ARTICLE IN PRESS

Engineering Science and Technology, an International Journal xxx (2016) xxx–xxx

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

Full Length Article

Load frequency control of large scale power system using quasi-oppositional grey wolf optimization algorithm

Dipayan Guha [a,*], Provas Kumar Roy [b], Subrata Banerjee [c]

[a] Department of Electrical Engineering, Dr. B.C.Roy Engineering College, Durgapur, West Bengal, India
[b] Department of Electrical Engineering, Jalpaiguri Government Engineering College, Jalpaiguri, West Bengal, India
[c] Department of Electrical Engineering, National Institute of Technology, Durgapur, West Bengal, India

ARTICLE INFO

Article history:
Received 2 August 2015
Revised 14 May 2016
Accepted 6 July 2016
Available online xxxx

Keywords:
Load frequency control
Grey wolf optimization
Oppositional based learning
Quasi-oppositional based learning
Sensitivity analysis

ABSTRACT

This article presents a newly developed, novel and efficient optimization technique called quasi-oppositional grey wolf optimization algorithm (QOGWO) for the first time to solve load frequency control problem (LFC) of a power system. Grey wolf optimization (GWO) is a recently developed meta-heuristic optimization technique based on the effect of leadership hierarchy and hunting mechanism of wolves in nature. Two widely employed test systems; viz. two-area hydro-thermal and four-area hydro-thermal power plant, are considered to establish the effectiveness of the proposed QOGWO algorithm. Optimal proportional-integral-derivative controller (PID) is designed for each area separately using proposed algorithm employing integral time absolute error (ITAE) based fitness function. The validity of proposed QOGWO method is tangibly verified by comparing its simulation results with those of GWO and other approaches available in the literature. Time domain simulation results confirm the potentiality and efficacy of the proposed QOGWO method over other intelligent methods like fuzzy logic, artificial neural network (ANN) and adaptive neuro-fuzzy interface system (ANFIS) controller. Finally, sensitivity analysis is performed to show the robustness of the designed controller under different uncertainty conditions.

1. Introduction

Stable operation of power system requires matching between total generation with total load demand and with accompanying system losses. Due to rising and falling of load demand, the real and reactive power balance is disturbed, resulting deviation of system frequency and tie-line interchange power from their scheduled value. High deviation of system frequency may lead to system collapse. This encourages designing of an accurate, effective and fast controller in power system called load frequency controller (LFC) to maintain system parameters, i.e. area frequency, and tie-line interchange power, at their predefined values. LFC is one of the most profitable ancillary services to be maintained for the smooth and secure operation of power system [1,2]. The objective of LFC is to diminish transient deviations of area frequency and tie-line interchange power and to confirm their steady state errors to be zeros. In today's scenario, LFC is one of the most prominent issues for supplying sufficient and reliable electric power with good quality to the customers and is becoming much more significant in accordance with increasing size of power system unit, changing of structure and drastic change in load demand. The main functions of load frequency controller are as follows [3]:

1. The steady state frequency error following a step load change should vanish. The transient frequency and time errors should be small.
2. The static change in tie-line power following a step load perturbation in any area should be zero, provided each area can accommodate its own load change.
3. Any area in need of power during any emergency should assist from others.

During the last few decades, various control strategies based on classical controllers [4–10], adaptive controller [11], robust controller [12], intelligent controllers including neural network [1,2,13], fuzzy logic [14–16], H_∞ controller [17], fractional order controller [18], internal model control [19], hybrid neuro-fuzzy controller [20] etc. have been demonstrated to maintain the system frequency and tie-line interchange power at their nominal value under normal and disturbed conditions. In [6], several classical controllers' structure like integral (I), proportional integral (PI),

* Corresponding author.
E-mail address: guha.dipayan@yahoo.com (D. Guha).

Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.07.004
2215-0986/

Please cite this article in press as: D. Guha et al., Load frequency control of large scale power system using quasi-oppositional grey wolf optimization algorithm, Eng. Sci. Tech., Int. J. (2016), http://dx.doi.org/10.1016/j.jestch.2016.07.004

integral derivative (ID), proportional integral derivative (PID) and integral double derivative (IDD) were implemented and their comparative performances for the LFC system have been presented. Oysal [11] proposed dynamic neural network (DNN) model for adaptive LFC design in power systems. In [18], authors have designed an optimal fractional order PI and PID controller to improve the dynamic stability of automatic generation control (AGC) system employing integral time absolute error (ITAE) based performance index. Internal model control scheme with model order reduction technique was elaborated in [19]. A hybrid neuro-fuzzy controller was suggested in [20] as a supplementary controller to solve LFC problem in a restructured environment of the power system. Although the aforesaid methods improve the dynamic stability of power system, they require extensive computation. Moreover, high order, complexity, a requirement of large training data set, defuzzification operations, inference mechanism etc. makes the controller inapplicable for the real-time implementation. Recently, the effect of redox flow batteries in LFC of multi-area power system has been investigated in [21].

It is perceived in the power system that parameter values in the various power generating units, viz. governors, turbines, generators etc., are endlessly varying w.r.t time subject to system and power flow condition. Thus, the controller parameters design at normal operation may not able to give satisfactory performance under external disturbed and/or parameter uncertainty condition. To ensure robustness and to preserve the system stability, various populations based meta-heuristic optimization techniques such as particle swarm optimization (PSO) [22], genetic algorithm (GA) [23], biogeography-based optimization (BBO) [24,25], krill herd algorithm (KHA) [26], teaching learning based optimization (TLBO) [27,28], bacteria foraging optimization (BFOA) [7], gravitational search algorithm (GSA) [29], hybrid PSO-pattern search (hPSO-PS) algorithm [30], hybrid FA-PS [31], Tabu search algorithm (TSA) [32], quasi-oppositional harmony search algorithm (QOHSA) [33,34], BAT algorithm [35], backtracking search algorithm (BSA) [36], were proposed in the literature. Padhan et al. [4] have designed an optimal LFC by employing firefly algorithm (FA) and showed its superiority over other similar optimization techniques. Nanda et al. [6] demonstrated that BFOA has better tuning ability than GA and Zeigler–Nichols (ZN) based controller for an interconnected power system. An improved PSO algorithm was elaborated in [8] for a nonlinear multi-area hybrid power system comprising thermal-hydro-gas power plant. In [9], lozi map chaotic optimization algorithm was proposed for the design of PID-controller to solve LFC problem in power system. In [24,25], BBO algorithm was successfully designed and applied to a nonlinear interconnected power system and showed its superiority over other optimization methods. However, the performance of BBO is highly determined by the maximum emigration and immigration rate, mutation probability, the step size of integration, habitat modification probability etc. Guha et al. [26] have offered KHA for multi-area power system considering flexible alternating current transmission system (FACTS) controller. A tabu search algorithm (TSA) for finding the optimal solution of LFC problem was reported in [32]. The main advantage of TSA is its ability to escape from local solution and fast convergence speed. However, conventional TSA might have the problem of reaching a global optimum solution in an equitable time when the initial solution is far away from the region where the global solution exists. Shiva et al. [33] have addressed an improved harmony search algorithm with the theory of quasi-oppositional based learning (Q-OBL) so as to tune the LFC parameters under the deregulated environment. In the design of HAS, determination of harmony memory consideration rate, pitch adjusting rate and a number of improvisation are obligatory. Abd-Elazim et al. [35] have proposed bat algorithm based optimal PI-controller for the effective solution of LFC problem and established the supremacy of bat algorithm over simulated annealing in tuning PI-controller using different performance indices. Guha in his most recent endeavor has explained the solution of LFC problem using BSA [36]. Shabani et al. [37] have employed an imperialist competitive algorithm (ICA) to optimize the PID-controller gains in a multi-area multi-unit power system. Simulated annealing based optimal controller for the control of system frequency and terminal voltage of an interconnected multi-area multi-source power system is discussed in [38]. In [39], the use and effectiveness of interline power flow controller (IPFC) in LFC area have been investigated. Although the aforementioned methods give an optimal solution of LFC problem leaving behind some deficiencies which are further corrected by the researchers. The main drawback is the slow convergence towards the optimal solution and more or less all aforesaid techniques depends on the proper initialization of input parameters. Additionally, the algorithms demand proper tuning of some of their own input control parameters. For example, GA involves the determination of algorithm-specific parameters such as crossover rate and mutation rate. PSO has its own parameters like inertia weight, social and cognitive parameters. If the parameters are not properly defined, the algorithm may easily trap into local optimum solution. Thus exploring new optimization technique is still prevailing to enhance the relative stability of power system, especially, by the design of an optimal controller.

Grey wolf optimization (GWO) [40] is a new optimization technique proposed by Mirjalili et al. in 2014 and hardly being used in power system to solve LFC problem. However, the literature review reveals that the proposed GWO algorithm has been successfully applied to different areas of power system for betterment of the existing results [41–45]. The GWO algorithm simulates the leadership hierarchy and hunting mechanism of grey wolves in nature. Unlike other optimization technique, GWO only requires defining of population size and a maximum number of iteration for its functionality. In this article, the quasi-oppositional based learning (Q-OBL) theory is integrated into conventional GWO to accelerate its convergence rate and to minimize the computational intricacy. The proposed approach is applied for the first time to solve LFC problem in an interconnected power system.

The main contribution of this paper to:

(i) demonstrate the effectiveness of proposed scheme, initially two-area hydro-thermal power plant is investigated and then the study is forwarded to a more complex and realistic test system considering the four-area hydrothermal system.
(ii) propose an optimal design of PID-controller for the effective and simple solution of load frequency control problem.
(iii) frame a novel optimization scheme utilizing Q-OBL theory with original GWO algorithm.
(iv) add some degree of complexity, possible inherent power system nonlinearities like governor dead-band, time-delay, and generation rate constraint are integrated into the system modeling.
(v) demonstrate the advantage of proposed algorithm, dynamic responses of the concerned power system are compared to those yielded by other existing results available in the literature by transient analysis method.
(vi) discuss the dynamic behavior of the concerned test system by applying a realistic load pattern and aggregated load in all the areas for the sake of its robustness analysis.
(vii) show the robustness of proposed technique, sensitivity analysis is performed over a wide variation of system parameters and loading conditions.

The rest of the paper is organized as follows: The dynamic model of test systems is presented in Section 2 followed by the

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