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Research Article

Solution to automatic generation control problem using firefly algorithm optimized $I^{\lambda}D^{\mu}$ controller

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ABSTRACT

Present work focused on automatic generation control (AGC) of a three unequal area thermal systems considering reheat turbines and appropriate generation rate constraints (GRC). A fractional order (FO) controller named as $I^{\lambda}D^{\mu}$ controller based on crone approximation is proposed for the first time as an appropriate technique to solve the multi-area AGC problem in power systems. A recently developed metaheuristic algorithm known as firefly algorithm (FA) is used for the simultaneous optimization of the gains and other parameters such as order of integrator (λ) and differentiator (μ) of $I^{\lambda}D^{\mu}$ controller and governor speed regulation parameters (R). The dynamic responses corresponding to optimized $I^{\lambda}D^{\mu}$ controller gains, λ, μ, and R are compared with that of classical integer order (IO) controllers such as I, PI and PID controllers. Simulation results show that the proposed $I^{\lambda}D^{\mu}$ controller provides more improved dynamic responses and outperforms the IO based classical controllers. Further, sensitivity analysis confirms the robustness of the so optimized $I^{\lambda}D^{\mu}$ controller to wide changes in system loading conditions and size and position of SLP. Proposed controller is also found to have performed well as compared to IO based controllers when SLP takes place simultaneously in any two areas or all the areas. Robustness of the proposed $I^{\lambda}D^{\mu}$ controller is also tested against system parameter variations.

1. Introduction

Automatic generation control (AGC) issue is becoming one of the major subjects in the interconnected power system because of increasing size and complexity. The main goal of AGC is to maintain schedule frequency and schedule tie line flow in normal power system to their desired tolerance values for each control area of an interconnected power network [1–3]. Literature survey shows that lot of investigations with number of control methodologies have been reported in the past to eliminate automatic generation control problem [1–13,19,23]. Shabani et al. [4] had used integer-order (IO) based proportional plus integral plus derivative (PID) controller along with filtering technique to damp the transient deviations in area frequency and tie-line power interchange. Saikia et al. [5] highlighted the performance comparisons of several integer order (IO) controllers, such as integral (I), PI, PID, IDD controller etc in a multi-area interconnected model of AGC. However, the investigations in [4,5] were limited to classical based IO controllers only. Although, conventional IO controllers are well known for their simplicity and are widely used in AGC as secondary controllers, but there is no guarantee that such controllers would provide the best dynamic response under realistically constrained conditions like generation rate constraints (GRC). It has been seen that the basic approaches of integer-order (IO) based classical controllers are not effective in achieving good dynamic performances when subjected to wide changes in magnitude of step load perturbation (SLP). In the past decade, the focus has been to optimize the gains of supplementary controller (basically classical IO controller) using various optimization techniques [6–8] and very less efforts have been made to design and apply robust AGC controller that can well compete and even provide better performance than these conventional controllers. Many research works [8–10] have been carried out considering fuzzy logic controller (FLC) and supervised artificial neural network (ANN) controller in AGC system. However, in case of FLCs, a considerable computational time is required for rule base to be examined and more time required for the data base for training the ANN controller in supervised learning. A critical introductive literature review pertaining to various control methodologies based on the classical and optimal control, robust, adaptive, self-tuning control, VSC systems, digital and artificial intelligent/soft computing control techniques are well presented in [11]. Considerable research works attempting to propose better AGC systems based on modern optimal control theory is available in [12,13].

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Nomenclature

f	nominal system frequency (Hz)
i	subscript referred to area i (1, 2, 3);
P_{ri}	rated power of area i (MW);
ΔP_{Di}	incremental load change in area i (p.u);
D_i	$\Delta P_{Di}/\Delta f_i$ (p.u MW/Hz).;
R_i	governor speed regulation parameter of area i (Hz/pu MW)
T_{gi}	steam governor time constant of area i (s).
K_{ri}	steam turbine reheat coefficient of area I;
B_i	frequency bias constant of area i (p.u MW/Hz);
K_{pi}	$1/D_i$. (Hz/pu).;
K_{Pi}	proportional gain of controller in area i;
μ_i	order of derivative of FO controller in area i;
β_i	area frequency response characteristics of area i ($=D_i+1/R_i$).
T	simulation time (s).
$\Delta P_{tie\ i\text{-}j}$	incremental change in tie line power connecting between area i and area j (p.u)
*	superscript denotes optimum value
H_i	inertia constant of area i (s)
ΔP_{gi}	incremental generation change in area 1 (p.u)
T_{ij}	synchronizing coefficients.
T_{ti}	steam turbine time constant of area i (s)
T_{ri}	steam turbine reheat time constant of area i (s)
T_{pi}	$2H_i/f\,D_i$ (s)
K_{Ii}	integral gain of controller in area i.
K_{Di}	derivative gain of controller in area i.
λ_i	order of integrator of FO controller in area i.
Δf_i	incremental change in frequency of area i (Hz).

Almost all the past research conducted was focused mainly on using classical integer order (IO) controller to ensure robustness and stability issues in AGC design under both conventional and deregulated environment.

Recently, fractional order based classical controller have been gaining attention to several research communities. Many investigations have been carried out using FO controller in different areas of engineering [14–17]. Alomoush in [18] has introduced the effect of fractional-order (FO) controller as a secondary controller in the two-area AGC system under conventional environment with non-reheat turbine and proved that FO controller is far better than IO controllers. However, their investigations were limited to classical approach and the optimization of secondary controller gains only. Some aspects like reheat turbine, GRC, selection of governor speed regulation parameter "R", optimization of design and performances of $I^{\lambda}D^{\mu}$ controller using powerful search algorithms had not been addressed by any of the authors. This needs further investigations. Moreover, no literature reported so far has investigated sensitivity analysis of the optimum FO controller and its performances when subjected to step perturbations in all the areas of thermal system. Till date, very few literatures have been reported related to the performance of non-integer or FO controller pertaining to AGC system [19]. Debbarma et al. [19] have investigated and solved the problems of multi area AGC system under deregulated environment successfully using bacterial foraging based FOPID controller. Apparently, no investigation report is available in the literature about the performance of $I^{\lambda}D^{\mu}$ controller in the area of automatic generation control (AGC) when subjected to simultaneous perturbations in all the areas under both conventional and deregulated power system.

It is seen from the past work [6] that higher value of speed regulation parameter (R) of governor results into more economical and simple governor. Many works has been reported pertaining to selection of optimum R parameter [6,19]. However, the selection of optimum value of R for each area using $I^{\lambda}D^{\mu}$ controller is yet to be explored.

Numerous intelligent optimization techniques such as genetic algorithm (GA), particle swarm optimization (PSO), bacterial foraging optimization (BFO) etc are successfully applied to solve the AGC problems and are available in the literatures [6–8]. Nanda et al. [6] have demonstrated that BFO technique based controller provides better performance compared to classical and GA techniques in multi-area thermal system. Similarly Saikia et al. [8] also proved that BFO can outperform PSO and GA. The complexity of AGC problems reveals the necessity for development of more efficient algorithms in order to accurately minimize the ACE signal to zero. Recently, a new metaheuristic nature-inspired algorithm, called firefly algorithm (FA), based on the flashing light of fireflies has been successfully applied to solve different engineering problems [20–22]. Although, the FA has got many similarities with other algorithms, which are based on the so-called swarm intelligence, such as the famous PSO, BFO etc, it is indeed much simpler both in concept and implementation. FA can find the global optima as well as all the local optima simultaneously in a very effective manner. According to [20] the characteristic feature of the FA is the fact that it simulates a parallel independent run strategy, where in every iteration, a swarm of n fireflies has generated n solutions. Each firefly works almost independently and as a result the algorithm, will converge very quickly with the fireflies aggregating closely to the optimal solution [21]. To show the efficiency and applicability of the FA method over other methods, Yang et al. [22] analysed economic dispatch (ED) problems and the performance are compared with those available in the literature such as GA, PSO, BFO, biogeography-based optimization (BBO) etc. The proposed optimization technique is found to be very efficient and outperforms the other techniques [22], thus encouraging further researches for complex problems. Also, the same algorithm remains unexplored for simultaneous optimization of gains and R parameters in AGC of multi area thermal system considering reheat turbine and GRC, which needs further investigations. In this context, the objectives of the present work are:

(a) To optimize the gains of several IO controllers such as I, PI, PID controller simultaneously with regulation parameters (R_i) using a new metaheuristic nature-inspired algorithm so called firefly algorithm (FA) keeping frequency bias (B_i) fixed at area frequency response characteristics (β_i) and compare its performance with newly introduced $I^{\lambda}D^{\mu}$ or FOID (fractional order based integral plus derivative) controller in three unequal area reheat thermal system considering GRC in order to assess the best controller.
(b) To study the sensitivity analysis for the $I^{\lambda}D^{\mu}$ controller with its optimum parameters and its robustness to wide changes in the loading condition, changes in size and location of SLP.
(c) To investigate the performance of $I^{\lambda}D^{\mu}$ controller when perturbations takes place in any two areas or simultaneously in all areas of the three area thermal system and compare it with IO based controller.

2. System investigated

The proposed AGC systems, on which investigations have been carried out, are three unequal area system of area1: 2000 MW,