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Automatic generation control of multi area thermal system using Bat algorithm optimized PD–PID cascade controller

Puja Dash *, Lalit Chandra Saikia [1], Nidul Sinha

Department of Electrical Engineering, National Institute of Technology Silchar, Assam, India

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ABSTRACT

This article presents automatic generation control (AGC) of an interconnected multi area thermal system. The control areas are provided with single reheat turbine and generation rate constraints of 3%/min. A maiden attempt has been made to apply a Proportional derivative–Proportional integral derivative (PD–PID) cascade controller in AGC. Controller gains are optimized simultaneously using more recent and powerful evolutionary computational technique Bat algorithm (BA). Performance of classical controllers such as Proportional Integral (PI) and Proportional Integral Derivative (PID) controller are investigated and compared with PD–PID cascade controller. Investigations reveal that PI, and PID provide more or less same response where as PD–PID cascade controller provides much better response than the later. Dynamic analysis has also been carried out for the controllers in presence of random load pattern, which reveals the superior performance of the PD–PID cascade controller. Sensitivity analysis reveals that the BA optimized PD–PID Cascade controller parameters obtained at nominal condition of loading, size and position of disturbance and system parameter (Inertia constant, H) are robust and need not be reset with wide changes in system loading, size, position of disturbance and system parameters. The system dynamic performances are studied with 1% step load perturbation in Area1.

Introduction

In automatic generation control (AGC) of interconnected power system puts the limelight towards the maintenance of system frequency within specified limits around the nominal value, to uphold the scheduled exchange of power between the interconnected areas and to keep each unit's generation at the most economic level. This requires the balance between the net generation and corresponding loads with losses. Many investigative research works exist in the past literature on AGC of isolated and interconnected systems. The idea of modeling multi-area interconnected power system has been presented by Elgerd and Fosha [1]. A performance comparison of several classical controllers, such as Integral (I), Proportional-Integral (PI), Integral-Derivative (ID), Proportional-Integral-Derivative (PID) and Integral-Double Derivative (IDD) have been carried out by Saikia et al. [2]. Their investigations reveal the superior performance of IDD controller in two, three and five area thermal systems. However, their studies are limited to single controllers where there is less number of tuning knob. If tuning knobs are more in a controller, there may be possibility of better result from that controller. A two degree of freedom (2DOF) controller named as 2DOF-PID has been introduced by Sahu et al. [3] in AGC. Later on, the performance of a new 2DOF controller named as 2DOF- Integral double derivative (2DOF-IDD) has been evaluated by Puja Dash et al. [4]. However, all the above controllers are non cascaded single controllers. In process control, many controllers and control strategies are available. These are suitable for controlling large-scale networked systems. In the controlling process, the controllers are either optimized by optimization techniques or self tuned with the help of different control strategies such as model predictive control (MPC), Smith predictor, etc. Yongho Lee et al. [5] proposed a method for PID controller tuning based on process models for cascaded control systems. Cheng et al. [6] have made application of two PID controllers in a cascade control system directly based on the process data collected from a one-shot plant and found it to be the best. Rather than cascade control, many other control approaches generally model based controls are commonly used in process control such as Neural network control [7], fuzzy based control [8], MPC [9,10], Smith predictor [13], etc. Saikia [7] has applied the multi layer perception neural network (MLPNN) controller using reinforcement learning in AGC of a three area thermal system. Chown and Hartman [8] has implemented the fuzzy controller in the control ACE (area con-

* Corresponding author. Tel.: +91 8822951213.
E-mail addresses: pujadash83@gmail.com (P. Dash), lcsaikia@yahoo.com (L.C. Saikia), nidulsinha@hotmail.com (N. Sinha).
[1] Tel.: +91 9435173835; fax: +91 3842 233797.

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Nomenclature

n	population size
N	number of generations
a	loudness
r	pulse rate
f	nominal system frequency (Hz)
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)
ΔP_{gi}	Incremental generation change in area i (p.u)
D_i	$\Delta P_{Di}/\Delta f_i$(pu/Hz)
T_{12}, T_{23}, T_{13}	synchronizing coefficients
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
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

T_{pi}	$2H_i/f^* D_i$
K_{pi}	$1/D_i$. (Hz/pu)
K_{Ii}	integral gain of PI, PID controller in area i
K_{Di}	derivative gain of PI, PID controller in area i
K_{Pi}	proportional gain of PI, PID controller in area i
K_{Iij}	integral gain of PID controller in area i, for $i = 1$, $j = 2$ (for $i \neq j$), 3)
K_{Pij}	integral gain of PID controller in area i, for $i = 1$, $j = 2$ (for $i \neq j$), 3)
K_{Dij}	integral gain of PID controller in area i, for $i = 1$, $j = 2$ (for $i \neq j$), 3)
β_i	(=$D_i + 1/R_i$), Area frequency response characteristics of area (AFRC) i
J	cost index ($J = \int_0^T \{(\Delta f_i)^2 + (\Delta P_{tie\,j-k})^2\} dt$), $j = 1, 2$, $k = 2$ (for $k \neq j$), 3)
T	simulation time (s)
Δf_i	incremental change in frequency of area i (Hz)
ΔP_{gi}	Incremental generation of area i (p.u);
$\Delta P_{tie\ i\text{-}j}$	incremental change in tie line power connecting between area i and area j (p.u)

trol error) calculation in AGC, which determines the shortfall or surplus generation that has to be corrected. MPC is a family of controllers in which there is a direct uses of an explicit certain model. It is also described as a class of computer control schemes that utilizes a process model [9,10]. In AGC, the MPC control technique has been applied successfully [11,12] to accomplish the desired control of frequency automatically. Venkat et al. [11] have designed a distributed model predictive control (MPC) framework for controlling of large-scale networked systems such as AGC of power systems. Liu et al. [12] has employed MPC to control load frequency of a non-reheat type two area thermal systems. The Smith predictor, another popular control in process industry is available in literature [13]. Smith predictor with cascade controller has been used in controlling the temperature of a gas furnace. As these model based controls have many advantages, also having some limitations such as (a) Modeling of error can essentially influence the performance of the controller, during the tuning of the controller the robustness properties of the resulted control loop must be considered, (b) Its derivation is more complex than the traditional PID controller. [9]. However, the advantages of these model based control processes dominate the limitations. Many research works are present in process control industry, where the performance of cascade controller is improved by incorporating with model predictive control [12], Smith predictor control techniques [13]. This review of literatures gives the limelight towards the heuristically optimized cascade controller which is simple to apply and is not yet investigated in AGC. Hence, this necessitates further investigation.

Many control and optimization, such as classical, optimal, fuzzy logic (FL), artificial neural networks (ANN), genetic algorithm, bacterial forging, particle swarm, DE, firefly algorithms (FA) are available and most of them are used in AGC. Classical technique is a trial and error method and in some cases yields suboptimal results and time consuming [14]. Some literatures exist about the application of supervised artificial neural networks [7,15] and some authors have used fuzzy logic (FL) controller [8,16] for achieving better performance in AGC. In case of FL controller, more computational time is required for rule base to be formed. In case of neural network, time required for training is more. Modern metaheuristic algorithms have been developed with an aim to carry out inclusive search, which cannot be solved by classical techniques. The efficiency of metaheuristic algorithms can be ascribed to the fact that they imitate the best features in nature, especially the selection of the fittest in biological systems, which have evolved by natural selection over millions of years. As given the features or nature of a particular problem, one type of search algorithm may prove to be more efficient than others in solving that particular problem, while the same algorithm may perform poorly in other problems. GA has been applied for optimization of controller gains [16] and recent research identified some of the deficiencies. To overcome the difficulties of local optimum methods, BF [17] technique is used by the researcher for optimization. In [17] the foraging behavior of bacteria is formulated as an optimization technique. Another metaheuristic algorithm, fire fly algorithm (FA) is developed by [18] and successfully applied in AGC of an isolated CCGT plant [19]. A more recent meta-heuristic search algorithm, Cuckoo search (CS) has been developed by Yang and Deb [20]. Cuckoo is a fascinating bird, for its beautiful sounds they can make and for their aggressive reproduction strategy. Ani and Guira, species of cuckoos lay their eggs in communal nests, though they may remove others' eggs to increase the hatching probability of their own eggs [21]. Quite a number of species engage the obligate brood parasitism by laying their eggs in the nests of other host birds (often other species). CS algorithm is based on the obligate brood parasitic behavior of some cuckoo species in combination with the Lévy flight behavior. The cuckoo's follow three basic types of brood parasitism such as Intraspecific brood parasitism, Cooperative breeding, and Nest takeover. CS algorithm follows three idealized rules. They are (a) Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest, (b) The best nests with high quality of eggs (solutions) will carry over to the next generations, (c) The number of available host nests is fixed, and a host can discover an alien egg with a probability pa $\in$ [0,1]. This powerful algorithm has been proved its fast and accurate optimization proficiency in various relevance grounds [21]. Tan et al. [22] used the CS algorithm for allocation and sizing of DG. Yildiz [23] has tested this CS algorithm for the selection of optimal machining parameters in milling operations, and has got a superior conclusion, where Bhandari et al. has applied the CS algorithm for satellite image contrast and brightness enhancement using [24]. Dash et al. [4,25] used CS for optimization of 2DOF-IDD controller gains in multi area thermal systems. Nguyen et al. [26] used the CS algorithm for solving short-term hydrothermal scheduling problem. A