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Automatic generation control of a multi-area system using ant lion optimizer algorithm based PID plus second order derivative controller

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ABSTRACT

This article presents the automatic generation control of an unequal three area thermal system. Single stage reheat turbines and generation rate constraints of 3%/min are considered in each control area. Controllers such as Integral (I), Proportional – Integral (PI), Proportional – Integral – Derivative (PID), and Proportional – Integral – Derivative Plus Second Order Derivative (PID + DD) are treated as secondary controllers separately. A nature inspired optimization technique called Ant Lion Optimizer (ALO) algorithm is used for simultaneous optimization of the controller gains. Comparison of dynamic responses of frequencies and tie line powers corresponding to ALO optimized I, PI, PID and PID + DD controller reveal the better performance of PID + DD controller in terms of lesser settling time, peak overshoots as well as reduced oscillations. Robustness of the optimum gains of best controller obtained at nominal conditions is evaluated using sensitivity analysis. Analysis exposed that the optimum PID + DD controller gains obtained at nominal are robust and not necessary to reset again for changes in loading, parameter like inertia constant (*H*), size and position of disturbance. Furthermore, the performance of PID + DD controller is found better as compared to PID controller against random loading pattern condition.

Introduction

As the complexity of the power system is increasing day by day, it is necessary to maintain the frequency and tie line powers within their pre specified limits in order to keep the interconnected system reliable and secure. Whenever there is a change in loading on power system, frequency and tie line powers deviates from their nominal or scheduled values, which is undesirable and may lead to unsuccessful operation of the power system. Hence the continuous monitoring between load demand and generation is required, which is called as load frequency control (LFC) or Automatic Generation Control (AGC), keeps Area Control error (ACE) to zero. ACE is the term used to represent the deviations in both frequency and tie line powers as a linear combination, which is given by (1).

$$ACE_i = \Delta P_{tie\ j-k} + B_i \Delta f_i \tag{1}$$

where suffixes i, j represent areas (i = 1, 2, 3 and j = 1, 2, k = 2 (for $k \neq j$), 3) and B_i (bias factor of area i) = β_i (area frequency response characteristics (AFRC) of area i). From literature survey, it can be observed that LFC issue is studied in both isolated as well as inter connected power systems [1–11]. Wang et al. [1] studied AGC in single area power system with generation rate constraints (GRC). The concept of multi area modelling of interconnected system through tie line is proposed by Elgerd et al. [2]. Researchers in [3–5] carried out AGC study of two area interconnected power system with help of model proposed in [2]. Recent research is centered on AGC of an interconnected system whose controlling areas are more than two [6,8,12,13].

For the smoother control of frequency, apart from speed governing system, one can go for the secondary controller which can guarantee zero ACE. AGC of an interconnected system with Integral and Proportional – Integral (PI) controllers is presented in Ref. [4]. Authors in [6,7] presented AGC with Proportional – Integral – Derivative (PID) controller. Saikia et al. [8] introduced a new classical controller, Integral plus double derivative (IDD) and proved IDD controller superiority over Integral (I), Proportional-Integral (PI), Proportional – Integral – derivative (PID) and Integral – Derivative (ID) controllers. Sahu et al. [9] introduced two degree of freedom Proportional – Integral – Derivative (2 DOF – PID) controller in AGC [9]. Alomoush [10] investigated AGC of isolated and interconnected system with both integer order (IO) as well as fractional order (FO) controllers and concluded the better performance of FO controllers over IO controllers. Intelligent techniques such as fuzzy logic and neural networks are also applied to investigate AGC

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Nomenclature

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)
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 Integral, PI, PID and PID + DD controllers in area i
K_{Pi}	proportional gain of PI, PID and PID + DD controller in area i
K_{Di}	derivative gain of PID and PID + DD controllers in area i
K_{DDi}	double derivative gain of PID + DD controller in area i
β_i	area frequency response characteristics (AFRC) of area i (=$D_i + 1/R_i$)
J	cost index $\left(J = \int_0^T \left\{(\Delta f_i)^2 + (\Delta P_{tie\ j-k})^2\right\}dt\right)$, $j = 1, 2$, $k = 2$ (for $k \neq j$), 3
T	simulation time (s)
PI	π
Δf_i	incremental change in frequency of area i (Hz)
$\Delta P_{tie\ i-j}$	incremental change in tie line power connecting between area i and area j (p.u)
w	constant based on iterations
n	number of ants (population size)
t	step of random walk

issue [11,12]. Sahu et al. [11] presented fuzzy logic PI controller to AGC of two area system where as Kuntia et al. applied neural network approach to study multi area AGC [12]. The drawbacks of fuzzy logic and neural networks such as time consuming in different stages like formation of rule base and training the neural network are pointed out in [13]. Recently, in [14] authors applied a new controller called PID plus second order derivative (PID + DD) controller to Automatic Voltage Regulator (AVR) system and proved better performance over PID and fractional order PID (FOPID) controllers. PID + DD controller also proved its robustness against model uncertainties of AVR system. Surprisingly, PID + DD controller is not presented to study AGC problem. This needs further investigations.

ACE effectively will become zero if and only if the controller gains are optimized properly. Initially to select controller gains classical method was used. Classical technique is a trial and error method and inefficient. Later on researchers used population based algorithms or optimization techniques in order to obtain the suitable values of the controller gains. The population based algorithms evolves in different stages through generations to find the fittest best solution. However particular optimization technique may perform better in solving a specific problem where as other algorithm may not. Different optimization techniques such as Genetic Algorithm (GA) [15], Particle Swarm Optimization (PSO) [16], hybrid Particle Swarm Optimization and Pattern Search (hybrid PSO and PS) [11], Differential Evolution (DE) [9], Artificial Bee Colony (ABC) [17], Bacterial Foraging Optimization (BFO) [18], Gravitational Search Algorithm (GSA) [7], Fire fly algorithm (FA) [13], hybrid firefly algorithm and pattern search (hybrid FA and PS) [19], Cuckoo Search (CS) [20], and Bat Algorithm (BA)

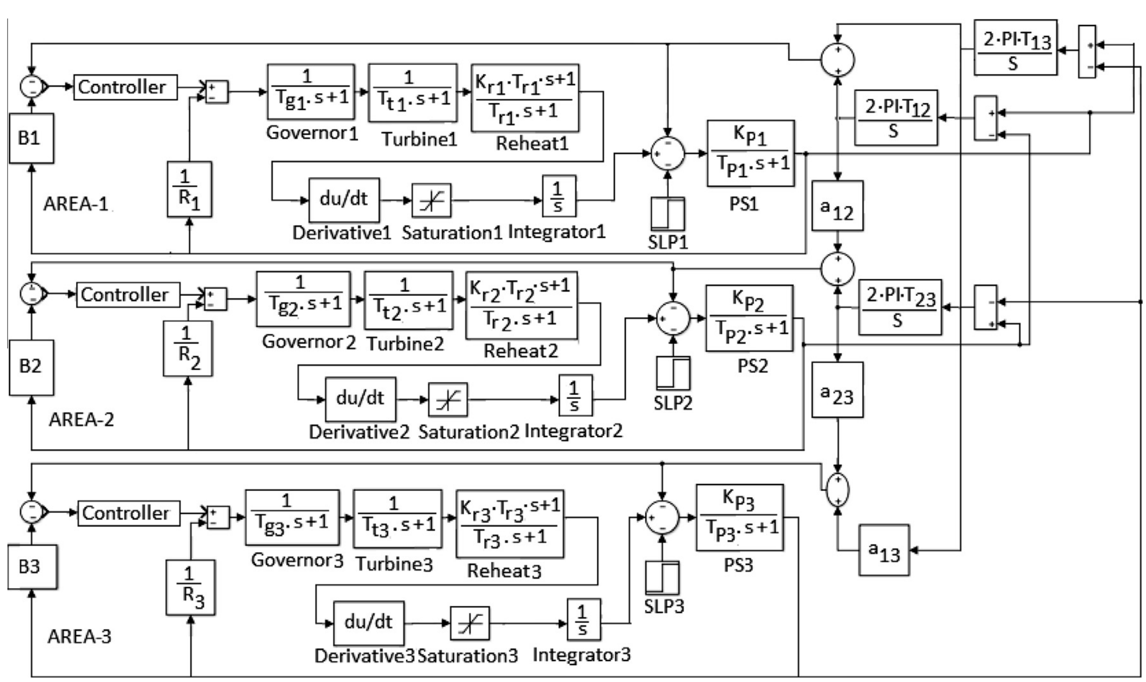

Fig. 1. Transfer function model of interconnected three area thermal system.