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Maiden application of bacterial foraging based fuzzy IDD controller in AGC of a multi-area hydrothermal system

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This paper dealt with the automatic generation control of an unequal multi-area hydrothermal system. The performance of several classical controllers such as integral (I), proportional–integral (PI), proportional–integral–derivative (PID) and integral–double derivative (IDD) are compared, and it is found that IDD controller gives better performance over the other controllers. A maiden application of Bacterial Foraging (BF) optimized fuzzy integral–double derivative (FIDD) controller has been made in the system. Comparison of the dynamic responses of the system for FIDD and IDD reveals that FIDD controller gives better dynamic performance than the later. Sensitivity analysis has been performed to find the robustness of the FIDD controller for wide change in loading. Simultaneous optimization of IDD controller gains (K_I and K_D) and speed regulation parameters (R) by BF technique which surprisingly has not been attempted in the past for the system provides not only the best dynamic response for the system but also provides higher values of R, that will appeal for easier and cheaper realization of the governor.

1. Introduction

Large scale power systems are divided into numbers of coherent areas and they are interconnected through tie lines to facilitate for contractual power exchange among them. This interconnected system also provides the inter-area support during the abnormal operations. The tie line power and system frequency changes due to change in loading, change in parameters of the system and any other abnormal conditions. Many investigations [1–22] in the area of automatic generation control (AGC) of interconnected power system have been reported in the past. Many of them are associated with AGC of two equal area thermal systems. Since practical interconnected systems are multi-area and most of the cases hydrothermal. Surprisingly little attention has been paid to multi-area hydrothermal system. In most of the earlier literatures [1–10] some common classical controllers such as integral (I), proportional plus integral (PI), integral plus derivative (ID) and proportional plus integral plus derivative (PID) have been used. The performance of I, PI, ID, PID and integral–double derivative (IDD) are tried and their performances compared so as to assess the best controller in [10]. But their investigations limited to thermal system only. How these classical controllers perform in multi-area hydrothermal system? Literature survey does not provide any answer to this question.

An I or PI or ID or PID or IDD controller optimized at a particular operating condition may not perform satisfactorily when there is a change in operating condition [3]. Moreover, the non-linear nature of AGC problem makes it difficult to ensure stability at all operating conditions with classical integral or PI or PID controllers being optimized at a particular operating condition [4]. Some investigations have been carried out using fuzzy logic controller (FLC) [13–18] and artificial neural network (ANN) controller [17–19] for better dynamic performance in the AGC system. Fuzzy Integral, Fuzzy PI and Fuzzy PID controllers have been discussed in [14–16]. But, no literature reported in the past concerned with Fuzzy integral plus double derivative controller (FIDD).

Only two techniques namely genetic algorithm (GA) and classical technique based on integral square error (ISE) are used in the earlier literatures in AGC for the design of Fuzzy integral, Fuzzy PI and Fuzzy PID controllers. GA explores many search space rather than single region effectively and hence it is less sensitive to local minimum as compared to conventional approach and GA manipulates the representation of potential solution, rather than the solutions itself [7]. Only two operations such as cross over and mutation are performed to overcome the possibility of being trapped into local minimum in GA. Some of deficiencies in GA performance, like premature convergence which again degrades its efficiency and reduces the search capability has been pointed out in [7]. Some of the search techniques like Bacterial Foraging technique (BF) [7,8], Particle Swarm optimization (PSO), etc. are also available [9,11] for optimization of several parameters. PSO is developed through simulation of bird flocking in

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Nomenclature

f	nominal system frequency (Hz)
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_{gi}	incremental generation change in area i (p.u)
D_i	$\Delta P_{Di}/\Delta f_i$ (p.u/Hz)
T_{12}, T_{23}, T_{13}	synchronizing coefficients
R_i	governor 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
T_{pi}	$2H_i/(f \times D_i)$
K_{pi}	$1/D_i$ (Hz/p.u)
β_i	area frequency response characteristics of area i ($=D_i + 1/R_i$)
T_w	water starting time for hydro turbine (s)
Δf_i	incremental change in frequency of area i (Hz)
ΔP_{gi}	incremental generation of area i (p.u)
$\Delta P_{tie\ i-j}$	incremental change in tie line power connecting between area i and area j (p.u)
K_d, K_p, K_i	electric governor derivative, proportional, and integral gains respectively
p	number of parameters to be optimized
S	number of bacteria
N_S	swimming length after which tumbling of bacteria will be undertaken in a chemotactic loop
N_C	number of iterations to be undertaken in a chemotactic loop ($N_C > N_S$)
N_{re}	maximum number of reproduction to be undertaken
N_{ed}	maximum number of elimination and dispersal events
P_{ed}	probability with which elimination and dispersal will continue

multi-dimensional space. Like GA, PSO is also less susceptible to getting trapped on local optimum [12]. The authors in [12] have shown that performance of BF is better than PSO in terms of convergence, robustness and precision. Though, both BF and PSO techniques are used for optimization of secondary controller gains and some other parameters in AGC [7–9], surprisingly they are not used for design of any Fuzzy logic controller which needs further investigations.

In almost all the past literature on Fuzzy logic controller in AGC, more attention has been paid to the design of the controller but never investigate the controller performance in different loading conditions which are generally occurs in the system.

Almost all the past works centred on the design of secondary or supplementary controllers and surprisingly little attention have been paid to the design of primary controller, i.e., selection of proper governor speed regulation parameters (R). It is known that with only primary control (i.e. secondary or supplementary control absent) the smaller the governor drop the smaller the steady state error in frequency but in the presence of supplementary control there is nothing to be sacrosanct about a small governor droop (of the order of 4–6% used in practice) and for any large but credible value of R, zero steady state error in frequency is guaranteed. A few works [5–7,10] have been reported to an extent selection of governor speed regulation parameter R. A comprehensive approach or optimization procedure has been provided for selection of suitable value of R in [7] using BF technique. But till date no such investigations have been (i.e., optimization of R parameters) done in multi-area area hydrothermal system. In view of the above, the objectives of the present works are

(a) Optimization of classical I, PI, PID, IDD controllers gains using BF technique with $R_i = 2.4$ in multi-area hydrothermal system and to Comparison of dynamic responses for the above controllers to get the best controllers.
(b) Design of a new bacterial foraging optimized fuzzy logic controller named as fuzzy logic based integral double derivative (FIDD) controller and to compare the dynamic responses of the system for the best classical controller found in (a) and FIDD controller.
(c) Sensitivity analysis of the IDD and FIDD controller in the system investigated for different loading conditions.
(d) Simultaneous optimization of IDD controller gains and R parameters to obtain better dynamic performance and for easier and cheaper realization of the governor.

2. System investigated

Investigations have been carried out on a three unequal area hydro-thermal system of area 1: 2000 MW, area 2: 6000 MW, area 3:10,000 MW. The area 1 and area 2 are thermal systems and area 3 is a hydro system provided with electric governor. Thermal areas are provided with single reheat turbine. Generation rate constraints (GRC) of 3% per minute in thermal areas and 270% per minute for raising and 360% per minute for lowering generation in hydro area are considered. The optimum values of integral gain K_i, proportional gain K_p and derivative gain K_d of electric governor and other parameters of hydro area are taken from [6] and the nominal parameters of the thermal systems are taken from [10] and given in Appendix. The classical controllers like I, PI, PID and IDD are considered separately with the system. The classical controllers are replaced by FIDD controller to study the dynamic performances. Per unit values of different parameters of the three unequal areas are considered to be same on their respective bases. Hence, while modeling interconnected areas of different capacities, a parameter $a_{12} = -P_{r1}/P_{r2}$, $a_{23} = -P_{r2}/P_{r3}$ and $a_{13} = -P_{r1}/P_{r3}$ are considered in the three area system. The transfer function model of the system with FIDD controller is shown in Fig. 1. The system dynamic performance is evaluated by considering 1% step load perturbation (SLP) in area 1.

3. Bacterial foraging optimization technique

Bacterial Foraging (BF) technique is a powerful evolutionary optimization technique proposed by Passino [23] in which the number of parameters that are used for searching the total solution space is much higher compared to those in GA. In BF technique, the foraging behavior of *Escherichia coli* bacteria present in our intestine is mimicked. The control system of these bacteria that dictates how foraging should proceed can be subdivided into four sections namely chemotaxis, Swarming, Reproduction and Elimination and dispersal.