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Solution of economic load dispatch using hybrid chemical reaction optimization approach

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ABSTRACT

In this paper, a new and efficient optimization technique based on hybridization of chemical reaction optimization (CRO) with differential evolution (DE) is developed and demonstrated to solve the ELD problem with thermal cost function having valve point loading effect together with and without multiple fuel options and with and without considering prohibited operating zone and ramp rate constraint. When valve-point effects, multi-fuel operations and the constraints of prohibited operating zone and ramp rate are taken into account, ELD problem become more complex than conventional ELD problem. To show the priority of the proposed algorithm, it is implemented on six different test systems for solving ELD problems. Comparative studies are carried out to examine the effectiveness of the proposed HCRO-DE approach with conventional DE, CRO and the other algorithms reported in the literature. The simulation results show that the proposed HCRO-DE method is capable of obtaining better quality solutions than DE, CRO and the other well popular optimization techniques.

Introduction

Economic load dispatch (ELD) has become an essential part in operation and control of modern power system. Its main objective is to seek the best generation schedule for the generating plants whereby the required demand together with the transmission losses can be produced with the minimum production cost. The ELD problem is formulated in various ways in the literature. Some researchers used non-smooth operational cost function as the objective function for ELD with simple power balance and power range constraints. The non-smooth cost function is used to reflect the actual realistic operational condition, such as the multi-fuel effect caused by the changes of fuel types and the valve-point loading effect due to operation of the multi-valve steam turbine. Few researchers considered a smooth cost function for cost minimization objective of ELD but with more complex constraints, such as ramp rate limits, prohibited operating zones, and transmission losses in the power balance constraint. However, most of the researchers used non-smooth cost function with complex constraints, such as ramp rate limits, prohibited operating zones, spinning reserve, transmission losses in the power balance in ELD problem formulation. A practical optimal ELD problem should consider generation limit, ramp rate, prohibited operating zone, transmission loss at every time interval such that the total cost is minimum. A bibliographical survey of existing literature on ELD methods reveals that various numerical optimization techniques are employed to solve the ELD problem. Some of these methods are conventional classical optimization technique and others are modern heuristic optimization technique. Previously, many classical methods like gradient method [1], lambda iteration method (LIM) [2], linear programming (LP) [3], quadratic programming (QP) [4], dynamic programming (DP) [5], non-linear programming method (NLP) [6], Lagrangian method [7], etc. gained a lot of popularity in the last few decades to solve the objective function for ELD problem along with its constraints. The ELD problem with valve-point effects, multiple fuel options, prohibited operating zone and ramp rate is represented as a non-smooth optimization problem having complex and non-convex characteristics with heavy equality and inequality constraints, which makes the challenge of finding the global optimum hard. Conventional optimization methods that make use of derivatives and gradients, in general, are not able to locate or identify the global optimum. Most of these techniques are not capable of solving efficiently optimization problems with a non-convex, non-continuous and highly non-linear solution space. In these numerical methods for solution of ELD problems, an essential assumption is that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. For the nonlinear characteristics of the practical systems, this assumption makes these methods infeasible. LIM method [2] has a problem in handling large number of inequality constraint. The major

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disadvantage of LP method [3] is piecewise linear cost approximation though this method is fast and reliable whereas NLP method [6] has a disadvantage of algorithmic complexity.

On the other hand, evolutionary computation approaches obtained remarkable importance in this domain since they can provide solutions leading to a considerable reduction of generator fuel consumption and provide these solutions at low computational time. Besides this, recent advances in computation and the search for global optimum solutions of complex optimization problem have fomented the development of a group of techniques known as modern heuristic algorithms. The methods that qualify are evolutionary programming (EP) [8,9], artificial intelligence (AI) [10], neural networks (NN) [11], genetic algorithm (GA) [12], particle swarm optimization (PSO) [13,14], simulated annealing (SA) [15], differential evolution (DE) [16,17], bee colony optimization (BCO) [18], bio-geography based optimization (BBO) [19], modified sub-gradient algorithm [20], etc. The PSO technique developed by Kennedy and Eberhart [13] has made an impact for solving ELD problem and is based on the social behaviour of bird flocking and fish schooling. The PSO algorithm is quite impressive for solving ELD problem because of its first convergence feature. Baskar and Mohan [21] modified and improved original PSO to solve ELD problem for utility system. Cai et al. [22] proposed a fuzzy adaptive chaotic ant swarm optimization (CASO) for ELD in which a fuzzy system was dynamically tuned the characteristic parameters of CASO. Tsai et al. [23] developed a novel stochastic search (NSS) method for the solution of ELD problems with non-convex fuel cost functions. Vaisakh et al. [24] presented a hybrid heuristic optimization methodology, namely, bacterial foraging based PSO-DE (BPSO-DE) algorithm by integrating bacterial foraging optimization (BFO), PSO and DE for solving non-smooth non-convex dynamic ELD (DELD) problem. Sa-ngiamvibool et al. [25] invented multiple tabu search (MTS) algorithm to solve the ELD problem. Seeker optimization algorithm (SOA) [26] was presented by Shaw et al. for solution of ELD problems. PSO with bacterial foraging effect was come into lime light by Saber [27]. Chaotic quantum GA [28] was first used by Liao for solving environmental economic dispatch problem of smart micro grid. The studies of above evolutionary algorithms, over the past few years, have shown that these methods can be efficiently applied to solve nonlinear optimization problems. However, each of these methods has its own characteristics, strengths and weaknesses; but long computational time is a common drawback for most of them, especially when the solution space is hard to explore. Many efforts have been made to accelerate convergence of these methods.

In this article, hybridization of DE with chemical reaction optimization (CRO), is proposed to improve the convergence property of individual DE and CRO algorithms. Using mutation, crossover and selection operators, DE effectively improves candidate solutions of a population over several generations. DE has an ability to search for the optimal solution in a faster manner using its unique crossover strategies. CRO is a chemical reaction-inspired meta-heuristic algorithm recently proposed by Lam and Li [29]. It has already proven itself a worthy optimization technique compared to other existing techniques. By choosing different combination of elementary reactions, CRO acquires both global and local search ability and does not need a local search method to refine the search. Furthermore, this method does not require tuning of large number of input parameters. Only number of initial reactants is enough for the algorithm implementation. The initial reactants are distributed over feasible search region. CRO manipulates multiple tanks of molecules in parallel. CRO performs different chemical reaction simultaneously. Therefore, CRO is best suited to those types of problems which will benefit from parallel processing rather than sequential processing. Moreover, advantage of CRO over other meta-heuristic methods is its flexible structure which can be easily adjusted to fit the problem.

These versatile properties of CRO algorithm encourage the present authors to apply this newly developed algorithm for solving ELD problems. Moreover, to speed up the convergence property and to find better results a hybrid technique combining CRO and DE is introduced in this article In order to utilize the exploration ability of CRO and the exploitation capability of DE, the hybridization of CRO with DE (HCRO-DE), is being proposed to solve ELD problem. Here, a mutation operator of DE is combined with on-wall ineffective collision, decomposition operation and inter-molecular ineffective collision of CRO to explore and exploit the search space effectively.

The aim of this paper is to introduce a much simplified, flexible and efficient hybrid optimization algorithm based on chemical reaction optimization (CRO) and differential evolution (DE) which may outperform the ELD based optimization methods reported recent past in literature. In the proposed HCRO-DE approach, CRO algorithm that emphasizes on exploring the entire search space and a local version of DE algorithm that emphasizes on exploitation is combined to achieve better performance. In order to show the validity of the proposed approach, the developed algorithm is illustrated on six test systems. Results obtained from the proposed method are compared with multiple tabu search (MTS) [30], PSO [14,31,32], adaptive PSO (APSO) [32], iteration PSO (IPSO) [33], quantum-inspired PSO (QPSO) [34], new PSO (NPSO) [14], PSO with local random search (PSO-LRS) [14], new PSO with local random search (NPSO-LRS) [14], new adaptive PSO (NAPSO) [35], self-organizing hierarchical PSO (SOH-PSO) [36], hybrid multi-agent based PSO (HMAPSO) [31], PSO with time varying acceleration coefficients (PSO-TVAC) [37], iteration PSO with time varying acceleration coefficients (IPSO-TVAC) [38], ICA-PSO [39], constriction factor and inertia weight based PSO with real-valued mutation (CBPSO_RVM) [40], GA [14], hybrid GA (HGA) [41], conventional GA with multiplier updating (CGA_MU) [42], improved GA with multiplier updating (IGA_MU) [42], DE [43], modified DE (MDE) [44], variable DE with the fuzzy adaptive PSO (FAPSO-VDE) [45], self-tuning hybrid DE (SHDE) [46], BFO [47], hybrid harmony search (HHS) [48], Maclaurin series-based Lagrangian (MSL) [49], pattern search method (PSM) [50], BBO [51] and DE/BBO [52].

The rest of the paper is organized as follows. In section 'Mathematical problem formulation', the ELD problem formulation is introduced. The CRO and DE algorithms are briefly explained in sections 'Chemical reaction based optimization' and 'Differential evolution', respectively. Section 'HCRO-DE algorithm' illustrates the different steps of the proposed HCRO-DE technique. To prove the efficiency of the solution technique, the simulation results along with cost convergence of the six different test cases are presented in section 'Computational experiment and results'. Finally, Section 'Conclusion' concludes the findings and contributions of this paper.

Mathematical problem formulation

The ELD is one of the most important optimization considerations for management of the power system operation. The ELD problem can be formulated as to find the optimal thermal unit generations to minimize the total cost of fuel while satisfying different operational constraints of thermal unit and load balance constraints.

Objective function

The ELD problem may be described as a minimization problem with the objective as below:

$$\text{Min} \quad \text{FC}(P_g) = \min\left(\sum_{i=1}^{n} FC_i(P_{gi})\right) \tag{1}$$