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Optimal gravitational search algorithm for automatic generation control of interconnected power systems

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Sensitivity

Abstract An attempt is made for the effective application of Gravitational Search Algorithm (GSA) to optimize PI/PIDF controller parameters in Automatic Generation Control (AGC) of interconnected power systems. Initially, comparison of several conventional objective functions reveals that ITAE yields better system performance. Then, the parameters of GSA technique are properly tuned and the GSA control parameters are proposed. The superiority of the proposed approach is demonstrated by comparing the results of some recently published techniques such as Differential Evolution (DE), Bacteria Foraging Optimization Algorithm (BFOA) and Genetic Algorithm (GA). Additionally, sensitivity analysis is carried out that demonstrates the robustness of the optimized controller parameters to wide variations in operating loading condition and time constants of speed governor, turbine, tie-line power. Finally, the proposed approach is extended to a more realistic power system model by considering the physical constraints such as reheat turbine, Generation Rate Constraint (GRC) and Governor Dead Band nonlinearity.

1. Introduction

The main objective of a power system utility is to maintain continuous supply of power with an acceptable quality to all the consumers in the system. The system will be in equilibrium, when there is a balance between the power demand and the power generated. There are two basic control mechanisms used to achieve power balance; reactive power balance (acceptable voltage profile) and real power balance (acceptable frequency values). The former is called the Automatic Voltage Regulator (AVR) and the latter is called the Automatic Load Frequency Control (ALFC) or Automatic Generation Control (AGC). For multiarea power systems, which normally consist of interconnected control area, AGC is an important aspect to keep the system frequency and the interconnected area tie-line power as close as possible to the intended values [1]. The mechanical input power to the generators is used to control the system as it is affected by the output electrical power demand and to maintain the power exchange between the areas as planned. AGC monitors the system frequency and tie-line flows, calculates the net change in the generation

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required according to the change in demand and changes the set position of the generators within the area so as to keep the time average of the ACE (Area Control Error) at a low value. ACE is generally treated as controlled output of AGC. As the ACE is adjusted to zero by the AGC, both frequency and tie-line power errors will become zero [2].

Several control strategies for AGC of power systems have been proposed in order to maintain the system frequency and tie line power flow at their scheduled values during normal and disturbed conditions. In [3], a critical literature review on the AGC of power systems has been presented. It is observed that, considerable research work is going on to propose better AGC systems based on modern control theory [4], neural network [5], fuzzy system theory [6], reinforcement learning [7] and ANFIS approach [8]. But, these advanced approaches are complicated and need familiarity of users to these techniques thus reducing their applicability. Alternatively, a classical Proportional Integral Derivative (PID) controller and its variant remain an engineer's preferred choice due to its structural simplicity, reliability, and the favorable ratio between performances and cost. Additionally, it also offers simplified dynamic modeling, lower user-skill requirements, and minimal development effort, which are major issues of in engineering practice. In recent times, new artificial intelligence-based approaches have been proposed to optimize the PI/PID controller parameters for AGC system. In [9], several classical controllers structures such as Integral (I), Proportional Integral (PI), Integral Derivative (ID), PID and Integral Double Derivative (IDD) have been applied and their performance has been compared for an AGC system. Nanda et al. [10] have demonstrated that Bacterial Foraging Optimization Algorithm (BFOA) optimized controller provides better performance than GA based controllers and conventional controllers for an interconnected power system. In [11], Ali and Abd-Elazim have employed a BFOA to optimize the PI controller parameters and shown its superiority over GA in a two area non-reheat thermal system. A gain scheduling PI controller for an AGC system has been proposed by Gozde and Taplamacioglu [12] for a two area thermal power system with governor dead-band nonlinearity where the authors have employed a Craziness based Particle Swarm Optimization (CPSO) with different objective functions to minimize the settling times and standard error criteria. Shabani et. al [13] employed an Imperialist Competitive Algorithm (ICA) to optimize the PID controller parameters in a multiarea multiunit power system. In [14], a modified objective function using Integral of Time multiplied by Absolute value of Error (ITAE), damping ratio of dominant eigenvalues and settling time is proposed where the PI controller parameters are optimized employed Differential Evolution (DE) algorithm and the results are compared with BFOA and GA optimized ITAE based PI controller to show its superiority.

It obvious from literature survey that, the performance of the power system not only depends on the artificial techniques employed but also depends on the controller structure and chosen objective function. Hence, proposing and implementing new high performance heuristic optimization algorithms to real world problems are always welcome. Gravitational Search Algorithm (GSA) is a newly developed heuristic optimization method based on the law of gravity and mass interactions [15]. It has been reported in the literature that GSA is more efficient in terms of CPU time and offers higher precision with more consistent results [16]. However, studied on choosing the controller parameters of GSA has not been reported in the literature. In a PID controller, the derivative mode improves stability of the system and increases speed of the controller response but it produces unreasonable size control inputs to the plant. Also, any noise in the control input signal will result in large plant input signals which often lead to complications in practical applications. The practical solution to these problems is to put a first filter on the derivative term and tune its pole so that the chattering due to the noise does not occur since it attenuates high frequency noise. Surprisingly, in spite of these advantages, Proportional Integral Derivative with derivative Filter (PIDF) controller structures are not attempted for the AGC problems. Having known all this, an attempt has been made in the present paper for the optimal design of GSA based PI/PIDF controller for AGC in a multiarea interconnected power system.

The aim of the present work is as follows:

(i) to study the effect of objective function of the system performance
(ii) to tune the control parameters of GSA
(iii) to demonstrate the advantages of GSA over other techniques such as DE, BFOA and GA which are recently reported in the literature for the similar problem
(iv) to show advantages of using a modified controller structure and objective function to further increase the performance of the power system
(v) to study the effect of the physical constraints such as Generation Rate Constraints and governor dead band on the system performance.

2. System modeling

The system under investigation consists of two area interconnected power system of non-reheat thermal plant as shown in Fig. 1. Each area has a rating of 2000 MW with a nominal load of 1000 MW. The system that is widely used in the literature is for the design and analysis of automatic load frequency control of interconnected areas. 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 form the controller; R_1 and R_2 are the governor speed regulation parameters in pu Hz; T_{G1} and T_{G2} are the speed governor time constants in s; ΔP_{V1} and ΔP_{V2} are the change in governor valve positions (pu); ΔP_{G1} and ΔP_{G2} are the governor output command (pu); T_{T1} and T_{T2} are the turbine time constant in s; ΔP_{T1} and ΔP_{T2} are the change 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 constant in s; 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 A.

Each area of the power system consists of speed governing system, turbine and generator as shown in Fig. 1. Each area has three inputs and two outputs. The inputs are the controller input ΔP_{ref} (denoted as u_1 and u_2), load disturbances (denoted as ΔP_{D1} and ΔP_{D2}), and tie-line power error ΔP_{Tie}. The