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Firefly algorithm optimized fuzzy PID controller for AGC of multi-area multi-source power systems with UPFC and SMES

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ABSTRACT

In this paper, a Firefly Algorithm (FA) optimized fuzzy PID controller is proposed for Automatic Generation Control (AGC) of multi-area multi-source power system. Initially, a two area six units power system is used and the gains of the fuzzy PID controller are optimized employing FA optimization technique using an ITAE criterion. The superiority of the proposed FA optimized fuzzy PID controller has been demonstrated by comparing the results with some recently published approaches such as optimal control and Differential Evolution (DE) optimized PID controller for the identical interconnected power system. Then, physical constraints such as Time Delay (TD), reheat turbine and Generation Rate Constraint (GRC) are included in the system model and the superiority of FA is demonstrated by comparing the results over DE, Gravitational Search Algorithm (GSA) and Genetic Algorithm (GA) optimization techniques for the same interconnected power system. Additionally, a Unified Power Flow Controller (UPFC) is placed in the tie-line and Superconducting Magnetic Energy Storage (SMES) units are considered in both areas. Simulation results show that the system performances are improved significantly with the proposed UPFC and SMES units. Sensitivity analysis of the system is performed by varying the system parameters and operating load conditions from their nominal values. It is observed that the optimum gains of the proposed controller need not be reset even if the system is subjected to wide variation in loading condition and system parameters. Finally, the effectiveness of the proposed controller design is verified by considering different types of load patterns.

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1. Introduction

The main objective of power system utility is to maintain continuous supply of electrical power with an acceptable quality, to all the consumers in the system. The power system will be in equilibrium, when there is a balance between electrical power demand and the power generated. There are two basic control mechanisms used to achieve reactive power balance (acceptable voltage profile) and real power balance (acceptable frequency values). The former is called Automatic Voltage Regulator (AVR) and latter is called Automatic Generation Control (AGC) [1]. The goal of AGC in an interconnected power system is to minimize the transient deviations in area frequency, tie-line power interchange and to ensure their steady state errors to be zeros [2]. A considerable drop in frequency could result in high magnetizing currents in induction motors and transformers. The wide-spread use of electric clocks and the use of frequency for other timing purposes require accurate maintenance of synchronous time which is proportional to frequency as well as its integral. According to Indian Electricity Grid Code (IEGC), if the rated system frequency is 50 Hz and the target range for frequency control should be 49.0 Hz–50.0 Hz, the statutory acceptable limits are 48.5–51.5 Hz. However, the users of the electric power change the loads randomly and momentarily. This results in sudden appearance of generation-load mismatches. The mismatch power enters into/drawn for the rotor thus causing a change generator speed and hence the system frequency (as frequency is closely related to the generator speed). It is impossible to maintain the balances between generation and load without control. So, a control system is essential to cancel the effects of the random load changes and to keep the frequency at the standard value. The AGC loop continuously regulates the active power output of the generator to match with the randomly varying load [3].

In a practically interconnected power system, the generation normally comprises of a mix of thermal, hydro, nuclear and gas power generation. However, owing to their high efficiency, nuclear plants are generally kept at base load close to their maximum output with no participation in AGC. Gas power generation is ideal for meeting

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the varying load demand. So, Gas plants are used to meet peak demands only [4,5]. Parmar et al. have reported in [4] a multi-sources generation including thermal-hydro-gas systems, considering HVDC link connected in parallel with existing AC link for stabilizing frequency oscillation and used an optimal output feedback controller for frequency stabilization. Recently, Mohanty et al. [5] have studied the controller parameters tuning of Differential Evolution (DE) algorithm and its application to optimize the parameters of I, PI and PID controllers of multi-sources power system. The authors have demonstrated the superiority of DE approach over optimal output feedback controller for the same power systems. Keeping in view the present power scenario, combination of multi-source power generation is considered with their corresponding participation factors.

When the governor system is not able to absorb the frequency fluctuations due to its slow response, active power source with fast response such as Superconducting Magnetic Energy Storage (SMES) is highly effective in improving the dynamic performance of the system [6,7]. In Banerjee et al. [8], the effectiveness of small-sized superconducting and normal loss types Magnetic Energy Storage (MES) units for load frequency control is investigated and means of best utilizing the small energy storage capacity of such units to improve the dynamics performance of large power areas are suggested. As the SMES unit is capable of concurrently controlling both active and reactive powers [9], it is one of the most effective and vital stabilizer of frequency oscillations. The feasibility of SMES for improving load frequency performance has been reported in literature [10,11]. The recent advances in power electronics have led to the development of the Flexible Alternating Current Transmission Systems (FACTS) controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and can be employed for improving the performance of a power system. The Unified Power Flow Controller (UPFC) is member of the FACTS family with very versatile features. UPFC which consists of a series and shunt converter connected by a common dc link capacitor can simultaneously perform the function of transmission line real and active power flow control in addition to UPFC bus voltage /shunt reactive power control [12]. The impact of different FACTS controllers such as Static Synchronous Series Compensator (SSSC) and Thyristor Controlled Phase Shifter (TCPS) in coordination with SMES for AGC has been reported in literature [13,14]. In view of the above, AGC in presence of SMES and UPFC has been carried out in the present paper.

Literature study reveals that several control strategies have been proposed by many researchers over the past decades for AGC of power system [15]. Many control and optimization techniques such as conventional [16], optimal control [4], Genetic Algorithm [17], Particle Swarm Optimization [18], Bacteria Foraging Optimization Algorithm [19], Artificial Neural Network [20], linear-quadratic optimal output feedback controller [21], sub-optimal controller [22], AGC with wind generators and flywheel energy storage system [23] etc. have been proposed for AGC.

To get an accurate insight of the AGC problem, it is necessary to include the important physical constraints in the system model. The major physical constraints which affect the power system performance are Time Delay (TD) and Generation Rate Constraint (GRC) [3]. In view of the above, TD and GRC associated with both communication channels and signal processing are considered in the present paper to have more realistic power system.

In the load frequency control, integral controller is sufficient to reduce the frequency and tie-line power deviations and bring them back to nominal values. However, the disadvantage of integral controller is that it might produce a closed loop system with significantly slower response times. To improve the system performance, Proportional Integral (PI), Integral Derivative (ID), Proportional Integral Derivative (PID) and Integral Double Derivative (IDD) controllers have been proposed in literature [4,5,16]. However, the above conventional controllers perform satisfactorily at the operating point at which the controllers are designed and their performance degrades when there is any change in operating point or in system parameter. It has been reported by many researchers that Fuzzy Logic Controller (FLC) improves the closed loop performance of I/PI/PID controller and can handle any changes in operating point or in system parameter by online updating of the controller parameters [24–26]. Fuzzy logic based PID controller can be successfully used for all nonlinear system but there is no specific mathematical formulation to decide the proper choice of fuzzy parameters (such as inputs, scaling factors, membership functions, rule base etc.). Normally these parameters are selected by using certain empirical rules and therefore may not be the optimal parameters. Improper selection of input-output scaling factor may affect the performance of FLC to a greater extent.

It is obvious from literature survey that the performance of the power system depends on the controller structure and the techniques employed to optimize the controller parameters. Hence, proposing and implementing new controller approaches using 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 [27,28]. 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 [29]. Recent research shows that FA is very efficient and could outperform other meta-heuristic algorithms [30].

In view of the above, a maiden attempt has been made in this paper to apply an FA optimization technique to tune the input and output scaling factors of fuzzy PID controller for the AGC of multi area power systems with the consideration of time delay, reheat turbine and Generation Rate Constraint (GRC). The structure of the fuzzy PID used here is inherited from a combination of fuzzy PI and fuzzy PD controllers from Mudi and Pal and Sahu et al. [24,26], with K_1 and K_2 as input scaling factors of Fuzzy Logic Controller (FLC). The FLC output is multiplied K_P, its integral and derivative are multiplied K_I and K_D respectively, and then summed to give the total controller output. Fixed membership functions and rule base are assumed for the FLC structure. The input scaling factors (K_1 and K_2) and output scaling factors (K_P, K_I and K_D) are optimized in presence of FLC employing FA technique to minimize the objective function. The results are compared with some recently published approaches such as DE optimized PID controller and optimal control. The superiority of FA over GA, GSA and DE techniques is also demonstrated. Further, UPFC is employed in series with the tie-line in coordination with SMES to improve the dynamic performance of the power system. Finally, sensitivity analysis is carried out by varying the loading condition and system parameters.

2. Materials and methods

2.1. Power system model

A two area six unit thermal, hydro and gas power system [4,5] as shown in Fig. 1 is considered for design and analysis purpose. Each area comprises reheat thermal, hydro and gas generating units. A fuzzy PID controller is considered for each unit. In Fig. 1, R_T, R_H, *and* R_G are the regulation parameters of thermal, hydro and gas units respectively; B_1 and B_2 represent the frequency bias parameters; ACE_1 and ACE_2 stands for Area Control Errors; U_T, U_H and U_G are the control outputs for thermal, hydro and gas units respectively; K_T, K_H and K_G are the participation factors of thermal, hydro and gas generating units, respectively; T_G is speed governor time constant of thermal unit in sec; T_t is steam turbine time constant in sec; K_r is the steam turbine reheat constant; T_r is the steam turbine

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