Energy 113 (2016) 1147–1161

Contents lists available at ScienceDirect

Energy

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

An efficient crisscross optimization solution to large-scale non-convex economic load dispatch with multiple fuel types and valve-point effects

Anbo Meng*, Jinbei Li, Hao Yin

School of Automation, Guangdong University of Technology, Guangzhou 510006, China

ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form
9 July 2016
Accepted 26 July 2016

Keywords:
Economic dispatch problem
Crisscross optimization algorithm
Multiple fuel options
Valve-point effects
Large-scale optimization

ABSTRACT

As one of important optimization problems in power system, economic dispatch (ED) with multiple fuel options is characterized by high non-convexity, non-linearity and discontinuity. The combined action of multiple fuel options and valve-point effects increases the degree of difficulty to solve the ED problem. In this paper, a recently developed heuristic algorithm called crisscross optimization algorithm (CSO) is attempted to address the large-scale and non-convex ED problem with both multiple fuel options and valve-point effects taken into account. The proposed CSO method solves the ED problem through horizontal crossover and vertical crossover. The former searches for the new solutions within a half population of hyper-cubes by adopting a cross-border search approach while the latter provides a unique mechanism to prevent from the premature convergence problems based on the concept of dimensional local minimum. Both operators alternatively generate moderation solutions which are subsequently updated by an elite selection strategy. The proposed method is validated on six test systems consisting of 10–640 generating units and compared with other state-of-the-art methods in the literature. The results show that CSO yields higher quality solutions especially for solving large-scale ED problems with multiple fuel options.

1. Introduction

Scarcity in energy resources, increasing power generation cost and ever-growing demand for electric energy necessitates optimal economic dispatch in today's power systems [1]. The objective of economic dispatch (ED) is to minimize the cost of operation by optimally allocating power output among the committed generating units while satisfying various constraints imposed on the system and units. Usually, the ED problem is a complex optimization problem characterized by non-convexity, non-linearity and high dimensionality. The complexities are due to the design specifications and operation constraints of the generating units such as the spinning reserve, transmission losses, prohibited operation zones, valve-point effects and multiple fuel options. In the traditional ED problem, the cost function for each thermal generating unit is often approximated by a single quadratic function and the valve-points effects are ignored, which would often introduce inaccuracy into the resulting dispatch [2]. But in practical power system, many thermal generating units are supplied with multiple fuels like coal, natural gas and oil. In this circumstance, the cost function of ED problem is no longer represented as a single quadratic function but non-smooth piecewise quadratic function. Besides, to obtain more accurate cost model, the valve-point effects must also be taken into account in practical ED problems. When both multiple fuel options and valve-point effects are simultaneously considered in the large-scale ED problem with hundreds of units, it would pose a big challenge for the optimization techniques to deal with such a complex non-convex problem due to a sharp rise in discontinuous values and local optima.

Conventional approaches to solve the convex ED problem usually use deterministic methods like hierarchical approach based on the numerical method (HNUM) [3], Maclaurin series-based Lagrangian method (MSL) [4], Quadratic Programming (QP) [5] and others. Unfortunately, most of these methods require that the cost curves of thermal generating units be smooth and differentiable. Apparently, they fail to address more realistic non-convex ED problems considering the valve-point effects and multiple fuel options. Although the dynamic programming technique does not

* Corresponding author.
E-mail address: menganbo@vip.sina.com (A. Meng).

http://dx.doi.org/10.1016/j.energy.2016.07.138

impose any restrictions on the structure of the optimization system but it is easy to suffer from the curse of dimensionality [6], especially for large-scale test system.

In recent years, many researchers devote more efforts to solve the non-convex ED problems by applying various heuristic search techniques. Some of them only consider the valve-point effects, such as improved fast evolutionary programming (IFEP) [7], improved group search optimization (IGSO) [8], chaotic differential evolution and sequential quadratic programming (DEC-SQP) [9], incremental artificial bee colony with local search (IABC-LS) [10], particle swarm optimization technique with the sequential quadratic programming (PSO-SQP) [11], chaotic bat algorithm (CBA) [12], hybrid grey wolf optimizer (HGWO) [13], bacterial foraging with Nelder–Mead algorithm (BF-NM) [14], self-organizing hierarchical particle swarm optimization (SOH_PSO) [15], chaotic particle swarm optimization algorithm and sequential quadratic programming techniques (CPSO-SQP) [16], hybrid algorithm consisting of genetic algorithm, pattern search and sequential quadratic programming techniques (GA-PS-SQP) [17], firefly algorithm (FA) [18], particle swarm optimization with time varying acceleration coefficients (IPSO-TVAC) [19], modified shuffled frog leaping algorithm (MSFLA) [20], shuffled differential evolution algorithm (SDE) [21], chaotic self-adaptive particle swarm optimization algorithm (CSAPSO) [22], multi-strategy ensemble biogeography-based optimization (MsEBBO) [23]. Other heuristic algorithms, such as enhanced augmented Lagrange Hopfield network (EALHN) [24], adaptive hopfield neural networks (AHNN) [25], integer coded differential evolution-dynamic programming (ICDEDP) [26], augmented Lagrange Hopfield network (ALHN) [27], are committed to the multiple fuel options without taking into account the valve-point effects. However, in more realistic ED problem, both of them need to be taken into account for obtaining more accurate scheduling results of generation. In view of this, a number of heuristic algorithms are used to address the ED problems with multiple fuel options and valve-point effects considered. According to the reported literature, they can be classified as original, improved or hybrid heuristic algorithm. The original heuristic algorithms include cuckoo search algorithm (CSA) [6], particle swarm optimization (PSO) [28], genetic algorithm (GA) [28], tabu search algorithm (TSA) [28], differential evolution (DE) [29], auction-based algorithm (AA) [30], differential harmony search algorithm (DHS) [31], group search optimizer (GSO) [32], biogeography-based optimization (BBO) [33], seeker optimization algorithm (SOA) [34]. However, the original methods are usually easy to suffer the convergence stagnancy especially when directly applied to large-scale test systems consisting of hundreds of units. To further enhance global search ability for solving the ED problem with multiple fuel options and valve-point effects, some improved and hybrid enhanced versions have also been reported in the literature, including real-coded genetic algorithm (RCGA) [35], adaptive real coded genetic algorithm (ARCGA) [36], new adaptive particle swarm optimization algorithm (NAPSO) [37], chaotic modified shuffled frog leaping algorithm (CMSFLA) [38], improved particle swarm optimization (IPSO) [39], anti-predatory particle swarm optimization (APSO) [40], incorporating a real-valued mutation operator into the particle swarm optimization algorithms (PSO-RVM) [41], particle swarm optimization with both chaotic sequences and crossover operation (CCPSO) [42], rank cuckoo search algorithm (ORCSA) [43], global-best harmony search algorithm (GHS) [44], estimation of distribution and differential evolution cooperation (ED-DE) [45], combines differential evolution and particle swarm optimization algorithms (DEPSO) [46], oppositional real coded chemical reaction algorithm (ORCCRO) [47], real coded chemical reaction algorithm (RCCRO) [48], colonial competitive differential evolution (CCDE) [49], synergic predator-prey optimization algorithm (SPPO) [50], new particle swarm optimization with local random search (NPSO_LSR) [51]. Compared with traditional mathematical methods, these aforementioned methods are commonly inspired by observing natural swarming behavior or physical phenomenon. As they have no restrictions on the cost function of units, it is feasible to use them to solve the non-smooth ED problem with multiple fuel options and valve-point effects. However, when applied to large-scale test system, they are usually prone to suffer from the premature convergence problem. So far, the majority of them are mainly validated on the 10-unit system [2] and only few of them are attempted to be applied into test systems with more than 100 units. Therefore, it is still a big challenge for heuristic algorithms to overcome the curse of dimensions and address premature convergence problem in solving the large-scale ED problem consisting of hundreds of generating units with multiple fuel options.

In this paper, a novel heuristic search technique called crisscross optimization (CSO) algorithm [52] is applied to solve the large-scale ED problems with both multiple fuel types and valve-point effects taken into account. CSO is our recently developed optimization algorithm for numeric optimization, which has proved a great advantage over other methods in addressing the high-dimensional multimodal problems. For example, in Refs. [53] and [54], CSO has successfully been applied to address the large-scale dynamic economic dispatch problem (DED) and combined heat and power economic dispatch problem (CHPED), respectively. In view of this, we first attempt to use it to address the non-convex ED problem with multiple fuel types in large-scale electric power system. It needs to point out that the main scope of the paper is to assess the effectiveness of the proposed CSO algorithm on the large-scale ED problem with multiple fuel types and valve-point effects. Due to its complexity, CSO, like other compared methods in the literature, only considers the generation capacity limits. Some other constraints such current fuel prices, spinning reserve requirements, prohibited operating zones and others are not taken into account in this study. Therefore, the simplified ED problem can not reflect the real complexity of power system.

The novelty and contributions of this paper can be summarized as follows: 1) The proposed CSO method addresses the ED problem with multiple fuel options through two interacting search operators, namely horizontal crossover and vertical crossover. The former enhances the global search ability by adopting a cross-border search mechanism while the latter addresses the premature convergence problem by applying a unique arithmetic crossover operation in dimensional directions. This feature of CSO seems to be able to alleviate the convergence stagnancy phenomena even for the large-scale test system consisting of up to hundreds of units with multiple fuel options. 2) The proposed CSO method has only one adjustable parameter, namely the vertical crossover probability P_v. An interesting finding is that the P_v value seems to have little influence on the optimal results obtained in different test systems once it is set to more than 0.35. This feature shows the robustness and adaptability of CSO for solving the ED problems with multiple fuel options. 3) Several test cases are used to validate CSO's effectiveness and the results show the proposed method yields better solutions than other heuristic algorithms in the literature. To further test the comprehensive performance of CSO, two new test systems consisting of up to 640 generating units are also considered. The obtained result again confirms the suitability of the proposed CSO approach to solve large-scale ED problems with multiple fuel options.

The rest of this paper is organized as follows. Section 2 presents the ED's mathematical formulation. The proposed CSO method is described in detail in Section 3 and the implementation of CSO to the ED problem is described in Section 4. In Section 5, six test