Electrical Power and Energy Systems 82 (2016) 339–353

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Multiobjective thermal power dispatch using opposition-based greedy heuristic search

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ARTICLE INFO

Article history:
Received 19 March 2015
Accepted 11 March 2016
Available online 31 March 2016

Keywords:
Random search
Heuristic search
Economic load dispatch
Fuzzy theory
Environmental economic load dispatch
Multiple-fuel dispatch

ABSTRACT

This paper proposes an opposition-based greedy heuristic search (OGHS) strategy to solve multi-objective thermal power dispatch problem as a non-linear constrained optimization problem considering operating cost and pollutant emissions as competing objectives. The optimization problem is solved to find global solution, in case any one objective function is non-convex and non-differentiable. To generate initial population opposition-based learning is applied to select good candidates by exploring the search space extensively. Further, opposition-based learning is exploited for migration to maintain the diversity in the set of feasible solutions. Proposed method applies mutation strategy by perturbing the genes heuristically and seeking better one. This concept introduces parallelism and makes the algorithm always greedy for better solution. The greediness and randomness pulls the algorithm towards the global solution. The algorithm is also self sufficient without the need of tuning any parameter that effects acceleration of the algorithm. Fuzzy-theory is employed for decision-making that selects best solution from available non-inferior solutions. Feasible solution is also achieved heuristically that modifies the generation-schedule and avoids violation of operating generation limits. Proposed method has been implemented to analyze economic and multi-objective thermal power dispatch problems considering ramp-rate limits, prohibited-operating-zones, valve-point-loading effects, multiple-fuel options, environmental effects, and exact transmission losses encountered in realistic power system operation. The validity of proposed method is demonstrated on medium and large power systems. Proposed optimization technique is emerged out to compete with existing solution techniques. Wilcoxon signed-rank test for independent samples also proves the supremacy of proposed algorithm OGHS.

Introduction

Today's competitive electric power market necessitates economic thermal power load dispatch of electric power generation due to increasing electric energy demand, shortage of energy resources and deteriorating environment. The basic objective of economic load dispatch of electric power generation is to allocate the output of the committed generating units to meet the load demand at minimum operating cost, while satisfying the physical and operating systems' constraints. Traditionally, fuel cost function of each generation unit has been represented as convex quadratic cost function ignoring valve-point effects. It provides optimum solution that is different from the actual practical solution. Considering physical and operating constraints, economic load dispatch (ELD) problem becomes a non-linear constrained optimization problem. In thermal dispatch problem, the cost function is non-convex as the generating units are composed of multi-valve steam turbines. Prohibited-operating-zones and multi-fuel effects add non-linearity to the problem. A non-convex optimization problem with non-linear constraints cannot be directly solved by conventional mathematical methods. With the increasing concern for the environmental considerations, a revised power dispatch for power generation system came into existence that meets the demand for power while accounting for both cost and emission objectives. However, the operating cost and pollutants emission functions are of conflicting nature that means while minimizing the pollution, the operating cost is maximized and vice versa [24].

The thrust of research has been focused on various optimization techniques and procedures incorporating extended and complex constraints. The mathematical programming that is based on gradients, such as the Newton based solution of optimality conditions, hybrid versions of linear and integer programming, hybrid versions of linear programming and quadratic programming, lambda iterative method, gradient projection method, Lagrange relaxation, linear programming, non-linear programming, interior point

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http://dx.doi.org/10.1016/j.ijepes.2016.03.016

methods, dynamic programming, quadratic programming [29] etc. has been applied to solve ELD. The advantages of these methods include optimality which is mathematically proven in some algorithms [59]; application to large-scale problems [59]; free from problem-specific parameters to specify and are computationally fast. However, these methods converge to a local optimum and are sensitive to the initial starting points. Despite many advantages, gradient methods fail to get global optimal solution for non-smooth and non-convex objective function [22].

Presently, heuristic optimization techniques become popular to solve the economic dispatch problem having non-differentiable regions. Such techniques are genetic algorithm (GA) [6,14,15,20], evolutionary programming (EP) [2,8], differential evolution (DE) and its variants [7,10,18,19,27,28,32,41,68], particle swarm optimization (PSO) [1,5,21,23,25,29,33] and its variants [11,16], Taguchi method [12], bacterial foraging optimization (BFO) [17], ant colony optimization (ACO) [37], cultural self-organizing migrating strategy (CSMS) [30], biogeography-based optimization (BBO) [31,59], firefly algorithm (FA) [50], opposition-based harmony search algorithm (OHSA) [51], artificial bee colony (ABC) [36,58,67] and gravitational search algorithm (GSA) [69], etc. These methods are known for their capabilities of fast search of large solution spaces. However, the heuristic techniques suffer from the drawbacks of the large number of arbitrary or problem-specific parameters [22]. Al-Sumait et al. [13] presented constrained pattern search algorithm to solve power system ELD problem with valve-point effect. Dhillon et al. [24] proposed a binary successive approximation-based evolutionary search strategy to solve economic-emission load dispatch (EELD) problem. Coelho and Mariani [30] proposed a self-organizing migrating algorithm approach combined with a cultural algorithm based on normative knowledge.

Nowadays hybrid methods [15,58] are in use which combines two or more local and global optimization techniques in order to get best features of each algorithm. Victoire and Jeyakumar [3] presented a method for solving the ELD dispatch problem by integrating the PSO with the sequential quadratic programming (SQP) technique. Coelho and Mariani [7] proposed the method which combines the DE algorithm with the generator of chaos sequences and SQP technique to optimize the performance of ELD problems. Wang et al. [10] proposed self-tuning hybrid DE which utilizes the concept of the 1/5 success rule of evolution strategies in the original HDE to accelerate the search for the global optimum. Panigrahi and Pandi [17] used the hybrid BFO technique. The simplex algorithm is used along with BF algorithm. Bhattacharya and Chattopadhyay [27] presented a hybrid technique combining DE with BBO algorithm to solve ELD problems Amjady and Sharifzadeh [28] proposed modified DE which is in the framework of DE owning mutation operator and selection mechanism inspired from GA, PSO and SA, respectively. Jiang et al. [69] discussed a hybrid PSO and GSA to solve EELD problems considering various practical constraints. Fuzzified multi-objective Interactive honey bee mating algorithm is proposed by Ghasemi [65] to solve EELD problem. Ghasemi et al. [74] employed Chaotic local search technique to enhance learning capabilities of ABC algorithm for the solution of EELD problem.

Any proposed optimization method can be attractive choice to solve multi-objective thermal power dispatch problem that may have exclusive advantages like robust and reliable performance, global search capability, little information requirement, ease of implementation, parallelism, no requirement of differentiable and continuous objective function. Moreover, a heuristic search technique requires good exploration and exploitation abilities. A new and simple opposition-based greedy heuristic search technique (OGHS) is proposed to solve economic and multi-objective thermal power dispatch problems. Opposition-based learning is adopted to select the good candidates that accelerate the convergence speed. Opposition-based learning is applied by comparing the objective functions at a point of solution in search space to its opposite solution and preserving the better solution during the initialization of the population and in further flow of algorithm. Mutation operator follows the heuristics to perturb each gene and seek for better gene. As the algorithm progresses to explore the search space, migration introduces the new member from the search space or it's opposite to that of existing point member. Migration provides efficient information sharing mechanism and enhances exploitation ability of the algorithm and makes the algorithm greedy. Moreover, the algorithm doesn't require any tuning of the parameters. Multi-objective thermal power dispatch problems with various variations in problem formulations in term of physical operating conditions of generating units and transmission system are undertaken. Transmission losses, VPL effect and POZ in single and multi-objective frame-work are considered. Multiple-fuels are also considered to solve thermal power dispatch problem. An effective perturbation strategy is applied to move the solutions from infeasible into feasible region.

The paper consists of five sections in total. The ensuing Section 'Problem formulation' concentrates on the mathematical formulation of the problem under consideration along with various constraints that include generation limits, power demand, prohibited-operating-zones, ramp-rate limits and exact transmission losses. Constraint handling strategy is discussed in Section 'Con straint handling'. Section 'Proposed method' explains the OGHS algorithm in detail. In Section 'Test systems and results', the results on different power systems by applying proposed OGHS algorithm and the comparison of results is performed with those available in literature. Sections 'Convergence and sensitivity' and 'Statistical analysis' discuss the tests to ascertain the competitiveness of the algorithm.

Problem formulation

Power load dispatch problem can be solved as single or multiple objective optimization problems. One optimization problem is defined as economic load dispatch problem where single objective that is operating cost is minimized under physical and operating constraints. Other optimization problem is defined as economic-emission load dispatch problem where two objectives that are operating cost and environmental effects are minimized simultaneously under physical and operating constraints.

Economic thermal power dispatch problem

Economic thermal power dispatch problem is basically revolves around minimizing the cost of operation constrained with the physical operating conditions. The major factor which defines the feasible region for the solution schedule are generating units' maximum and minimum operating limits, prohibited operating zones and ramp-rates of these units, power demand constraint, transmission losses. Economic dispatch problem is defined as single objective problem in which the operating cost of committed thermal generating units is the main objective along with its constraints and is given below:

$$\textit{Minimize } F_1(P_{gi}) = \begin{cases} \sum_{i=1}^{N_g}\left(a_iP_{gi}^2 + b_iP_{gi} + c_i + \left|d_i\sin\left\{e_i\times\left(P_{gi}^{min} - P_{gi}\right)\right\}\right|\right)\ \$/\mathrm{h}; & \textit{one type of fuel} \\ \sum_{i=1}^{N_g}\left(a_{ik}P_{gi}^2 + b_{ik}P_{gi} + c_{ik} + \left|d_{ik}\sin\left\{e_{ik}\times\left(P_{gik}^{min} - P_{gi}\right)\right\}\right|\right)\ \$/\mathrm{h}; & \textit{multiple type of fuel} \end{cases} \tag{1a}$$