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Load frequency control of power system under deregulated environment using optimal firefly algorithm

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ABSTRACT

In this paper, a novel Firefly Algorithm (FA) optimized hybrid fuzzy PID controller with derivative Filter (PIDF) is proposed for Load Frequency Control (LFC) of multi area multi source system under deregulated environment by considering the physical constraints such as Generation Rate Constraint (GRC) and Governor Dead Band (GDB) nonlinearity. As the effectiveness of FA depends on algorithm control parameters such as randomization, attractiveness, absorption coefficient and number of fireflies are systematically investigated, the control parameters of FA are tuned by carrying out multiple runs of algorithm for each control parameter variation then the best FA control parameters are suggested. Additionally, the superiority of the FA is demonstrated by comparing the results with tuned Genetic Algorithm (GA). To investigate the effectiveness of the proposed approach, time domain simulations are carried out considering different contracted scenarios and the comparative results are presented. Further, sensitivity analysis is performed by varying the system parameters and operating load conditions. It is observed from the simulation results that the designed controllers are robust and the optimum gains of 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 control scheme is evaluated under random step load disturbance.

Introduction

In modern power systems, deviation in frequency and tie-line power is due to mismatch between the total generated power and electrical load demand. This change in frequency is to be corrected by Load Frequency Control (LFC). The main objective of LFC is to maintain the steady frequency, control the tie-line flows, to control the frequency deviation by maintaining the total power generated by power stations is equal to the system load and losses [1–3]. However, the users of the electric power change the loads randomly and momentarily. This results in sudden appearance of generation-load mismatches. It is impossible to maintain the balance 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.

In the deregulation of power system, the structure of conventional power system has been modified. It consists of number of independent entities such as generation companies (GENCOs), distribution companies (DISCOs), and transmission companies (TRANSCOs) and independent system operator (ISO). In this scenario, GENCOs as independent power utilities may or may not participate in the LFC task. On the other hand, DISCOs may contract individually with GENCOs, non-conventional energy source plants, or independent power producers (IPPs) for power in different areas. Hence, in the deregulated scenario, control is highly decentralized and Independent System Operators (ISOs) are responsible for maintaining steady frequency and tie-line power flows [4].

Many researchers on LFC issues in power system operation after deregulation have been reported in past. Several intelligent control and optimization techniques such as optimal control [5], fractional order PID [6], Genetic Algorithm [7], Particle Swarm Optimization [8], Bacteria Foraging Optimization Algorithm [6] (BFOA), and Fuzzy Logic Controller [9], have been suggested for LFC under deregulation. Debbarma et al. [6] have studied AGC of multi-area thermal systems under deregulated environment considering reheat turbines and GRC, where the fractional order PID controller parameters are optimized employed Bacterial Foraging (BF) optimization technique and the results are compared with classical controller show its superiority. Parmar et al. [5] have studied the multi-source power generation in deregulated power environment using optimal output feedback controller. Demiroren and Zeynelgil

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Nomenclature

i	subscript referred to area i (1, 2, 3, 4)
F	nominal system frequency (Hz)
P_{Ri}	rated power of area i (MW)
B_i	frequency bias parameter of area i (p.u. MW/Hz)
R_i	governor speed regulation parameter (Hz/p.u. MW)
T_{Gi}	speed governor time constant (s)
T_{Ti}	steam turbine time constant (s)
T_{Ri}	steam turbine reheat time constant (s)
K_{Ri}	steam turbine reheat constant
T_{psi}	power system time constant (s)
K_{psi}	power system gain (Hz/p.u. MW)
ΔF_i	incremental change in frequency of area i (Hz)
ΔP_{Di}	incremental step load change of area i
ACE_i	area control error of area i
T_{ij}	synchronizing coefficient between areas i and j (p.u.)
$\Delta P_{Tie,ij}$	incremental change in tie-line power between areas i and j (p.u.)
t_{sim}	simulation time (s)
a_{ij}	$-P_{Ri}/P_{Rj}$
cpf_{kl}	contract participation factor between kth *GENCO* and lth *DISCO*
apf_i	*ACE* participation factor of ith generating unit
$\Delta P_{Tie,ij,schedule}$	scheduled steady state power flow on the tie-line between areas i and j (p.u. MW)
ΔP_{gi}	incremental change in power output of ith generating unit (p.u. MW)
$\Delta P_{Tie,ij,actual}$	actual tie-line power between areas i and j (p.u. MW)
$\Delta P_{Tie,ij,error}$	tie-line power error between areas i and j (p.u. MW)
U_k	control signal to the kth generating unit
GRC	Generation Rate Constraint
GDB	Governor Dead Band
DPM	*DISCO* Participation Matrix

[7] have studied automatic generation control in three area power system after deregulation and uses GA technique to find the optimal integral gains and bias factors. Bhatt et al. [8] have studied the AGC problem in four area power system under deregulation. Hybrid particle swarm optimization is used to obtain optimal gain of PID controller. The authors have not considered the important physical constraints such as Generation Rate Constraint (GRC) and Governor Dead Band (GDB) in the system model which affect performance of the power system. Thus, to study the realistic power system under deregulation, it is necessary to include the GRC and GDB nonlinearity. Tan et al. [10] have proposed two degree of freedom (TDF) internal model control (IMC) method to tune decentralized PID type load frequency controllers for multi area power systems in deregulated environments. Liu et al. [11] have proposed optimal Load Frequency Control (LFC) under restructured power systems with different market structures. Donde et al. [12] have demonstrated the concept of restructured power system and DISCO Participation Matrix (DPM).

As the realistic power system is nonlinear in structure it is very difficult to ensure stability of the system by using classical controllers such as I/PI/PID controller optimized at a particular operating condition may not perform satisfactorily when there is a change in operating condition [13]. Therefore, there is a need of intelligent controller which can overcome this problem. It has been reported by many researchers that Fuzzy Logic Controller (FLC) improves the closed loop performance of PID controller and can handle any changes in operating point or in system parameter by online updating the controller parameters [14,15]. 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, and rule base). 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 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. Hence, proposing and implementing new high performance heuristic optimization algorithms to real world problems are always welcome. Recently, a new biologically-inspired meta-heuristic algorithm, known as the Firefly Algorithm (FA) has been developed by Yang [16,17]. 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 [18,19]. Recent research shows that FA is a very efficient and could outperform other meta-heuristic algorithms. A binary real coded firefly algorithm has been applied to a static problem of power system in [20] and the results are compared with GA and PSO. In [21] FA is used for clustering on benchmark problems and the performance of the FA is compared with other two nature inspired techniques such as Artificial Bee Colony (ABC) and PSO.

Having known all this, a maiden attempt has been made in this paper for the optimal design of FA based fuzzy PIDF controller for LFC under deregulated environment. The aim of the present work is as follows:

(a) to tune the control parameters of FA,
(b) to demonstrate the advantages of optimal FA over the GA for the similar problem,
(c) to show advantages of using a hybrid fuzzy PIDF controller compare others during possible of all transaction for deregulated environment,
(d) to demonstrate the ability of the proposed approach to handle nonlinearity and physical constraints,
(e) to study the effectiveness of the proposed controller with the change in system parameters or loading conditions,
(f) to understand the robustness of proposed controller under random step load disturbance.

Material and method

Power system under study

The schematic diagram of the system under study is shown in Fig. 1. The system is widely used in literature for the design and analysis of automatic load frequency control under deregulated power system [8]. It consists of four control areas in which each area has different combinations of GENCOs and DISCOs. Area1 comprises of two reheat thermal power systems and two DISCOs, Area2 consists of one reheat thermal power systems and two DISCOs, Area3 comprises of three GENCOs with all reheat thermal power systems and two DISCOs, Area4 comprises of two reheat thermal power systems and two DISCOs. The MATLAB/SIMULINK diagrams for the present study are shown in Figs. 2(a) and 2(b). Fig. 2(a) shows the part of DISCOs and Fig. 2(b) shows the portion of GENCOs. The study has been carried out on four control areas