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Load frequency controller design via BAT algorithm for nonlinear interconnected power system

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ABSTRACT

BAT algorithm is proposed in this paper for optimal tuning of PI controllers for load frequency controller (LFC) design. The problem of robustly tuning of PI based LFC design is formulated as an optimization problem according to time domain objective function that is solved by BAT algorithm to find the most optimistic results. To demonstrate the effectiveness of the proposed method, a two-area interconnected power system is considered as a tested system. To ensure robustness of the proposed control strategy to stabilize frequency oscillations, the design process takes a wide range of operating conditions and system nonlinearities into account. The simulation results are given to detect the superiority of BAT algorithm over Simulated Annealing (SA) in tuning PI controller parameters through different indices. Results evaluation show that the proposed algorithm achieves good robust performance for wide range of system parameters and load changes compared with SA.

Introduction

In the large scale electric power systems with interconnected areas, Load Frequency Control (LFC) plays an important role. The LFC is aimed to maintain the system frequency of each area and the inter-area tie line power within tolerable limits to deal with the fluctuation of load demands and system disturbances [1,2]. These important functions are delegated to LFC due to the fact that a well-designed power system should keep voltage and frequency in scheduled range while providing an acceptable level of power quality [3,4].

During the last decades several researches and techniques had been applied to the field of LFC. Robust control [5–12], pole placement approach [13,14], variable structure control [15], and state feedback [16], are used to deal with LFC problem design. These strategies have some disadvantages such as high order controller, difficulty, complexity and inapplicable to implement. In an effort to overcome aforementioned disadvantages, several researches have used Artificial Intelligence (AI) approaches such as Fuzzy Logic Controller (FLC) [17–23] and Artificial Neural Network (ANN) [24–27]. Although these methods are effective in dealing with the nonlinear characteristics of power system, they require extensive computation. For example, FLC has to deal with fuzzification, rule base storage, inference mechanism, and defuzzification operations. For ANN, the large amount of data required for training are a major source of constraint. Clearly, a low-cost processor cannot be employed in such a system.

An alternative approach is to employ Evolutionary Algorithm (EA) techniques. Due to its ability to handle nonlinear objective functions, EA is visualized to be very effective to deal with LFC problem. Among the EA techniques, Genetic Algorithm (GA) [28–33], Particle Swarm Optimization (PSO) [34–38], Ant Colony Optimization (ACO) [39], Bacteria Foraging (BF) [40–44] and Artificial Bee Colony (ABC) [45,46] have attracted the attention in LFC controller design. However, these algorithms appear to be effective for the design problem, they pain from slow convergence in refined search stage, weak local search ability and may lead to possible entrapment in local minimum solutions. Recently, a new evolutionary computation algorithm, called BAT algorithm has been presented by [47] and further established recently by [48–53]. It is a very simple and robust population based optimization algorithm. Moreover, it requires less control parameters to be tuned. Hence, it is suitable optimization tool for power system controller design.

This paper proposes BAT algorithm for optimal tuning of PI controllers. The motivation behind this research is to ensure and prove the robustness of BAT based PI controller in enhancing the performance of both frequency deviation and tie line power under various loading conditions in presence of system nonlinearities.

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Nomenclature

f	the system frequency in Hz
i	subscript referring to area ($i = 1, 2$)
R_i	the regulation constant (Hz/p.u MW) for area i
T_{gi}	the speed governor time constant in second for area i
T_{ti}	the turbine time constant in second for area i
T_{ri}	the reheat time constant in second for area i
K_{ri}	the p.u megawatt rating of high pressure stage for area i
T_w	the hydro turbine time constant
T_{Pi}, K_{Pi}	the time constant and gain of power system respectively for area i
$\Delta Ptie_i$	the difference between the actual tie-line power and scheduled one
B	the biasing factor in pu MW/Hz
K_{PPi}, K_{IIi}	the gains of PI controller of area i
N	the number of area in power systems
tsim	the simulation time in second
t	time in second
T_{ij}	synchronizing coefficient
J	objective function
U_i	the control signal of area i
K_i	the controller of area i
K_{PPi}^{min}, K_{PPi}^{max}	the lower and the upper limit of proportional gain of area i
K_{IIi}^{min}, K_{IIi}^{max}	the lower and the upper limit of Integral gain of area i
x_i	the position of each bat
v_i	the velocity of each bat
L^t	the mean loudness
x_i^t	the new position
v_i^t	the new velocity
F_{min}, F_{max}	the minimum and maximum frequency

List of abbreviations

LFC	load frequency control
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
AI	Artificial Intelligence
FLC	Fuzzy Logic Controller
ANN	Artificial Neural Network
ACO	Ant Colony Optimization
BF	Bacteria Foraging
ABC	Artificial Bee Colony
PI	Proportional plus Integral
GRC	Generation Rate Constraint
ACE	Area Control Error
IAE	the Integral of Absolute value of the Error
ITAE	the Integral of the Time multiplied Absolute value of the Error
ISE	the Integral of Square Error
ITSE	the Integral of Time multiply Square Error

Two area power system

A two area model of a hydrothermal power station including nonlinearities is shown in Fig. 1. Area 1 is reheat thermal system and area 2 is a hydro system [39]. The steam chest time constant which is related to the non-reheat stage ranges from 0.1 to 0.5 s whereas the time constant for the reheat stage ranges from 4 to 10 s. Nonlinearities are represented in Generation Rate Constraint (GRC) and governor dead band. The first one as its name implies GRC that illustrates the limitation on the generation rate due to the limitation of thermal and mechanical movements [4], for thermal stations it is taken to be 0.1 pu Mw per minute. The second

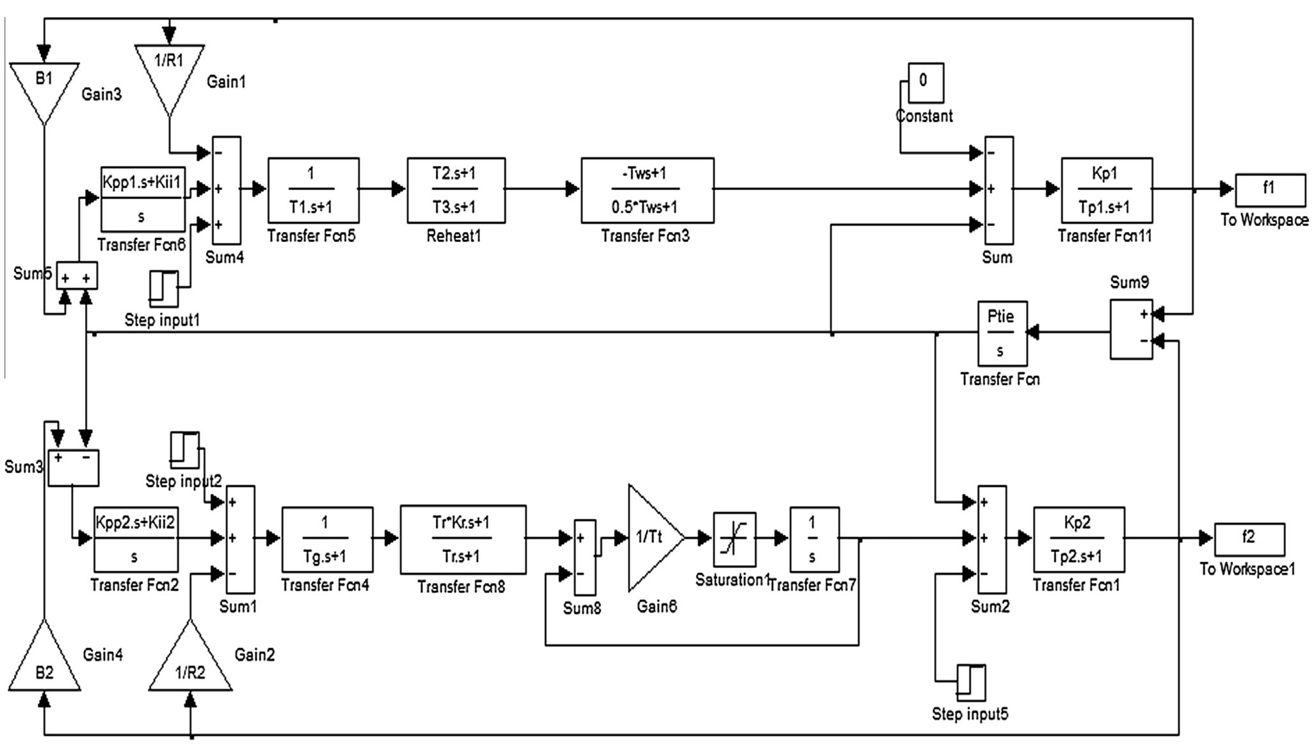

Fig. 1. Block diagram of two area system.