Electrical Power and Energy Systems 73 (2015) 787–804

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Automatic generation control of power system using a novel quasi-oppositional harmony search algorithm

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ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form 25 May 2015
Accepted 26 May 2015
Available online 21 June 2015

Keywords:
Automatic generation control
Generation rate constraint
Governor dead band
Interconnected power system
Optimization
Proportional–integral–derivative controller

ABSTRACT

The present work approaches a novel quasi-oppositional harmony search (QOHS) algorithm, as an optimization technique, for its optimum performance in the subject area of automatic generation control (AGC) of power system. The proposed QOHS algorithm is applied with an aim to converge rapidly towards the optimal solution(s) that houses both the characters of two guesses, i.e. opposite-point and quasi-opposite point. The area of concern of this study is to discuss the multi-objective problems of an interconnected power system for the benefits of AGC. The proposed QOHS algorithm is, individually, applied to single-area, precede to two-area considering the non-linearity effects of governor dead band and generation rate constraint and, finally, extended to four-area power system showing the consequences of multiple load disturbances. A case of robustness and stability analysis are also investigated for the studied two-area power system model. The control strategy, for the dynamic power system model, is based on area control error. The simplicity of the structure and acceptability responses of the well-known proportional–integral–derivative controller enforces to implement as a controller in this work. The comparative evaluation of the proposed QOHS algorithm is carried out by the way of comparing the dynamic performances of the studied power system model with those offered by other algorithms reported in the recent state-of-the-art literature. The simulation works, presented in the paper, reveal that the proposed QOHS algorithm may be effectively utilized for the purpose of AGC study of power system having varying degrees of complexities and non-linearities. Moreover, the proposed QOHS based control strategy adopted in this work provides a robust and stable speed control mechanism.

Introduction

General

In power system dynamics, the control of generation and frequency is the most important issue for its reliable operation [1]. The term frequency of a power system is dependent on active power balance and, hence, a change in active power at one point reflects the system operation at some other points. A considerable drop in frequency may result in high magnetizing currents in ac motors and transformers [2]. The other problem for interconnected power system is power exchange among control areas which may result in frequency deviation from its nominal one. Automatic generation control (AGC) performs a continuous real-time task to adjust the power generation economically with active focus on frequency control. The main issues regarding AGC are (a) the time-variant characteristics of power system, (b) an uncertainty in increase of load demand during the whole day and (c) generation losses which may change in operating point of power system [3].

Literature review

An initial attempt in the area of AGC subject has been to control the frequency deviation of power system via a flywheel governor of synchronous machine [4]. This technique was not sufficient to control the frequency deviation at the instant application of load demand. For the first time, it was apprehended that a supplementary action (i.e. load frequency controller) must be needed for stable speed control mechanism. This concept constitutes the classical approaches to the AGC of power system. An early work with the supplementary controller has been suggested by Cohn [5] which was based on tie-line bias control strategy. The first classified optimal control theory has been initiated by Fosha and Elgard [6]. In their work, they have proposed classical linear

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http://dx.doi.org/10.1016/j.ijepes.2015.05.048
0142-0615/

Nomenclature

ACE	area control error
B_i	frequency bias constant of *i*th area (p.u.MW/Hz)
c	portion (percentage) of power generated by the reheat process in the total generated power
D_i	frequency dependency parameter of *i*th area (p.u.MW/Hz)
H_i	inertia constant of *i*th area (s)
i	subscript referred to *i*th area
K_{pi}	power system gain constant of *i*th area (Hz/p.u.MW)
K_{ri}	reheat gain constant of *i*th area
R_i	speed regulation parameter of *i*th area (Hz/p.u.MW)
T_{gi}	governor time constant of *i*th area (s)
T_{pi}	power system time constant of *i*th area (s)
T_{ri}	reheat time constant of *i*th area (s)
T_{ti}	turbine time constant of *i*th area (s)
Δf_i	incremental change in frequency of *i*th area (Hz)
ΔP_{tiei}	incremental change in tie-line power flow of *i*th area (p.u.MW)
ΔP_{di}	incremental change in load demand of *i*th area (p.u.MW)

control theory based on state variables and developed different feedback theories for the design of AGC regulator.

Over the years, a number of evolutionary computational intelligence-based techniques have been developed as well as employed in the AGC study of power system. Pataya and Vichit [7] have proposed genetic algorithm (GA) based intelligent controller for AGC design strategy. Ghoshal [8] has proposed GA/GA-SA based fuzzy AGC scheme for multi-area thermal generating system. Denna et al. [9] have presented an automatic definition of fuzzy rules based on Tabu search algorithm (TSA) for AGC design. The concepts based on reinforcement learning have been suggested by Imthias et al. [10] for AGC mechanism as a stochastic multistage decision problem. In [11], particle swarm optimization (PSO) algorithm has been proposed for optimization of proportional-integral-derivative (PID) gains in a fuzzy based AGC system. An application of TSA has been presented by Pathiya et al. in [12] for AGC design of a two-area power system. The design of multi-objective PID controller, optimized by PSO for AGC study of power system, may be found in [13]. The utilization of PSO based multi-stage fuzzy controller has been incorporated in [14] for the AGC study. A modified GA based proportional-integral (PI) controller has been appeared in [15] for interconnected power system including the effects of generation rate constraint (GRC) and governor dead band. Nanda et al. [16] have proposed bacterial foraging optimization algorithm (BFOA) for multi-area AGC system. The PI and integral controller gains have been tuned by hybrid PSO for deregulated power system in [17]. In [18], BFOA has been adopted for the tuning of PI controller gains for the AGC study of two-area power system. A novel gain scheduling control strategy, based on craziness based PSO (CRAZYPSO), have been adopted by Gozde and Taplamacioglu in [19] for AGC application. Gozde et al. [20] have proposed artificial bee colony algorithm in AGC study of reheat thermal power system. Shabani et al. [21] have adopted imperialist competitive algorithm for the design of robust PID controller for resistance to continuous load disturbances. An application of non-dominating sorting GA for AGC study of multi-area power system may be found in [22]. Panda et al. [23] have employed BFOA-PSO for the AGC study of linear and non-linear interconnected power system.

Literature survey reveals that a number of evolutionary optimization techniques are being employed by the researcher pools in the conventional vertical integrated utility model to study its importance in AGC performance. These optimization techniques have shown substantial improvement in AGC performance of power system leaving behind some drawbacks those have been further rectified by some other applied techniques. The possibility of exploring some new hybrid optimization techniques is still prevailing for the benefits of AGC performance, especially, by the way of optimal tuning of controller gains. Therefore, it is justified that optimization techniques may be, significantly, explored in AGC domain and might become an integral part for the design of AGC controller.

Motivation behind the present work

Most of the solutions, surfaced in the literature so far for AGC mechanism, have shown improved results. However, it does not mean that these methods have not any limitations. During the evolution of some new optimization techniques, a number of limitations and problems have been found. The identified deficiencies in GA are (a) the involvement of lots of crossover and mutation operation in each iteration cycle, (b) taking more overall execution time and (c) exhibiting premature convergence, i.e. trapping into local minima [8,15]. PSO is developed through the simulation of bird flocking in multi-dimensional search space. Empirical studies, performed on PSO, indicate that even when the maximum velocity and acceleration constant are correctly defined, the particles may still diverge, i.e. go to infinity; a phenomena known as "*explosion*" of the swarm. Relay based identification technique needs extensive mathematical calculations in order to obtain the optimal solution. The final solution is approximated value rather than true optimal one. The basis of calculation of this method is supported by Laurent series expansion. BFOA is based on chemotactic movement of virtual bacterium models, i.e. instituted by a trial solution of the optimization problem. During the process of chemotactic, the performance of BFOA depends on random search direction that may lead to delay in reaching the global solutions. Also, the numbers of BFOA parameters, as used for searching the total solution space, are higher than GA and, hence, the possibility of trapping into local minima is higher than GA.

However, harmony search (HS) algorithm (HSA) is a derivative-free real-parameter optimization method [24]. HSA is one of the most recent population based optimization method that may be easily adopted for solving various kinds of engineering optimization problems [25]. It generates a new vector after considering all of the existing vectors whereas GA considers only the two parent vectors.

A few modified variants of HSA have been also proposed for enhancing its solution accuracy and convergence rate. Mahdavi et al. [26] have presented an improved HSA by introducing a strategy to, dynamically, tune the key parameters. Omran and Mahdavi [27] have proposed a global best HSA by borrowing the concept from the swarm intelligence. Pan et al. [28] have proposed a self-adaptive global best HSA for solving continuous optimization problems. Banerjee et al. [29] have proposed opposition-based HSA for engineering optimization problem with special emphasis on reactive power compensation of an autonomous hybrid power system model.