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The application of one rank cuckoo search algorithm for solving economic load dispatch problems

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ABSTRACT

In this paper, a one rank cuckoo search algorithm (ORCSA) is proposed for solving economic load dispatch (ELD) problems. The main objective of the ELD problem is to minimize total cost of thermal generators while satisfying power balance constraint, prohibited operating zones, ramp rate constraints and operating limits of generators. Moreover, the generating units considered in this paper have different characteristics such as quadratic fuel cost function, nonconvex fuel cost function and multiple fuel options. The proposed ORCSA method has been developed by performing two modifications on the original cuckoo search algorithm (CSA) to improve optimal solution quality and computational time. The first modification is to merge new solution generated from both Lévy flights and replacement a fraction of egg together and to evaluate and rank the solutions at once only. A bound by best solution mechanism has been used in the second modification for properly handling the inequality constraints. The proposed ORCSA method has been tested on different systems with different characteristics of thermal units and constraints. The results obtained by ORCSA have been compared to those from other methods available in the literature and the result comparison has indicated that the ORCSA method can obtain better solution quality than many other methods. Therefore, the proposed ORCSA can be a very effective and efficient method for solving ELD problems.

1. Introduction

Economic load dispatch (ELD) problem is one of the most popular and important problems and has been widely studied in optimal power system operation in recent decades. The main objective of the ELD problem is to determine power generation among a set of available generating units so that the objective of minimum total fuel cost is gained while all physical and operational constraints are satisfied [1]. The most conventional ELD problem was first introduced considering convex fuel cost function for the objective and linear constraints [1,2]. However, it is more realistic to consider the valve point effects on thermal units and this curve thus contains higher order nonlinearity and discontinuity [3,4]. The characteristic of the ELD problem becomes more complicated as generating units can be supplied with multiple fuel (MF) sources (such as gas and oil) to produce electricity [5]. Moreover, the ELD problem will be more complicated by a combination of the segmented piecewise quadratic function and the nonconvex fuel cost function in objective function [6] and each generating unit has to satisfy its own physical constraints including limits on generation and prohibited operating zones, and system spinning reserve constraint [7].

In the past, a large number of conventional methods were widely and successfully applied for solving the ELD problem such as gradient method [8], Lagrangian relaxation algorithm [9], dynamic programming (DP) [10], lambda iteration method [11], Newton's method [1], quadratic programming (QP) [12] and linear programming (LP) [13]. The conventional methods share the common fact that the solution is only obtained after one run on the ELD problem. Moreover, these methods also have the same advantages including few control parameters, short execution time and small standard deviation. However, these methods suffer difficulty when dealing with the problems with complex constraints and nonconvex objective functions. On the contrary to the conventional methods, artificial intelligence-based methods have become widely used for solving the ELD problem with more complex constraints and nonconvex objective function recently since these methods can properly deal with nonconvex optimization problem with near optimal solution.

In recent decades, several artificial intelligence-based methods have applied for solving the ELD problem and obtained promising

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Nomenclature

a_i, b_i, c_i	fuel cost coefficients of unit i
e_i, f_i	fuel cost coefficients of unit i reflecting valve-point effects
a_{ij}, b_{ij}, c_{ij}	fuel cost coefficients for fuel type j of unit i
e_{ij}, f_{ij}	fuel cost coefficients for fuel type j of unit i reflecting valve-point effects
B_{ij}, B_{0i}, B_{00}	B-matrix coefficients for transmission power loss
N	total number of generating units
P_i	power output of unit i
$P_{i,\max}$	maximum power output of unit i
$P_{i,\min}$	minimum power output of unit i
$P_{ij,\min}$	minimum power output for fuel j of unit i
$P^u{}_{ik}$	upper bound for prohibited zone k of unit i
$P^l{}_{ik}$	lower bound for prohibited zone k of generator i
P_D	total system load demand
P_L	total transmission loss
S_i	spinning reserve of unit i
$S_{i,\max}$	maximum spinning reserve contribution of unit i
S_R	total system spinning reserve requirement

results. Most of the methods have many advantages such as ability to handle complex constraints, capability of searching global optimal solution for nonconvex objective function problems and the potential for dealing with large-scale systems. These methods can be classified into the groups including swarm intelligence, evolutionary algorithms, neural networks and hybrid algorithms. The swarm intelligence (SI) is the collective behavior of decentralized, self-organized, natural inspired systems consisting of particles swam optimization (PSO) [14,15], cuckoo search algorithm [16], gravitational search algorithm (GSA) [17], firefly algorithm (FA) [18], simulated annealing (SA) [19], bacterial foraging algorithm (BFA) [20], invasive weed optimization (IWO) [21], oppositional invasive weed optimization (OIWO) [22], modified artificial bee colony algorithm (MABCA) [23], harmony search (HS) [24] and biogeography-based optimization (BBO) [25]. Among these methods, SA is considered the less effective method since its optimal solutions are usually trapped in the local optimum rather than global optimum as well as it must suffer a difficult task for setting control parameters in addition to the long execution time. Several other new algorithms such as IWO, FA and MABCA have a good capability of searching for high solution quality for systems with nonconvex fuel cost function of thermal units. However, the execution time from these methods is still long. Moreover, a series of experiments must be done to determine the values of control parameters for OIWO [22]. This disadvantage causes the method to have long simulation time and large number of trial runs. The methods in the evolutionary algorithms group are derived from the evolutionary progress including genetic algorithm (GA) [26,27], evolutionary programming (EP) [3,28], and differential evolution algorithm (DE) [29,30]. Among these methods, GA is the method early applied for solving optimization problems in engineering field, especially in electrical engineering. Although the GA has the ability of handling complex constraints and nonconvex objective function as well as simplicity of implementation for optimization problems, it still suffers several disadvantages such as low quality optimization solution and long execution time. The DE method can be considered as a more powerful method than the others since it can obtain better solution quality with shorter computation time for optimization problems and this method has been widely used in power system optimization problems in power systems. On the contrary to the two mentioned groups, the methods in the neural network group comprising of Hopfield neural network (HNN) [31,32] and augmented Lagrange Hopfield network (ALHN) [33–35] can deal with large-scale problems but they cannot deal with the ELD problem with non-differentiable objective function. Both the HLN and ALHN methods have been developed by combing the Lagrange function with Hopfield network. Therefore, these methods can overcome the drawbacks that the conventional Hopfield network (HNN) suffers such as simpler implementation, higher solution quality, higher convergence speed, and larger system scale. Finally, the hybrid group is totally different among the mentioned groups since it is built based on the combination between the conventional methods and meta-heuristic search methods or among the meta-heuristic search methods to improve the optimal solution. The hybrid methods have been implemented for solving the ELD problem comprising of genetic algorithm-pattern search-sequential quadratic programming (GA-PS-SQP) [36], EP-SQP, PSO-SQP [37], hybrid differential evolution with biogeography-based optimization (DE/BBO) [38], GA-DE [39], and GA-SQP [40]. By utilizing the advantages of each original one, these hybrid methods have good ability for searching for the better optimal solution with faster computational time. However, the combination of original methods may cause the hybrid method become more complicated with more control parameters and it may lead to difficulty for a proper selection of these parameters.

In this paper, a one rank cuckoo search algorithm (ORCSA) is first proposed for solving the ELD problem considering nonconvex and piecewise quadratic fuel cost functions of thermal units in the objective function of the problem with complicated constraints such as prohibited operating zones (POZ), spinning reserve and power losses. The ORCSA method was first proposed by Ahmed et al. in 2013 [41] by performing two modifications on the original cuckoo search algorithm (CSA) which was originally developed by Yang and Deb [42] is inspired from the reproduction strategy of cuckoo species in the nature. The first modification is to merge new solution generated from both Lévy flights and replacement a fraction of egg together and then evaluate and rank the solutions at once only. The second modification is a bound by best solution mechanism used for handling the inequality constraints to improve convergence rate and performance. The ORCSA method has shown more superior to the conventional CSA in terms of performance and convergence speed for the standard benchmark functions and a real-world problem of algorithmic trading systems optimization in the financial markets [41]. The proposed ORCSA method has been tested on different systems with different characteristics of thermal units and constraints. The results obtained by ORCSA have been compared to those from other methods available in the literature.

The organization of the remaining paper as follows. Section 2 addresses the problem formulation, Section 3 presents the implementation of ORCSA for the ELD problem, Section 4 provides the numerical results, and finally the conclusion is enclosed.

2. Problem formulation

The objective of the ELD problem is to minimize the total cost of thermal units as follows:

$$\mathrm{Min}\, F = \sum_{i=1}^{N} F_i(P_i) \tag{1}$$

In the classical ED problem, the fuel cost of each generating unit is expressed as a quadratic function of its power output. As the generating units use only one fuel option or multiple fuel options to generate electricity and the valve point effects considered, the fuel cost function is given as [4,27]:

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 + \left| e_i \times \sin(f_i \times (P_{i,\min} - P_i)) \right| \tag{2}$$