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Quasi-oppositional symbiotic organism search algorithm applied to load frequency control

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ABSTRACT

The present work approaches a relatively new optimization scheme called “quasi-oppositional symbiotic organism search (QOSOS) algorithm”, for the first time, to find an optimal and effective solution for load frequency control (LFC) problem of the power system. The symbiotic organism search (SOS) algorithm works on the effect of symbiotic interaction strategies adopted by an organism to survive and propagate in the ecosystem. To avoid the suboptimal solution and to accelerate the convergence speed, the theory of quasi-oppositional based learning (Q-OBL) is integrated with original SOS and used to solve the LFC problem. To demonstrate the effectiveness of QOSOS algorithm, two-area interconnected power system with nonlinearity effect of governor dead band and generation rate constraint is considered at the first instant, followed by the four-area power system showing the consequence of load perturbation. The structural simplicity, robust performance and acceptability of well-popular proportional-integral-derivative (PID) controller enforce to implement it as a secondary controller for the present analysis. The success of QOSOS algorithm is established by comparing the dynamic performances of concerned power system with those obtained by some recently published algorithms available in the literature. Furthermore, the robustness and sensitivity are analyzed for the concerned power system to judge the efficacy of the proposed QOSOS approach.

1. Introduction

In the power system dynamics, the control of generation and frequency are the most important ancillary service for its reliable and satisfactory operation. The term generation and frequency are interrelated and hence, small variations in the system generation directly affect the nominal value of system frequency. Any considerable change in the system frequency may lead to objectionable asynchronizing operation between the grid and power system. Thus, to ensure synchronization and to confirm uninterrupted power supply to the customers, a supplementary control scheme with governor fly-ball mechanism is built-in power system called “*load frequency control (LFC)*”. The term LFC is aiming to guarantee the frequency of each area and the interchange tie-line power between the nearby control areas within the tolerable limit so as to maintain the stability of power system under the fluctuations of load demand [1]. The main task of LFC is to make zero steady-state error in frequency and tie-line power deviations of different control areas under the normal as well as random step load perturbation (SLP) conditions. Additionally, it gives higher damping to the frequency and tie-line power oscillations so as to increase the degree of system stability. Since, the power system load is continuously changed, thus for the satisfactory operation of power system, LFC must include the following features [2]:

i. The standard deviation of each area control error (ACE) must be small, demanded to zero.
ii. ACE signal must not be allowed to drift.
iii. The amount of control action taken by the LFC system should be kept to a minimum level.
iv. Each area should carry its own load during the nominal operation of the system.

In the recent times, a great attention has been paid to the study of LFC scheme and a considerable effort has been given to the developed modern control methodologies for LFC system. A survey of literature on the LFC problem reveals that the works have been introduced by Chon [3]. A detailed survey of different LFC strategies is available in [4]. Hitherto, several control strategies like classical control [1,2,5–10], robust control [11], variable structure control [12], state feedback control [13], non-integer control [14] are commonly employed to deal

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Nomenclature

LFC	load frequency control
ACE	area control error
PID	proportional integral derivative
k_p, k_i, k_d	proportional, integral, and derivative gains of PID controller, in order
CLPSO	comprehensive learning particle swarm optimization
SOS	symbiotic organism search
KHA	krill herd algorithm
X, OX, QOX	number defined in real plane, opposite number, and quasi-opposite number, in order
a, b	minimum and maximum limits of the defined search space, respectively
J_r	quasi-oppositional jumping rate
NFC_{max}	maximum number of function call in the generation
NFC	maximum number of function call in the current generation
n_p	population size
dim	dimension of the problem
$iter_{max}$	maximum generation count

SOS algorithm

X_i	an organism in i^{th} ecosystem
X_{best}	best organism obtained so far
MV, BF	mutual vector and beneficiary factor, respectively

hBFOA-PSO algorithm

N_c	maximum number of iterations in chemotaxis loop
N_{re}	maximum number of reproduction to be performed
N_s	swarming length after which tumbling of bacteria is performed in a chemotaxis loop
N_{ed}	maximum no. of elimination and dispersal events to be performed over the bacteria
d_{at}, w_{at}, h_{re}, w_{re}	attractant and repellant coefficients
p_{ed}	probability of elimination and dispersal
c_1, c_2	cognitive and social acceleration factors, respectively
w	initial inertia weights
v_i^d, x_i^d	velocity and position of i^{th} particle for the d^{th} variable, respectively
p_{best}, g_{best}	best previous position of particle and best position discovered by the whole particles, respectively
$pbest_{f_i(d)}^{d}$	particles p_{best} or its own p_{best}

QOHS algorithm

HMS	harmony memory size
HMCR	harmony memory consideration rate
PAR	pitch adjusting rate
BW	distance bandwidth
NI	number of improvisation
dim	total no. of search space, i.e. the dimension of the problem

KHA algorithm

$N_{\max}$	maximum induced speed
$V_d^{\max}$	maximum diffusion speed
V_f	foraging speed
V_f	position factor
α_n, α_f	inertia weights, set to 0.9 for exploration and then gradually reduced to 0.1 to exploit the search space

with LFC problem of power system. Variable structure controller has been reported [12] for the extensive analysis of dynamic behavior of interconnected power system. But for the successful implementation of same, the exact power system model is required to known while satisfying the system constraints. However, in actual practice, it is somewhat difficult to identify all the state variables of the system which reduces its acceptability in real time applications. Some investigations have been carried out using the fuzzy logic controller (FLC) [15–17], artificial neural network [18,19], and adaptive neuro-fuzzy inference system (ANFIS) controller [20]. Yesil et al. [15] proposed "self-tuning fuzzy proportional-integral-derivative (PID) controller" for LFC of a two-area interconnected power system. In [17], the fuzzy logic controller was designed using the genetic algorithm (GA) for a two-area hydro-thermal power plant in deregulated environment. But, this method identifies some shortcomings during their practical execution like large oscillation in the transient response as well as no specific mathematical relationship is defined to decide the scaling factor, rule base, membership function for the FLC. Moreover, large computational time is needed to design the specific rule base for FLC and in the case of the neural network to train the data. Fuzzy neural network (FNN) includes the advantages of FLC, handling uncertainty and ANN, in learning the process. Although, it shows significant improvement in the system performances but it is not used for noise measurement and parametric uncertainties of power system [21].

The PID-controller or its variant is still remained an acceptable controller in the industrial application because of its simplicity and robust structure, ease realization, and suitable reliability. Moreover, it requires lower user skills and gives favorable ratio between the cost and performance despite to the variation of system parameters. The PID-controller detects the average value of error and subsequently tries to nullify the error. But, the main problem with PID controller is that its performance is highly sensitive to the selection of its operating coefficients. It is obvious that the fixed gains controller, designed for a specific working condition, fails to give healthier performance under the perturbed situation. Thus, to have a superior performance in any working environment, the controller coefficients must be well-tuned. In this connection, different optimization algorithms like GA [17], particle swarm optimization (PSO) [22], cuckoo search algorithm (CSA) [1], differential evolution (DE) [23], biogeography-based optimization (BBO) [24], oppositional BBO [9], quasi-oppositional harmony search algorithm (QOHSA) [2,5], imperialist competitive algorithm (ICA) [11], firefly algorithm (FA) [14], hybrid FA-pattern search (PS) [16], krill herd algorithm (KHA) [25], pattern search based gravitational search algorithm (GSA) [8], bacteria foraging optimization algorithm (BFOA) [26], hBFOA-PS [10] etc. may prove to be efficient in solving LFC problem due to their computational facility. Hybrid evolutionary algorithms have also received a great attention to solving the LFC problems. The methodologies, architecture, and its review in the optimization filed are available in [27]. Shiva et al. [2,5] formulated QOHS algorithm to improve the quality of LFC performances of an interconnected power system. Guha et al. [6] in his most recent endeavor solved LFC problem using "grey wolf optimization (GWO)" and shows the excellence of GWO over DE, PSO, GA, BFOA, hBFOA-PS etc. Hosseini *et al.* [11] employed imperialist competitive algorithm based robust controller for the optimal solution of LFC problem. Debbarma et al. [14] suggested FA for optimal tuning of fractional order controller to solve LFC problem. Recently, the superiority and robustness of KHA over FA were established in [25] for an interconnected three-unequal-all-thermal power plant with turbine nonlinearity. Guha *et al.* [28] recently show the tuning feasibility and supremacy of a quasi-oppositional GWO algorithm for the large interconnected power system. The aforementioned algorithms also