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A novel hybrid gravitational search and pattern search algorithm for load frequency control of nonlinear power system

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ABSTRACT

In this paper, a hybrid gravitational search algorithm (GSA) and pattern search (PS) technique is proposed for load frequency control (LFC) of multi-area power system. Initially, various conventional error criterions are considered, the PI controller parameters for a two-area power system are optimized employing GSA and the effect of objective function on system performance is analyzed. Then GSA control parameters are tuned by carrying out multiple runs of algorithm for each control parameter variation. After that PS is employed to fine tune the best solution provided by GSA. Further, modifications in the objective function and controller structure are introduced and the controller parameters are optimized employing the proposed hybrid GSA and PS (hGSA-PS) approach. The superiority of the proposed approach is demonstrated by comparing the results with some recently published modern heuristic optimization techniques such as firefly algorithm (FA), differential evolution (DE), bacteria foraging optimization algorithm (BFOA), particle swarm optimization (PSO), hybrid BFOA-PSO, NSGA-II and genetic algorithm (GA) for the same interconnected power system. Additionally, sensitivity analysis is performed by varying the system parameters and operating load conditions from their nominal values. Also, the proposed approach is extended to two-area reheat thermal power system by considering the physical constraints such as reheat turbine, generation rate constraint (GRC) and governor dead band (GDB) nonlinearity. Finally, to demonstrate the ability of the proposed algorithm to cope with nonlinear and unequal interconnected areas with different controller coefficients, the study is extended to a nonlinear three unequal area power system and the controller parameters of each area are optimized using proposed hGSA-PS technique.

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 (LFC). For multiarea power systems, which normally consist of interconnected control area, in this regard LFC 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. LFC monitors the system frequency and tie-line flows, calculates the net change in the generation 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 LFC. As the ACE is adjusted to zero by the LFC, both frequency and tie-line power errors will become zero [2].

Several control strategies for LFC 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 LFC of power systems has been presented. It is observed that considerable research work is going on to propose better LFC 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

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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 favourable ratio between performances and cost. Additionally, it also offers simplified dynamic modelling, 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 LFC 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 LFC 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. Ali and Abd-Elazim [11] 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. [12] employed an imperialist competitive algorithm (ICA) to optimize the PID controller parameters in a multiarea multi unit power system. In [13], 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.

Recently, new hybrid/modified optimization techniques have been proposed in the literature. A self-organizing migration algorithm (SOMA) has been proposed in [14] for online tuning of an actively compensated Langmuir probe system. The results are compared with simulated annealing (SA) and differential evolution (DE) algorithm to show the superiority of SOMA. In [15], support vector regression (SVR) model with chaotic GA (SVRCGA) has been proposed to forecast the tourism demands where the superiority of SVRCGA model is demonstrated by comparing the results of other approaches reported in the literature. In [16], an enhanced cultural algorithms by diversified social networks has been employed to resolve complex mechanical design optimization problems and is compared to other well known algorithms from literature to illustrate its efficiency. An improved algorithm based on particle swarm optimization (PSO) by trying to increase the ability of local search around optimum with focusing on best found peak in each environment is proposed for optimization in dynamic environments [17]. The results of the proposed approach are evaluated on moving peak benchmarks and are compared with results of several state of the art algorithms to show its advantage. A cat swarm optimization (CSO) algorithm is applied in [18] to determine the best optimal impulse response coefficients of FIR filters, while trying to meet the respective ideal frequency response characteristics. The results of the CSO-based approach have been compared to those of other well known optimization methods such as real coded genetic algorithm (RCGA), standard PSO and DE to verify 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. Gravitational search algorithm (GSA) is a newly developed heuristic optimization method based on the law of gravity and mass interactions [19]. 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 [20]. However, the success of GSA in solving a specific problem crucially depends on appropriately choosing its control parameter values namely gravitational constant G_0, population size NP, number of iteration T and constant α. It is highly desirable to determine appropriate control parameter values which are often problem-dependent. The key to achieving high performance for any meta-heuristic algorithm is to maintain a good balance between exploitation and exploration during search. GSA 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 [21,22]. Due to their respective strength and weakness, there is motivation for the hybridization of GSA and PS.

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. In view of the above, an attempt has been made in the present paper for the optimal design of hybrid GSA and PS (hGSA-PS)-based PI/PIDF controller for LFC in a multi-area interconnected power system.

The aim of the present work is

(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 proposed hGSA-PS technique over other techniques such as GSA, FA, PSO, hBFOA-PSO, NSGA-II, DE, BFOA and GA 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 time delay, generation rate constraints and governor dead band nonlinearity on the system performance and design the controllers for this conditions.

2. Materials and methods

2.1. Modelling of power system for LFC studies

Load frequency control (LFC) provides the control only during normal changes in load which are small and slow. So the nonlinear equations which describe the dynamic behaviour of the system can be linearized around an operating point during these small load changes and a linear incremental model can be used for the analysis, thus making the analysis simpler. The linear model of LFC for an interconnected power system is presented in this section. Each area of the power system consists of speed governing system, hydraulic valve actuator (governor), turbine, generator and load as shown in Fig. 1. To simplify the frequency-domain analyses, transfer functions are used to model each component of the area [2].

The speed governing system has two inputs reference power setting ΔP_{ref} and frequency ΔF and one output, i.e. governor output command $\Delta P_{\mathrm{G}}(s)$ given by

$$\Delta P_{\mathrm{G}}(s) = \Delta P_{\mathrm{ref}}(s) - \frac{1}{R}\Delta F(s) \quad (1)$$

The governor valve is represented by transfer function as

$$G_{\mathrm{G}}(s) = \frac{\Delta P_{\mathrm{V}}(s)}{\Delta P_{\mathrm{G}}(s)} = \frac{1}{1 + sT_{\mathrm{g}}} \quad (2)$$