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ORIGINAL ARTICLE

Differential evolution algorithm based automatic generation control for interconnected power systems with non-linearity

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Differential Evolution (DE) algorithm

Abstract This paper presents the design and performance analysis of Differential Evolution (DE) algorithm based Proportional–Integral (PI) and Proportional–Integral–Derivative (PID) controllers for Automatic Generation Control (AGC) of an interconnected power system. Initially, a two area thermal system with governor dead-band nonlinearity is considered for the design and analysis purpose. In the proposed approach, the design problem is formulated as an optimization problem control and DE is employed to search for optimal controller parameters. Three different objective functions are used for the design purpose. The superiority of the proposed approach has been shown by comparing the results with a recently published Craziness based Particle Swarm Optimization (CPSO) technique for the same interconnected power system. It is noticed that, the dynamic performance of DE optimized PI controller is better than CPSO optimized PI controllers. Additionally, controller parameters are tuned at different loading conditions so that an adaptive gain scheduling control strategy can be employed. The study is further extended to a more realistic network of two-area six unit system with different power generating units such as thermal, hydro, wind and diesel generating units considering boiler dynamics for thermal plants, Generation Rate Constraint (GRC) and Governor Dead Band (GDB) non-linearity.

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1. Introduction

An interconnected power system is made up of several areas and for the stable operation of power systems; both constant frequency and constant tie-line power exchange should be provided. In each area, an Automatic Generation Controller (AGC) monitors the system frequency and tie-line flows, computes the net change in the generation required (generally

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referred to as area control error – ACE) and changes the set position of the generators within the area so as to keep the time average of the ACE at a low value [1]. Therefore ACE, which is defined as a linear combination of power net-interchange and frequency deviations, is generally taken as the controlled output of AGC. As the ACE is driven to zero by the AGC, both frequency and tie-line power errors will be forced to zeros [2]. AGC function can be viewed as a supervisory control function which attempts to match the generation trend within an area to the trend of the randomly changing load of the area, so as to keep the system frequency and the tie-line power flow close to scheduled value. The growth in size and complexity of electric power systems along with an increase in power demand has necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems.

Researchers all over the world are trying to understand several strategies for AGC of power systems in order to maintain the system frequency and tie line flow at their scheduled values during normal operation and also during small perturbations. A critical literature review on the AGC of power systems has been presented in [3] where various control aspects concerning AGC problem have been studied. Moreover the authors have reported various AGC schemes, AGC strategies and AGC system incorporating BES/SMES, wind turbines, FACTS devices and PV systems. There has been a considerable research work attempting to propose better AGC systems based on modern control theory [4,5], neural network [6–9], fuzzy system theory [10–12], reinforcement learning [13] and ANFIS approach [14,15]. From the literature survey, it may be concluded that there is still scope of work on the optimization of controller parameters to further improve the AGC performance. For this, various novel evolutionary optimization techniques can be proposed and tested for comparative optimization performance study. New artificial intelligence-based approaches have been proposed recently to design a controller. These approaches include particle swarm optimization [16,17], differential evolution [18,19], multi-objective evolutionary algorithm [20], NSGA-II [21,22], etc. Nanda et al. [23] have demonstrated that bacterial foraging, a powerful evolutionary computational technique, based integral controller provides better performance as compared to that with integral controller based on classical and GA techniques in a three unequal area thermal system. Ali and Abd-Elazim [24] have reported recently that Bacterial Foraging Optimization Algorithm (BFOA), based Proportional Integral (PI) controller provides better performance as compared to that with GA based PI controller in two area non-reheat thermal system. Gozde and Taplamacioglu [25] proposed a gain scheduling PI controller for an AGC system consisting of two area thermal power system with governor dead-band nonlinearity. The authors have employed a Craziness based Particle Swarm Optimization (CRAZYPSO) with different objective functions to minimize the settling times and standard error criteria.

Differential Evolution (DE) is a branch of evolutionary algorithms developed by Stron and Price in 1995 for optimization problems [26]. It is a population-based direct search algorithm for global optimization capable of handling non-differentiable, non-linear and multi-modal objective functions, with few, easily chosen, control parameters. It has demonstrated its usefulness and robustness in a variety of applications such as, Neural network learning, Filter design and the optimization of aerodynamics shapes. DE differs from other Evolutionary Algorithms (EA) in the mutation and recombination phases. DE uses weighted differences between solution vectors to change the population whereas in other stochastic techniques such as Genetic Algorithm (GA) and Expert Systems (ES), perturbation occurs in accordance with a random quantity. DE employs a greedy selection process with inherent elitist features. Also it has a minimum number of EA control parameters, which can be tuned effectively [18,19]. In view of the above, an attempt has been made in this paper for the optimal design of DE based PI/PID controller for LFC in two area interconnected power system considering the governor dead-band nonlinearity. The design problem of the proposed controller is formulated as an optimization problem and DE is employed to search for optimal controller parameters. By minimizing the proposed objective functions, in which the deviations in the frequency and tie line power and settling times are involved; dynamic performance of the system is improved. Simulation results are presented to show the effectiveness of the proposed controller in providing good damping characteristic to system oscillations over a wide range of loading conditions, disturbance and system parameters. Further, the superiority of the proposed design approach is illustrated by comparing the proposed approach with a recently published CPSO approach [25] for the same AGC system.

2. System under study

The Automatic Generation Control (AGC) provides the control only during normal changes in load which are small and slow. So the nonlinear equations which describe the dynamic behavior of the system can be linearized around an operating point during these small load changes and a linear model can be used for the analysis thus making the analysis simpler. The system under investigation consists of a two area interconnected power system of thermal plant as shown in Fig. 1. The system is widely used in the literature for the design and analysis of automatic load frequency control of interconnected areas [25]. In Fig. 1, B_1 and B_2 are the frequency bias parameters; ACE_1 and ACE_2 are area control errors; u_1 and u_2 are the control outputs from the controller; R_1 and R_2 are the governor speed regulation parameters in p.u. Hz; T_{G1} and T_{G2} are the speed governor time constants in seconds; ΔP_{G1} and ΔP_{G2} are the changes in governor valve positions (p.u.); T_{T1} and T_{T2} are the turbine time constants in seconds; ΔP_{T1} and ΔP_{T2} are the changes in turbine output powers; ΔP_{D1} and ΔP_{D2} are the load demand changes; ΔP_{Tie} is the incremental change in tie line power (p.u.); K_{PS1} and K_{PS2} are the power system gains; T_{PS1} and T_{PS2} are the power system time constants in seconds; T_{12} is the synchronizing coefficient and Δf_1 and Δf_2 are the system frequency deviations in Hz. The relevant parameters are given in Appendix. The transfer function of governor with non-linearity is given by [25]:

$$G_g = \frac{0.8 - \frac{0.2}{\pi}s}{1 + sT_g} \quad (1)$$

3. The proposed approach

The Proportional Integral Derivative controller (PID) is the most popular feedback controller used in the process