ARTICLE IN PRESS

Ain Shams Engineering Journal (2016) **xxx**, xxx–xxx

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com

ELECTRICAL ENGINEERING

Opposition-based krill herd algorithm applied to economic load dispatch problem

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Received 31 August 2015; revised 21 January 2016; accepted 23 February 2016

KEYWORDS

Economic load dispatch;
Valve point loading;
Opposition based learning;
Krill herd algorithm

Abstract Economic load dispatch (ELD) is the process of allocating the committed units such that the constraints imposed are satisfied and the production cost is minimized. This paper presents a novel and heuristic algorithm for solving complex ELD problem, by employing a comparatively new method named krill herd algorithm (OKHA). KHA is nature-inspired metaheuristics which mimics the herding behaviour of ocean krill individuals. In this article, KHA is combined with opposition based learning (OBL) to improve the convergence speed and accuracy of the basic KHA algorithm. The proposed approach is found to provide optimal results while working with several operational constraints in ELD and valve point loading. The effectiveness of the proposed method is examined and validated by carrying out numerical tests on five different standard systems. Comparing the numerical results with other well established methods affirms the proficiency and robustness of proposed algorithm over other existing methods.

1. Introduction

Computational intelligence is an emerging trend in different research areas in power system due to its ability to synthesize largely interconnected and complex system very quickly and accurately. Economic load dispatch (ELD) is one of the most fundamental and important areas in power system operation and planning. The main objective of ELD problem was to schedule a set of real power delivered by online generation resources to fulfil the required demand at any time subject to a set of constraints [1,2] related to unit and system technical limits, at minimum production cost. The overall problem of ELD can be formalized as a non-smooth, highly nonlinear constrained optimization problem particularly for larger systems. The fuel cost component is related to variable cost of electricity generation, reflected in the electricity bills.

The existing methods to solve ELD problem can be divided into two major groups: classical methods and heuristic

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Peer review under responsibility of Ain Shams University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2016.02.003
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Please cite this article in press as: Bulbul SMA et al., Opposition-based krill herd algorithm applied to economic load dispatch problem, Ain Shams Eng J (2016), http://dx.doi.org/10.1016/j.asej.2016.02.003

Nomenclature

$F_i(P_{gi})$	fuel cost of the i-th generating unit
P_{gi}	real power generation of the i-th generating unit
a_i, b_i, c_i	quadratic cost coefficient of the i-th generator
N_g	total number of committed generators
e_i,f_i	cost coefficients of the i-th generator representing valve-point effect
P_L	power loss of the transmission network
B_{00}, B_{0i}, B_{ij}	transmission loss coefficients
$P_{gi}^{\max}, P_{gi}^{\min}$	upper and lower limits of power generation capacity of the i-th unit
P_{gi}^0	previous operating point of the i-th unit
DR_i, UR_i	down rate and up rate limits, respectively, of the i-th unit
np_i i	number of prohibited zones of the i-th unit
$P_{gi,j}^l, P_{gi,j-1}^u$	lower and upper generation limits of prohibited zone j and $j-1$ of the i-th unit
$S_{\min}$	Minimum spinning reserve of the system
S_i i	Spinning reserve of the i-th unit
$v_i^{\max}$	maximum induced speed
v_i^k, v_i^{k-1}	induced motion of the i-th krill at the k-th and $(k-1)$-th movement
ω_n	inertia weight of the induced motion
$\alpha_i^{new}, \alpha_i^{target}$	local and the target effect of the i-th krill
f_w,f_b	worst and the best position among all krill individuals of the population
f_i,f_j	fitness value of the i-th and j-th krill individuals
S	number of krill individuals surrounding the particular krill
i	current iteration number
$i_{\max}$	maximum iteration number
N_P	population is size
z_i, z_j	position of the i-th and the j-th krill
ω_x	inertia weight of the foraging motion
$v_{f_i}^{k-1}, v_{f_i}^k$	foraging motion of the i-th krill at k-th and $(k-1)$-th movement
$v_d^{\max}$	maximum diffusion motion
λ	directional vector uniformly distributed between $(-1, 1)$
N	total number of control variables
U_i, L_i	upper and lower limits of the i-th control variable
c_t	position constant

methods. Some of the classical optimization techniques such as gradient method [3], linear programming (LP) [4], nonlinear programming (NLP) [5], quadratic programming (QP) [6], base point (BP) method [7] and interior point (IP) method [8] have been applied for solving ELD problem. Very recently, Yang et al. [9] presented an analytical method named quadratically constrained programming (QCP). In classical approach ELD problem is assumed to be a smooth and monotonically increasing continuous quadratic function. Despite the fact that some of these techniques have excellent convergence characteristics, various methods among them suffer from convergence as the global or local solution is highly sensitive to the initial guess. These methods have also severe difficulty in handling discrete variables. The validation of this supposition sacrifices considerable precision. Dynamic programming algorithm (DP) [10] does not approximate the cost curves but may suffer from "curse of dimensionality" and "local optimality".

However single quadratic function or piecewise quadratic function to represent the input–output characteristics (or cost function) in ELD does not solve the purpose in practical system. Higher-order nonlinearities and discontinuities are observed in real input–output characteristics. So various researchers propose higher order cost function for less approximation, better curve fitting of running cost to get more practical, accurate and reliable results. A nonlinear characteristic of the cost curve arises because of ramp rate limits [11], discontinuous prohibited operating zones [12] and multi-fuel effects [13]. Ramp rate limits arise because of generation resources in the actual operating processes is restricted that unit generation output cannot be changed instantaneously. Prohibited zones are the consequence of physical limitations of individual power plant components such as boilers, feed pumps. The amplification of vibrations in a shaft bearing at certain operating regions may lead to instabilities in operation for certain loads. The presence of prohibited zones for individual generator leads to a solution space with disjoint, non-convex, infeasible regions. Multi-fuel options based on availability of sources such as coal, nature gas, or oil, lead to determine most economic fuel to burn. Due to the aforesaid facts an alternative to the classical approaches, population-based (a class of meta-heuristics) optimization techniques are introduced in recent times. Some of these techniques introduced by earlier scholars are as follows: artificial immune system (AIS) [14], ant colony optimization (ACO) [15], gravitational search algorithm (GSA) [16], tabu search (TS) [17], simulated annealing (SA) [18], bacterial foraging (BF) [19], differential evolution (DE) [20], teaching–learning based optimization (TLBO) [21–23], firefly algorithm (FA) [24], genetic algorithm (GA) [25], particle swarm optimization (PSO) [26,27], biogeography based optimization (BBO) [28], and artificial bee colony (ABC) [29]. AIS is based on function of biological immune system. In fact, AIS copies the method which the human body acquires immunity using vaccination against diseases. In AIS, the decision points and solutions are antibodies and antigens in the immune system which are employed to solve optimization problems. ACO utilizes the foraging behaviour of real ants. When searching for food, these ants initially explore the area by performing a randomized walk from the nest to the food source and ants deposit pheromone on the ground in order to mark some favourable path to guide other ants to the food source. GSA is based on the physical law of gravity and the law of motion. In GSA a set of agents called masses have been proposed to find the optimum solution by simulation. TS is basically local search algorithm inspired by the human memory. It explicitly relies on history of the search, both to escape from local minima and to implement an explorative strategy. SA is a stochastic optimization approach inspired by the natural process of annealing related to thermodynamics. The main advantage of SA approach is that it does not need large computer memory and also it has ability to

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