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Automatic generation control using two degree of freedom fractional order PID controller

Sanjoy Debbarma [a,*], Lalit Chandra Saikia [b,1], Nidul Sinha [b,1]

[a] Department of Electrical & Electronics Engineering, National Institute of Technology Meghalaya, Shillong, India
[b] Department of Electrical Engineering, National Institute of Technology Silchar, Assam, India

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ABSTRACT

In this paper, Two-Degree-of-Freedom-Fractional Order PID (2-DOF-FOPID) controller is proposed for automatic generation control (AGC) of power systems. Proposed controller is tested for the first time on a three unequal area thermal systems considering reheat turbines and appropriate generation rate constraints (GRCs). The simultaneous optimization of several parameters of the controllers and speed regulation parameter (R) of the governors is done by a recently developed metaheuristic nature-inspired algorithm known as Firefly Algorithm (FA). Investigation clearly reveals the superiority of the 2-DOF-FOPID controller in terms of settling time and reduced oscillations. Present work also explores the effectiveness of the Firefly algorithm based optimization technique in finding the optimal parameters of the controller and selection of R parameter. Further, the convergence characteristics of the FA are compared to justify its efficiency with other well established optimization technique such as PSO, BFO and ABC. Sensitivity analysis confirms the robustness of the 2-DOF-FOPID controller for different loading conditions and wide changes in inertia constant (H) parameter. Furthermore, the performance of proposed controller is tested against higher degree of perturbation and random load pattern.

1. Introduction

Automatic generation control (AGC) deals with the controlling of active power, that is, generator output in response to changes in system frequency and tie-line power interchange. Increased in the complexity of the modern power system has necessitated the use of advanced intelligent control scheme. Various control methodologies, such as optimal control, variable structure control, adaptive and self-tuning control has been reported in the past to solve AGC problem and are available in [1–3]. Some authors have investigated fuzzy logic based control and ANN approaches for AGC [4,5]. The problems identified in fuzzy logic controller is that a considerable computational time is required for rules base to be examined and in case of artificial neural network (ANN), more time is required for the data base for training the neural network controller. Compare to the above mentioned approaches, classical based controller has been mostly used to suppress the oscillations due to their simplicity in execution. Authors in [6] suggested that classical integer order (IO) based integral plus double derivative (IDD) controller can outperform other conventional controller such as I, PI and PID controller. Although conventional IO controller are well known for its simplicity and widely used in AGC for controlling purpose, but there is no guarantee that such controller would provide the best dynamic response under realistically constrained conditions. It has been noticed that the basic approaches of IO based classical controller are not effective in achieving good dynamic performances when subjected to wide changes in magnitude of step load perturbation (SLP). To overcome this problems, authors in [7] has introduced fractional order (FO) based classical controller to solve multi-area AGC problem under deregulated environment and their investigation reveals that FOPID controller is far better than IO controller. The main advantages associated with FOPID controller is its two extra tuning knobs (parameters) known as λ (non-integer order of integrator) and μ (non-integer order of differentiator) that provides more flexibility for adjustment of system dynamics. Surprisingly, owing to this advantage of FO controller, most of the past researches were focused only on using IO based classical controller and their optimization using various optimization techniques and very less effort has been made to design and apply robust FO based AGC controller. References [8,9] used advanced control algorithm with two degree of freedom (2-DOF) concept to enhance the control performances of an IO based PI and PID controller. The flexibility of 2-DOF over single degree of freedom is from the point of view of achieving high performance in set-point tracking and the regulation in the presence of disturbance inputs. To provide this additional flexibility, authors in [10] and [11] attempted 2-DOF internal model control (IMC) based

* Corresponding author. Tel.: +91 9401154379; fax: +91 0364 250113.
E-mail addresses: sanjoy.debbarma@yahoo.in (S. Debbarma), lcsaikia@yahoo.com (L.C. Saikia), nidulsinha@hotmail.com (N. Sinha).
[1] Tel.: +91 9435173835; fax: +91 3842 233797.

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Nomenclature

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

controller and parallel 2-DOF-PID controller to solve the load frequency control (LFC) problem respectively. However their investigations have not dealt with fractional order controller and were limited to 2-DOF integer order (IO) controller. The superiority and advantage of fractional order controller along with two-degree-of-freedom concept is yet to be explored in the field of AGC. Also, no literature in the past compared and studied the performance of several fractional order (FO) controllers in AGC of three unequal area thermal systems which needs further investigations.

Literature survey shows that in the past many researchers have used different heuristic optimization techniques to deal with the AGC problem. The difficulties in AGC are not only designing of a robust controller but also to optimize its corresponding parameters effectively for optimal solution. To achieve optimal solution, many intelligent optimization approaches such as genetic algorithm (GA), particle swarm optimization (PSO), bacterial foraging optimization (BFO) and artificial bee colony (ABC) are successfully applied to solve the AGC problems and are available in the literatures [12–15]. Some authors have applied GA based optimization in [12]. Although GA has shown their effectiveness and dominancy over classical approach in some of the work pertain to AGC but recent research has identified some deficiencies in GA performance like premature convergence which may degrades its efficiency and reduces the search capability [13]. Authors in [13,4] clearly proved the superiority of the BFO over the classical technique, GA and PSO in terms of convergence, robustness and precision. Like GA, PSO is also less susceptible to getting trapped on local optimum. Gozde et al. [15] discussed that ABC can produce more optimal solutions than PSO technique in the field of AGC. The complexity of AGC problems and its optimal optimization 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 so called Firefly Algorithm (FA) based on the flashing light of fireflies has been successfully applied to solve different engineering problem [16–18]. Although the FA has got many similarities with other algorithms, which are based on the so-called swarm intelligence, such as the famous PSO, and BFO, it is indeed much simpler both in concept and implementation. The idea behind this algorithm is that the social behaviour and especially the flashing light of fireflies can be easily formulated and associated with the objective function of a given optimization problem [16]. FA seems very promising for dealing with optimization problem, but has been rarely reported. Recent analysis also identified the characteristic feature of the firefly algorithm 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. Authors in [17] proved that firefly algorithm is far superior to both PSO and GA in terms of both efficiency and success rate. Thus to justify the effectiveness of FA in the area of power system, authors in [18] analysed economic dispatch (ED) problems using FA technique and the performances are compared with those available in the literature such as GA, PSO, BFO, and biogeography-based optimization (BBO). Subsequently Debbarma et al. [19] explored the robustness of firefly algorithm in finding optimal solution for the controllers. The proposed optimization technique is found to be very efficient and outperforms the other techniques thus encouraging further researches for complex problems.

It is known that with only primary control (i.e. secondary control absent) the smaller the governor droop the smaller the steady state error in frequency but in the presence of secondary control there is nothing to be sacrosanct to use a small governor droop (of the order of 4–6% used in practice) as any large but credible value of R can also guarantee zero steady state error in frequency. Higher value of R results into easy realisation and economical governor [6,7].

In view of the above, the objectives of the present work are:

(a) To design and apply a new classical controller named as Two-Degree-of-Freedom-Fractional Order Proportional plus Integral plus Derivative (2-DOF-FOPID) controller and compare its performance with several FO based controllers as well as integer order (IO) based controllers.
(b) To compare the convergence characteristics of FA with other algorithms such as PSO, BFO and ABC.
(c) To apply Firefly Algorithm (FA) based optimisation technique for simultaneous optimization of several parameters.
(d) To study the performance of 2-DOF-FOPID Controller under random load pattern and higher magnitude of SLP.
(e) To check the robustness of the optimum parameters value of 2-DOF-FOPID through sensitivity analysis.

2. Description of the system model

The simulation based investigations have been carried on a three unequal area thermal system having area1: 2000 MW, area2: 4000, area3: 8000 MW provided with appropriate GRC of 3% per minute and reheat turbine in all the areas. The transfer function