would be possible with any heuristics algorithms relying on the fuzzy parallel architecture. In other words, the FGSA can guarantee high level damping for power system oscillations, which is the major objective of PSS.

2. Power system model and pss structure

Fig. 1 shows the schematic of a multimachine system consists of n machine. This schema describes the dynamic equations represented by each block shown in the ith machine and external network [13].

In multimachine system without infinite bus, it is necessary to take a reference angle to compare all other rotor angles of generators. Conventionally the rotor angle of the machine having highest inertia is taken as a reference. The center of inertia (COI) angle and speed deviation δ_0 and ω_0 and these are defined as:

$$\delta_{COI} = \frac{1}{M_T}\sum_{i=1}^{n} M_i\delta_i \tag{1}$$

$$\omega_0 = \frac{1}{M_T}\sum_{i=1}^{n} M_i\omega_i \tag{2}$$

where $M_T = \sum M_i$ is total inertia of n number of generators. In the case study the rotor angle and slip of the machine having highest inertia are taken as reference. A power system can be modeled by a set of nonlinear differential–algebraic equations. In this study, the fourth-order model, commonly used in PSS design, is employed to represent the system synchronous machines, i.e. with field circuit and one equivalent damper winding on q-axis [6,7], and so:

$$\frac{d\delta}{dt} = \omega_B(S_m - S_{mo}) \tag{3}$$

$$\frac{dS_m}{dt} = \frac{1}{2H}(-D(S_m - S_{mo}) + T_m - T_e) \tag{4}$$

$$\frac{dE'_q}{dt} = \frac{1}{T'_{do}}(-E'_q + (x_d - x'_d)i_d + E_{fd}) \tag{5}$$

$$\frac{dE'_d}{dt} = \frac{1}{T'_{qo}}(-E'_d + (x_q - x'_q)i_q) \tag{6}$$

$$Te = E'_d i_d + E'_q i_q + (x'_d - x'_q)i_d i_q \tag{7}$$

A widely used conventional PSS is considered throughout the study, as shown in Fig. 2. It consists of three units: phase compensation unit, washout filter, and gain unit. The PSS output signal V_{PSS} is a voltage added to the generator exciter input. While, the rotor speed deviation $\Delta\omega$ is typically used as the PSS input signal. In this study, attempts to optimize simultaneously five constants each of several PSS present in a multi machine power system. They are the time constants of the phase compensation unit (T_1, T_2, T_3, and T_4), and the PSS gain (K_{PSS}). The upper and lower limits (V_{Smax}, V_{Smin}) are assumed to be the same in absolute value. The time constant of the washout filter (T_w) is commonly fixed and chosen equal to 10 s [3].

3. Fuzzy gravitational search algorithm

3.1. Overview GSA

Gravitational search algorithm, proposed by Rashedi et al. in 2009 [14], is a new heuristic algorithm that has been proven efficient in solving many problems. One of the important advantages of GSA is its ability to find the global optimum in a shorter time

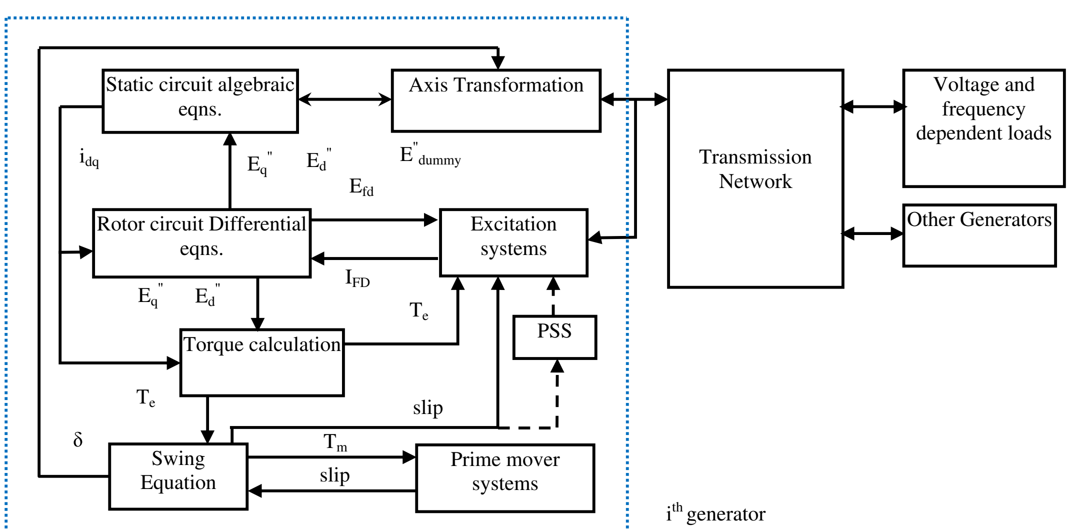

Fig. 1. Schematic of a multimachine system.