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Grey wolf optimization applied to economic load dispatch problems

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ABSTRACT

This article presents a new evolutionary optimization approach named grey wolf optimization (GWO), which is based on the behaviour of grey wolves, for the optimal operating strategy of economic load dispatch (ELD). Nonlinear characteristics of generators like ramp rate limits, valve point discontinuities and prohibited operating zones are considered in the problem. GWO method does not require any information about the gradient of the objective function, while searching for an optimum solution. The GWO algorithm concept, appears to be a robust and reliable optimization algorithm is applied to the nonlinear ELD problems. The proposed algorithm is implemented and tested on four test systems having 10, 40, 80 and 140 units. The results confirm the potential and effectiveness of the proposed algorithm compared to various other methods available in the literature. The outcome is very encouraging and proves that the GWO is a very effective optimization technique for solving various ELD problems.

Introduction

Nowadays, the electrical power market becomes highly competitive and more liberal for increasing energy demand. Economic load dispatch (ELD) is one of the useful tools in the modern energy management system of operation and planning. ELD plays a vital role in maintaining the economy of the power system. Reduction of the production cost and growth in the system reliability maximize the energy capability of thermal units through a good load dispatch. The main goal of ELD process is to schedule the power system control variables for sharing the total load to achieve highest economy of operation while satisfying all equality and inequality constraints. To achieve optimal solution of a practical ELD problem, the realistic operation of the ELD problem should consider valve point effects, ramp rate and multiple fuels. Several derivative based approaches such as the classical optimization methods based on Lagrangian relaxation [1], quadratic programming (QP) [2], branch and bound method [3], lambda iteration method (LIM) [4], gradient method [5], linear programming (LP) [6], co-ordination equation [7], dynamic programming (DP) [8] assuming monotonically increasing piecewise linear cost function, have successfully been applied to solve ELD. However, the classical optimization techniques are highly sensitive to staring points and often converge to local optimum or diverge altogether. Solutions of ELD problem applying DP may cause the dimensions extremely large, which requires enormous computational efforts. Due to the presence of nonlinear characteristics such as ramp rate limits, discontinuous prohibited operating zones and non-smooth cost functions of practical ELD problem, these methods are infeasible in practical systems and are unable to locate the global optima solution. To solve non smooth and non convex ELD problem, Yang et al. [9] presented an analytical method named quadratically constrained programming (QCP). Due to a large number of constraints and highly nonlinear characteristics of the ELD problem, the classical calculus based methods cannot perform satisfactorily and are trapped to local optimum. Hence, it becomes essential to overcome these drawbacks and handle such difficulties through developing a robust, improved and reliable technique. In the recent years, complex constrained optimization problems are solved by many artificial intelligent methods such as Hopfield neural network (HNN) [10,11] and adaptive HNN [12]. These techniques have successfully been applied in recent years to solve non-convex, non-smooth and non-differentiable ELD problems. However, due to excessive numerical iterations of these methods, more reliable and fast methods are needed.

With the development of computer technology, the population based modern intelligent heuristic and stochastic optimization methods such as evolutionary programming (EP) [13], hybrid evolutionary programming (HEP) [14], differential evolution (DE) [15], genetic algorithm (GA) [16], adaptive real coded GA (ARCGA) [17],

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Nomenclature

F_t	total fuel cost
Pg_i	power generation of the ith generating unit
$F_i(Pg_i)$	fuel cost function for power generation of the ith unit
n	number of generating units in the thermal power plant
P	population size
I	number of iterations
lb	lower boundary of search area
ub	upper boundary of search area
a_i, b_i, c_i, e_i, f_i	fuel cost coefficients of the ith generating unit
$a_{ik}, b_{ik}, c_{ik}, e_{ik}, f_{ik}$	the Kth type of fuel cost coefficients of the ith generating unit
$Pg_i^{\min}$	minimum amount of power generation of the ith unit
$Pg_i^{\max}$	maximum amount of power generation the ith unit
P_D	the total load demand
B_{ij}, B_{i0}, B_{00}	loss coefficients of the line connected between the ith and the jth bus
P_L	the transmission network losses
URR_i, DRR_i	up rate and down rate limit of the ith generating unit
ni	the number of prohibited zones of the ith generating unit
Pg_{i0}	previous operating zone of the ith generating unit
n_p	population size

hybrid GA (HGA)[18], particle swarm optimization (PSO) [19], anti predatory PSO (APSO) [20], civilized swarm optimization (CSO) [21], modified PSO (MPSO) [22], craziness based PSO (CRPSO) [23], hybrid PSO (HPSO) [24], ant colony optimization (ACO) [25,26], bacteria foraging optimization (BFO) [27], modified BFO (MBFO) [28], artificial bee colony (ABC) [29], seeker optimization algorithm (SOA) [30], chaotic ant swarm optimization (CASO) [31], tabu search (TS) [32], harmony search algorithm (HSA) [33], biogeography based optimization (BBO) [34,35], oppositional BBO (OBBO) [36], and quasi oppositional BBO (QOBBO) [37] algorithms, have been proposed for solving ELD problems. In the year of 2009, the gravitational search algorithm (GSA), a heuristic algorithm based on the Newtonian laws of gravity and motion, was developed by Rashedi et al. [38]. Affijulla et al. solved ELD problems by implementing GSA [39]. Roy et al. implemented GSA [40] to solve unit commitment problem for superior features including stable convergence characteristic and avoids premature convergence. A teaching learning based optimization (TLBO) was introduced to solve combined heat and power dispatch problem [41]. Very recently, quasi oppositional TLBO (QOTLBO) [42] technique which employed opposition based learning for TLBO initialization and generation jumping was proposed by Roy et al. An opposition based harmony search algorithm (OHSA) was introduced by Chatterjee et al. [43], where opposite numbers were utilized to improve the convergence rate of harmony search algorithm (HSA). Krill herd algorithm (KHA), first proposed by Gandomi and Alavi [44], was successfully applied to solve ELD problems [45]. Dutta et al. in their recent endeavour proposed hybrid chemical reaction optimization (HCRO) algorithm to explore the entire search space for solutions [46].

Recently, Barisal and Prusty [47] proposed invasive weed optimization (IWO) to solve ELD problem of large scale power system. Oppositional real coded chemical reaction optimization approach [48] has been extensively used in electrical power systems due to their ability to mould nonlinearity and uncertainty in practical problems. Shanhe et al. [49] in their recent endeavour implemented hybrid PSO/GSA approach to solve non-linearity based ELD problem. A new efficient optimization technique was proposed by Chen et al. [50] to solve wind based ELD problem of a multi-area power system. Bulbul et al. [51] introduced oppositional KHA approach to successfully solve ELD problem of small, medium and large scale power systems.

However, some of these heuristic methods may have poor performance on different set of problems. Some algorithms perform local exploitation at the mature stage of the search and global exploratory search at the early stages of the evolutionary process. Few of the aforementioned methods have excellent global search capabilities but, they have some limitations in their local search ability. Some of the techniques discussed above face premature convergence. To overcome premature convergence and speed up the search process a more powerful method is needed.

In this research work, a newly developed meta heuristic algorithm, named grey wolf optimization (GWO) [52], which does not have any affinity to stick in local optimum points in the complex multimodal optimization problem and which provides a more diverse search of the solution space is proposed to solve complex ELD problems. The GWO is based on behaviour of grey wolf [53]. The better optimum solutions with lower computation burden can be found in GWO compared to the existing stochastic search techniques mentioned above. The GWO is superior to these methods because (i) The GWO has better conveying mechanism and information sharing capability; (ii) it uses random function and considers three candidate solutions for getting better results and converges quickly by making jump from local minima towards global minima.

To justify the effectiveness of the proposed method, the proposed GWO approach is applied to solve different test systems with valve point effects, ramp rate limits, prohibited operating regions, multiple fuels, etc. The performance of the solution results are compared with those of the existing methods available in the literature.

The rest of the paper is organized as follows: ELD problem is formulated in Section ‘Problem formulation’. In Section ‘Grey wolf optimization algorithm’, the original GWO algorithm is briefly described. GWO applied to ELD problem is explained in Section ‘Gray wolf optimization applied to ELD’. The system simulation and results are provided in Section ‘Case studies and numerical results’. Section ‘Conclusion’ outlines the, conclusions followed by reference.

Problem formulation

The ELD is one of the important optimization strategies for management of the power system. The following objective and constraints are taken into account in the formulation of ELD problem.

Objective function

The objective of ELD is to minimize the total fuel cost while satisfying all equality and inequality constraints. The various cost functions used in ELD problem are as follows.