ARTICLE IN PRESS

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

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

Full Length Article

Quasi-oppositional differential search algorithm applied to load frequency control

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, NIT-Durgapur, Durgapur, West Bengal, India

ARTICLE INFO

Article history:
Received 14 July 2016
Revised 2 September 2016
Accepted 26 September 2016
Available online xxxx

Keywords:
Load frequency control
Differential search algorithm
Quasi-oppositional based learning
Generation rate constraint
Governor dead band
Transient analysis
Sensitivity analysis

ABSTRACT

In this article, quasi-oppositional differential search algorithm (QODSA) is proposed for finding an optimal and effective solution for load frequency control (LFC) problem in the power system. Initially, original DSA is employed for fine-tuning of the secondary controller of LFC system and then, quasi-oppositional based learning (Q-OBL) mechanism is integrated into the original DSA to enhance the convergence speed and to find a better solution of LFC problem. To validate the effectiveness of proposed QODSA, four widely used interconnected power system networks are designed and analyzed. The superiority of the proposed method is established by an extensive comparative analysis with other existing evolutionary algorithm's (EA) using transient analysis method. A critical investigation of simulation results reveals that the proposed QODSA gives simple and better solution compared to original DSA and other reported algorithms. To study the robustness of QODSA, two different random load patterns are projected and results confirm the robustness of the designed controllers. To add some degree of nonlinearity, generation rate constraint and governor dead band effects are considered and their consequence on the system dynamics has been examined. Finally, sensitivity analysis is performed with a wide variation of system parameters.

1. Introduction

The main idea of power system operation and control is to maintain an electric energy system to its equilibrium condition so that uninterrupted power can be delivered to the customers. This can be achieved by keeping system frequency and terminal voltage profiles to their nominal levels. In this context, two techniques are normally employed in power system. One is used to control the mechanical input power to the electrical generator so that active power and output frequency of the same can be controlled and another is about the control of reactive power and terminal voltage. The control of frequency and active power is referred to as load frequency control (LFC). Stabilization of area frequency and tie-line power oscillation caused by the step load perturbation (SLP) is the most challenging issue in power system operation and control and it received significant attention in LFC study [1–2]. The advanced power system networks are made up with several control areas and in each controlled area, LFC is used to monitor the error in frequency and tie-line power flow. Accordingly it compute the net change (generally named as area control error, ACE) in power generation is required to match the load demand. ACE is defined as a linear combination of frequency and tie-line power flow and used to show the deficiency or excess of power generation at any instant of time. The main objective of LFC is to nullify the ACE so that both frequency and tie-line power error can approaches to zero [3–4].

Several approaches for control and optimization like classical [1–8], optimal [9], robust [10], fractional order [11], fuzzy logic [12,13], artificial neural network [14–16], variable structure controller [17], adaptive control [18–20], fuzzy wavelet neural network [21], adaptive backstepping [22] etc. have been reported in the literature over the past two-three decades to enhance the degree of transient and steady-state stability of power system. In [23], authors have discussed global transient's stability and voltage regulation for power system. The control strategy employed in LFC system is not only used to maintain the constancy in frequency and tie-line power flow but also accomplishes zero steady state error and accidental interchanges. Among the aforesaid controllers, classical controllers in the form of proportional-integral (PI) and/or proportional integral derivative (PID) are quite in vogue because of its structural simplicity, ease realization, low cost, robust perfor-

* 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.2016.09.021
2215-0986/© 2016 Karabuk University. Publishing services by Elsevier B.V.

mance, shows better dynamic performance irrespective to the parameter variation etc. [17,24].

Usually, a linear model around the nominal operating point is used for LFC design. Because of the nonlinear, time-varying nature of the power system and inherent characteristic of the load, the operating point of the power system is continuously varying during a daily cycle. Therefore, the controller design at fixed operating point may not be able to give acceptable performance in another status. This encourages the present researchers to find an effective optimization method for the optimal design of supplementary controller in LFC system. Literature survey reveals that a number of optimization methods like bacterial foraging optimization algorithm (BFOA) [1,6], particle swarm optimization (PSO) [5], firefly algorithm (FA) [2], hybrid BFOA-PSO (hBFOA-PSO) [3], differential evolution (DE) [4,13], teaching learning based optimization (TLBO) [7], biogeography based optimization (BBO) [8], imperialist competitive algorithm [10], tabu search algorithm (TSA) [16], bat inspired algorithm (BIA) [24], backtracking search algorithm (BSA) [25], gravitational search algorithm (GSA) [26], improved PSO [27] etc. have been already applied to the LFC area over the past few decades for betterment of the system stability. Padhan et al. have demonstrated FA in [2] and compared its performance with BFOA, hBFOA-PSO, DE, GA, and conventional controllers for the similar interconnected power system. In [8], an optimal classical controller and superconducting magnetic energy storage (SMES) based frequency stabilizer were designed and implemented employing BBO method for an interconnected nonlinear power system and established the superiority of BBO over the other reported intelligent controllers. Variable structure controller (VSC) applied to LFC system is available in [16] and TSA was proposed to find optimal feedback gain and switching vector of VSC. An improved PSO algorithm is presented in [27] for optimal design of thyristor control series capacitor (TCSC) and transient responses validated that coordinated LFC-TCSC controller provide better damping to the system oscillations caused by the load perturbation. Sahib in [28] has demonstrated PSO for the optimal design of PID with double derivative controller and applied to automatic voltage regulator. The effectiveness of redox flow batteries and interline power flow controller in LFC area has been discussed in [29] and the gains of the optimal controller are searched by DE algorithm. Pradhan et al. [30] have proposed SMES and unified power flow controller (UPFC) in coordination with fuzzy PID controller to accelerate the degree of relative stability of power system. Recently, quasi-oppositional harmony search algorithm (QOHSA) has been discussed in [31] for multi-area multi-unit power system under the deregulation environment. The tuning ability and advantage of grey wolf optimization (GWO) algorithm to cope up with interconnected power system under the normal and perturbed scenario has been enumerated in [32,33].

However, the problem associated with the aforementioned techniques is that they suffer from poor convergence rate and low exploitation ability. Additionally, the performance of the aforesaid optimization techniques is highly determined by some of their input control parameters. For example, the performance of PSO algorithm is highly susceptible to the initial value of weighting factor of the cognitive and social components, and weighting strategy of the velocity vector. The search ability of DE is highly controlled by the mutation factor (F) and crossover rate (CR). In case of HAS, determination of harmony memory search, harmony memory consideration rate, the distance bandwidth, pitched adjusting factor, and number of improvisation is obligatory. In BFOA, during the chemotactic process, the performance of the algorithm is highly determined by the random search direction that may leads to delay to reach the global optimal point. Additionally, the no. of search agents involve in the BFOA is higher than GA and, hence, the possibility of getting suboptimal solution is more in BFOA. The input parameters of GSA are: initial gravitational constant (G_0), total no. of agents (K_0), and a constant α. Firefly algorithm (FA) is controlled by mainly three parameters, namely randomization parameter (α), the attractiveness (β), and the absorption coefficient (γ).

Further, in the line of "**no-free-lunch**" theorem, there is no optimization technique which is well defined for all type of optimization problems. This motivate us to propose a new algorithm, especially input control parameters free, with the hope to solve a wider range of unsolved problem. Therefore, it is justified to propose a new optimization method to explore the LFC performance so as to ameliorate the degree of stability of power system. The main motivation for the expansion of differential search algorithm (DSA) is to achieve a simpler and effective solution of LFC problem. DSA is a recently introduced population based stochastic optimization method proposed by Civicioglu in 2012, which is inspired by the *Brownian-like-random-walk* used by an organism to migrate [34]. It is an iterative process which tries to minimize the selected objective function. Additionally, authors have introduced quasi-oppositional based learning (QOBL) mechanism into the original DSA to accelerate the convergence speed and to improve the computational efficiency of same. The proposed quasi-oppositional DSA (QODSA) method is tested on four well-known interconnected power systems and established its superiority over some recently published control algorithms for the identical test system by the transient analysis method. Two types of random load perturbation (RLP) are projected in this article to verify the robustness of the designed controllers. Finally, parametric uncertainties are considered for sensitivity analysis of the designed controllers.

Rest of the article is organized as follows: Section 2 explains the mathematical model of test system followed by the definition of the fitness function. In Section 3, the proposed method, i.e. original DSA and QODSA, is briefly elaborated. Section 3 also gives the algorithmic steps of QODSA applied to LFC problem. Experimental verification including transient responses is described in Section 4. Concluding remarks is available in Section 5.

2. Problem formulation

To evaluate the performance of QODSA, four widely employed interconnected power systems viz. two-area non-reheat thermal power plant [1–4], three-area thermal power plant [2], two-area multi-source multi-unit power plant [35] and five-area thermal power plant [36] are considered for the present study. Firstly, a two-equal area non-reheat thermal power plant (test system 1) with 2000 MW capacity each is designed and analyzed. The classical controllers, i.e., PI and PID, are employed in the test system as a secondary controller. It is noted that for the sake of best possible generation, it is needed to utilize a distinct controller for each generating unit. Fig. 1 illustrates the linearized transfer function model of the concerned power system and 10% SLP in area-1 is considered for the assessment of transient responses. The system parameters are taken from [2] and presented in Appendix. In Fig. 1, T_g is the time constant of speed governor, T_t is the time constant of steam turbine, K_{ps} is the gain of power system unit, T_{ps} is time constant of power system unit, B_1 and B_2 are the frequency bias parameter of area-1 and area-2, respectively, R_1 and R_2 are the speed regulation parameter of speed governor in area-1 and area-2, respectively, T_{12} is the synchronizing time constant of tie-line, ΔP_D is the load disturbance, Δf_1 and Δf_2 are deviation of frequency in area-1 and area-2, respectively, ΔP_{tie} is the deviation of tie-line power. Furthermore, to perform the study in realistic scenario, appropriate value of GRC (3% min) and governor dead band nonlinearities are included in the system modeling and their impact on the system dynamics has been inspected.

Please cite this article in press as: D. Guha et al., Quasi-oppositional differential search algorithm applied to load frequency control, Eng. Sci. Tech., Int. J. (2016), http://dx.doi.org/10.1016/j.jestch.2016.09.021