Electrical Power and Energy Systems 63 (2014) 878–886

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Robust two-degree-of-freedom controller for automatic generation control of multi-area system

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

ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form 28 May 2014
Accepted 18 June 2014
Available online 22 July 2014

Keywords:
Automatic generation control
Firefly algorithm
PIDD controller
2-DOF-PIDD controller

ABSTRACT

This paper proposes a novel, integer-order based, two-degree-of-freedom Proportional plus Integral plus Double Derivative (2-DOF-PIDD) controller for automatic generation control of a three unequal area thermal system considering reheat turbines and appropriate generation rate constraints. The performance of proposed 2-DOF-PIDD controller is studied and compared with conventional integral (*I*) controller and recently reported single degree of freedom based Proportional plus Integral plus Double Derivative (PIDD) controller. Nature-inspired firefly algorithm (FA) based optimization is employed to search for optimal controller parameters and governor speed regulation parameters simultaneously. Critical examination clearly reveals that proposed 2-DOF-PIDD controller gives better dynamic responses than I and PIDD controller in terms of settling time and reduced oscillations. Analysis also explored the superiority of FA over bacterial foraging optimization and artificial bee colony techniques. Furthermore, proposed controller is tested against several uncertain circumstances such as different loading condition, wide variation in inertia constant (*H*), different position of step load perturbation (SLP) to check the robustness. Proposed controller is also found to have performed well when the system is subjected to a higher degree of SLP and simultaneous occurrence of SLPs.

Introduction

In an interconnected power systems, system frequency and tie-power deviations are considered as a direct result of the mismatch between the electrical load and the generation [1]. The problem of controlling generator output in response to changes in system frequency and tie-line power interchange is known as automatic generation control (AGC). There has been considerable research work attempting to propose better AGC systems [1–12]. Numerous control methodologies such as classical controller [2,3], optimal control [4], adaptive control [5], fractional order controller [6,23,24], fuzzy logic control [7,8], and neural network controller [9,10] had been proposed by researchers over the past decades. This extensive research is due to the complexity of AGC problems that demands more comprehensive research on the secondary (supplementary) controller designing. Till date very few literatures has reported the performance of secondary controller against simultaneous SLPs in all the areas [23]. Refs. [7–10] suggested fuzzy logic controller (FLC) and artificial neural network (ANN) controller for AGC system. However, in case of fuzzy logic controller considerable computational time is required for rule base to be examined and more time is required for the data base for training the neural network controller. Even though many advanced control theories have been established in the recent past, still most of the industries use classical based controller due to their simplicity in execution.

Authors in Ref. [11] proposed single degree of freedom (SDF) based Integral plus Double Derivative (IDD) controller for AGC of multi-area thermal system and concluded that IDD controller is far better and can outperform the conventional controllers such as I, PI and PID. Recently, authors in Ref. [12] has proposed another novel SDF based classical controller named as Proportional plus Integral plus Double Derivative (PIDD) for AGC system and surprisingly it is seen that proposed PIDD controller provides far better responses than the reported IDD controller. However, their investigation was limited to two-area thermal system. Also there is no guarantee that the same can perform better when the system is extended to three-area systems considering simultaneous SLPs in all the areas. The presence of double derivative terms in a controller helps to achieve fast responses and thus improves settling time and stability of the system. But in power system numerous on/off

* Corresponding author. Tel.: +91 9401154379; fax: +91 364 2501113.
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.

http://dx.doi.org/10.1016/j.ijepes.2014.06.053
0142-0615/

Nomenclature

f	nominal system frequency (Hz)	T	simulation time (s)
i	subscript referred to area i (1–3)	*	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)	ΔP_{gi}	incremental generation change in area 1 (p.u)
D_i	$\Delta P_{Di}/\Delta f_i$ (p.u MW/Hz)	T_{ij}	synchronizing coefficients
R_i	speed regulation parameter of area i (Hz/p.u 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/p.u)
K_{Ii}	integral gain of controller in area i	K_{Pi}	proportional gain of controller in area i
K_{DDi}	double 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
$\Delta P_{\mathrm{tie}\ i-j}$	incremental change in tie line power connecting between area i and area j (p.u)		

switching in the load side produces considerable noise in the frequency measurement that deteriorates the performance of derivative operator of the controller drastically. Therefore, to improve the performances when there is a noise in the measured process variable, derivative filter is usually employed. It not only reduces the detrimental effect of the high-frequency measurement noise but also helps to reduce the constant controller output fluctuations.

In a meanwhile, authors in Refs. [13,14] used advanced control algorithm with two degree of freedom (2-DOF) concept to enhance the control performances of PI and PID controller. The flexibility of 2-DOF over single degree of freedom (SDF) is from the point of view of achieving high performance in set-point tracking and the regulation in the presence of disturbance inputs. Owing to this advantages, authors in Refs. [15,16] attempted 2-DOF internal model control (IMC) based PID controller and parallel 2-DOF-PID controller respectively to solve the load frequency control (LFC) problem. However, investigation in Ref. [16] was limited to two-area system. Moreover, they have not dealt with the performance of proposed controller under higher degree of perturbation and simultaneous occurrence of SLPs. Till date, very less efforts have been made to design and apply robust two degree-of-freedom (2-DOF) controller in the area of AGC that can well compete and even provide better performance than the conventional controllers. Further, the 2-DOF controller structures must be duly subjected to sensitivity analysis to establish its robustness to wide changes in system loading and parameters. Also the controller must provide acceptable performance when subjected to simultaneous perturbations in all the areas.

Some papers [6,17] have been reported in the recent past pertaining to selection of speed regulation parameters (R) of primary controller (speed governor) in AGC of multiarea system. Usually the value of "R" parameter is taken as 2.4 Hz/p.u MW (4%) as higher values of "R" increases the nonlinearities in the system dynamics. However, in presence of effective supplementary controller one can go for a higher value of "R" parameters as it can also guarantee zero steady state error in the frequency. Such high values of "R" are recommended for adoption in practice for easy and cheaper realization of governors.

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. 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 [8,17–19]. Saikia et al. [8] discussed the application of bacterial foraging optimization (BFO) technique for multi-area AGC system and concluded that bacterial foraging is far better and can outperform the classical technique, genetic algorithm (GA) and particle swarm optimization (PSO). Gozde et al. [19] clearly show that the tuning performance of ABC algorithm is better than PSO algorithm. 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, several engineering problems in different areas have been solved using a new metaheuristic nature-inspired algorithm so called firefly algorithm (FA) [20–24]. Although FA has got many similarities with other algorithms which are based on the swarm intelligence, such as the famous PSO, and BFO, it is indeed much simpler both in concept and implementation. The idea behind firefly algorithm is that the social behavior and especially the flashing light of fireflies can be easily formulated and associated with the objective function of a given optimization problem [20]. Analysis also identified 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]. Owing to this advantages, authors in Ref. [22] analyzed economic dispatch problem using FA technique. Further, authors in Refs. [23,24] explored the superiority of FA tuned fractional-order controller in AGC of multiarea thermal system.

Therefore, in view of the above discussions, the objectives of the present work is

- To design and apply two-degree-of-freedom based Proportional plus Integral plus Double Derivative (2-DOF-PIDD) controller and compare its performance with commonly used integral (I) controller and recently reported SDF based PIDD controller for three unequal area thermal system considering GRC and reheat turbine in all areas.
- To apply firefly algorithm (FA) based optimization technique for simultaneous optimization of primary and secondary controller parameters such as K_{Pi}, K_{Ii}, K_{DDi}, λ_i, μ_i, N_i and R_i.
- To analysis the robustness of proposed 2-DOF-PIDD controller for different loading conditions, wide change in inertia constant parameter (H) and different location of SLP.
- To study the dynamical behavior of the FA optimized 2-DOF-PIDD controller under higher magnitude of SLP and simultaneous occurrence of SLPs.