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A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems

Rabindra Kumar Sahu, Sidhartha Panda *, Saroj Padhan

Department of Electrical Engineering, VSSUT, Burla 768018, Odisha, India

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ABSTRACT

In this paper, a novel hybrid Firefly Algorithm and Pattern Search (hFA–PS) technique is proposed for Automatic Generation Control (AGC) of multi-area power systems with the consideration of Generation Rate Constraint (GRC). Initially a two area non-reheat thermal system with Proportional Integral Derivative (PID) controller is considered and the parameters of PID controllers are optimized by Firefly Algorithm (FA) employing an Integral Time multiply Absolute Error (ITAE) objective function. Pattern Search (PS) is then employed to fine tune the best solution provided by FA. The superiority of the proposed hFA–PS based PID controller has been demonstrated by comparing the results with some recently published modern heuristic optimization techniques such as Bacteria Foraging Optimization Algorithm (BFOA), Genetic Algorithm (GA) and conventional Ziegler Nichols (ZN) based PI/PID controllers for the same interconnected power system. Furthermore, sensitivity analysis is performed to show the robustness of the optimized controller parameters by varying the system parameters and operating load conditions from their nominal values. Finally, the proposed approach is extended to multi area multi source hydro thermal power system with/without considering the effect of physical constraints such as time delay, reheat turbine, GRC, and Governor Dead Band (GDB) nonlinearity. The controller parameters of each area are optimized under normal and varied conditions using proposed hFA–PS technique. It is observed that the proposed technique is able to handle nonlinearity and physical constraints in the system model.

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 is desired. In each area Automatic Generation Control (AGC) monitors the system frequency and tie-line flows, calculates the net change in the generation required (known as Area Control Error: ACE) according to the change in demand and adjusts the set position of the generators within the area so as to keep the time average of the frequency and tie-line power deviations 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.

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. 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 [3], 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. [4] 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 [5], Ali and

* Corresponding author. Tel.: +91 9438251162.
E-mail addresses: rksahu123@gmail.com (R.K. Sahu), panda_sidhartha@rediffmail.com (S. Panda), callsaroj201@rediffmail.com (S. Padhan).

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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. Shabani et al. [6] employed an Imperialist Competitive Algorithm (ICA) to optimize the PID controller parameters in a multiarea multi unit power system. In [7], 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 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. Recently, a new biologically-inspired metaheuristic algorithm, known as the Firefly Algorithm (FA) has been developed by Yang [8,9]. FA is a population based search algorithm inspired by the flashing behavior of fireflies. It has been successfully employed to solve the nonlinear and non-convex optimization problems [10–12]. Recent research shows that FA is a very efficient and could outperform other metaheuristic algorithms. The superiority of FA over ABC, PSO and BF has also been reported in the literature [11,13,14]. For any meta-heuristic algorithm, a good balance between exploitation and exploration during search process should be maintained to achieve good performance. FA being a global optimizing method is designed to explore the search space and most likely gives an optimal/near-optimal solution if used alone. On the other hand, local optimizing methods like Pattern Search (PS) are designed to exploit a local area, but they are usually not good at exploring wide area and hence not applied alone for global optimization [15,16]. Due to their respective strength and weakness, there is motivation for the hybridization of FA and PS.

In view of the above, a maiden attempt has been made in this paper for the application of a hybrid Firefly Algorithm and Pattern Search (hFA–PS) for the AGC of multi-area power system. Initially, PID controllers are considered for each area and FA is employed to minimize an ITAE criterion. Further, PS is employed to fine tune the controller parameters obtained by FA. FA and PS have complementary advantages, and a hybrid of the two algorithms can result in a faster and more robust technique. The superiority of the proposed design approach is illustrated by comparing the proposed method with some recently published technique such as BFOA, GA and ZN. Finally, the proposed approach is extended to multi area multi source hydro thermal power system models by considering the physical constraints such as time delay, GRC and GDB.

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 is widely used in the literature is for the design and analysis of automatic load frequency control of interconnected areas [17]. 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 p.u. Hz; T_{G1} and T_{G2} are the speed governor time constants in seconds; ΔP_{V1} and ΔP_{V2} are the change in governor valve positions (p.u.); ΔP_{G1} and ΔP_{G2} are the governor output command (p.u.); T_{T1} and T_{T2} are the turbine time constant in seconds; 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_{P1} and K_{P2} are the power system gains; T_{P1} and T_{P2} are the power system time constant in seconds; T_{12} is the synchronizing coefficient and ΔF_1 and ΔF_2 are the system frequency deviations in Hz. In thermal power plants, power generation can change only at a specified maximum rate known as Generation Rate Constraint (GRC). Typical values of GRC for a thermal plant are 2–5% per min. The relevant parameters are given in Appendix A. Each area of the power system consists of speed governing system, turbine and generator. Each area has three inputs and two outputs. The inputs are the controller input ΔP_{ref} (also denoted as u), load disturbance ΔP_D and tie-line power error ΔP_{Tie} The outputs are the generator frequency ΔF and Area Control Error (ACE) given by Eq. (1):

$$ACE = B\Delta F + \Delta P_{Tie} \tag{1}$$

where B is the frequency bias parameter.

To simplicity the frequency-domain analyses, transfer functions are used to model each component of the area. Turbine is represented by the transfer function [2]:

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+sT_T} \tag{2}$$

From [2], the transfer function of a governor is:

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1+sT_G} \tag{3}$$

The speed governing system has two inputs ΔP_{ref} and ΔF with one out put $\Delta P_G(s)$ given by [2]:

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \tag{4}$$

The generator and load is represented by the transfer function [2]:

$$G_P(s) = \frac{K_P}{1+sT_P} \tag{5}$$

where $K_P = 1/D$ and $T_P = 2H/fD$.

The generator load system has two inputs $\Delta P_T(s)$ and $\Delta P_D(s)$ with one out put $\Delta F(s)$ given by [2]:

$$\Delta F(s) = G_P(s)[\Delta P_T(s) - \Delta P_D(s)] \tag{6}$$

Firefly algorithm

The Firefly Algorithm (FA) is a population-based algorithm developed by Yang [8]. Fireflies are characterized by their flashing light produced by biochemical process bioluminescence. The flashing light may serve as the main courtship signals for mating. It is based on the following three idealized behavior of the flashing characteristics of fireflies [9]:

(a) All fireflies are unisex and are attracted to other fireflies regardless of their sex.
(b) The degree of the attractiveness of a firefly is proportional to its brightness. Their attractiveness is proportional to their light intensity. Thus for any two flashing fireflies, less bright firefly moves toward the brighter one. As brightness is proportional to distance, more brightness means less distance between two fireflies. If any two flashing fireflies have the same brightness, then they move randomly.
(c) The brightness of a firefly is determined by the objective function to be optimized.

For proper design of FA, two important issues need to be defined: the variation of light intensity (I) and the formulation of attractiveness (β). The attractiveness of a firefly is determined by its light intensity or brightness and the brightness is associated