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Chaotic differential bee colony optimization algorithm for dynamic economic dispatch problem with valve-point effects

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ABSTRACT

Dynamic economic dispatch (DED) plays an important role in thermal system operation, and it also presents non-smooth and non-convex characteristics while considering valve-point effects. In this paper, chaotic differential bee colony optimization algorithm (CDBCO) is adopted to solve DED problem considering valve-point effects. To increase the global search ability, chaotic sequences are applied to generate candidate solutions and a new searching mechanism based on DE/best/1 strategy and feasibility method is used to generate new solutions. Moreover, a chaotic local search (CLS) method is used to help bee colony optimization (BCO) overcome the drawback of premature convergence and increase the local exploitation capability. During the optimal process, a heuristic constraint handling strategy is introduced to deal with the various constraints of DED problem. Finally, the feasibility and effectiveness of the proposed CDBCO algorithm is proved by four test cases units and compared with other methods reported in recent literatures. The simulation results show that the proposed method can get higher-quality solutions with short computational time.

Introduction

The fundamental purpose of the power system is to determine the most effective, reliable and economic operation when a certain amount of electricity is required. To achieve this goal, the reasonable planning and operation instruction for generators is indispensable [1,2]. Dynamic economic dispatch (DED) is a real-time power system problem, which aims to reasonably arrange the power outputs of the committed generators hour by hour to meet the load demand and minimize the total fuel cost while satisfying ramp rate limits and other constraints. As a wise and proper scheduling of thermal units, DED can decrease the production cost significantly, at the same time increases the safety and reliability of the power system. Therefore, DED plays a critically important role in power system operation, the researching and solving for DED problem is meaningful and crucial to enhance the economy and reliability of the power system. Traditionally, the previous cost function for each generator is represented as a convex quadratic function. Due to the wire-drawing effects [3] of the steam valves in large steam turbines, the generator exhibits the characteristics of non-smooth and non-convex, neglecting of the valve-point effects would lead an inaccuracy to dispatch results. In addition, there are various complex equality and inequality constraints that include real power balance, unit ramp rate limits and prohibited operating zones limits need to consider. Thus, DED problem with valve point-effects is a more accurate formulation with large-scale, dynamic, nonlinear and non-convex characteristics which makes the global optimal searching more challenging [4].

Different methods have been proposed and discussed to solve the DED problem by many other scholars in the past decades. These traditional methods included linear programming (LP) [5], non-linear programming (NLP) [6], quadratic programming (QP) [7], lagrange relaxation (LR) [8], dynamic programming (DP) [9], and they received different degrees of success. However, most of these methods have their own shortcomings in finding the optimal solution while applying them to solve DED problem with valve-point effects. DED possesses the characteristics of nonlinear and non-smooth, therefore LP would generate errors due to the process of linearizing the DED model. For the implementation of NLP and QP, the objective function must be continuous and differential, which would lead the inaccuracy to the final solution. Lagrange multipliers updating strategy affects the efficiency of LR and produces the oscillation of the solution. DP is a useful method to deal with DED problem with valve-point effects, but it suffers from the "curse of the dimensionality" with a high computation cost while

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being applied in large scale power system. Hence, in order to improve the operation quality and efficiency, it is necessary to seek for other optimization techniques.

Recently, a lot of modern heuristics stochastic methods such as the genetic algorithm (GA) [10], evolution program (EP) [11], simulated annealing (SA) [12], differential evolution algorithm (DE) [3,13], and particle swam optimization (PSO) [4,14], harmony search (HS) [15], krill herd algorithm (KHA) [1], quantum evolutionary algorithm (QEA) [16], chemical reaction optimization (CRO) [2], bee matting algorithm (BMO) [17], bacterial foraging (BF) [18] and ant colony optimization (ACO) [19] have been successfully employed to solve the complex economic dispatch problem with practical modeling of operation constraints. Difference from traditional mathematical methods, these methods are not enslaved to any restrictions on the shape of the cost curves due to their powerful optimization searching ability, thus, high quality solutions can be gotten within an acceptable time. However, most of these heuristics stochastic methods may be premature due to their drawbacks in balancing global exploration and local exploitation [16]. Thus, to surmount the drawback of single intelligent algorithm, hybrid algorithms which consisted of two or more optimization methods are proposed to increase the global searching performance and accelerate the convergence speed. Recently, different hybridization techniques such as chaotic self-adaptive differential harmony search (CSADHS) [20], hybrid DE-PSO [21], Hybrid bare-bones PSO (BBPSO) [22], BCO-SQP [23], hybrid DE (HDE) [24] are proposed for obtaining better quality solutions of DED problems. Compared to a single algorithm, although sometimes hybrid methods spend more computation time and need to set more parameters, they can use the advantages of each method to get a better optimal solution with good efficiency. Therefore, it is meaningful to develop new algorithm to solve DED problem.

Bee colony optimization algorithm (BCO), a latest swarm based meta-heuristic algorithm, which was first proposed by Karaboga [25] in 2005, has provided good performance in solving various practical engineering problems in power system, and some applications of BCO are listed in the literatures [26–29]. BCO is specifically based on the foraging behavior of honey bee colonies. Compared with other evolution algorithm, BCO is a simple and convenient method with less control parameters, which demonstrated high efficiency in solving optimization problems with non-smooth and non-convex characteristics. However, the standard BCO still has some shortcomings. The week searching mechanism makes the convergence speed slow. BCO often suffers the premature convergence problem and falling into the local optimum easily. Furthermore, for the DED problem, the standard BCO normally lacks of effective mechanism to handle complicated constrains. In allusion to the problems mentioned above, chaotic differential bee colony optimization algorithm (CDBCO), combined with BCO and DE, is proposed to solve the DED problem with valve-point effects in this paper. In order to increase the diversity of the solutions and enhance convergence speed, the logistic map is used to generate the initial solutions. Moreover, to improve the global search ability and increase the convergence speed, the new searching mechanism based on DE/best/1 [30] strategy with the mutation, crossover and selection is introduced to generate new solutions. Besides, a chaotic local search (CLS) method is used to help BCO avoid premature convergence and increase the exploitation capability of algorithm. Especially, some heuristic constrain handling strategies are presented based on the characteristics of DED problem to handle various constrains effectively, especially for the real power balance, unit ramp rate limits and prohibited operating zones limits constraints. Finally, to verify the feasibility and effectiveness of the proposed CDBCO method, it is applied to four test cases, and the simulating results are compared with other methods reported in the recent literatures. The simulation results reveal that CDBCO can be a promising alternative for solving DED problem which can get higher-quality solutions with a short computational time.

The rest of the paper is organized as follows: Section 'Problem formulation' describes the model of the DED problem. Section 'Overview of standard bee colony optimization (BCO)' briefly introduces the standard BCO algorithm. Section 'Chaotic differential bee colony algorithm (CDBCO)' shows the idea of the proposed CDBCO method in details. Section 'Chaotic differential bee colony optimization for DED problem' proposes the application of the proposed to the DED problem. Section 'Numerical simulation' shows the result of the proposed CDBCO on benchmark problems. Section 'Case study' gives the numerical examples to verify the effectiveness of the proposed CDBCO. Section 'Conclusions' outlines the conclusions followed by acknowledgement.

Problem formulation

The objective of the classical DED problem is to make the total fuel cost minimum while satisfying various constraints during the given time periods. Normally, the objective function and constraints concerned of the DED problem are described as follows:

Objective function

$$F = \min \sum_{t=1}^{T} \sum_{i=1}^{N} f_i(p_i^t) \tag{1}$$

where T is the number of dispatch intervals. N is the number of thermal generators. F is the total fuel cost. p_i^t is the output of the ith unit at the tth interval. $f_i()$ is the cost function of the ith unit.

Traditionally, the cost function for each generator is represented as a convex quadratic function which can be described like this:

$$f_i(p_i) = a_i + b_i p_i + c_i p_i^2 \tag{2}$$

where a_i, b_i, c_i are the cost coefficients of unit i.

However, in reality, when the stream admission valve opens, the fuel cost will increase dramatically due to the wire drawing effect, which makes the practical objective function have non-differentiable points. Therefore, to make the cost function of thermal generators reflect the practical situation, the sinusoidal function is added into the model. The solid line of Fig. 1 shows the performance curve of the thermal unit with valve points. The cost function of units with the valve point affects considered can be expressed as follows:

$$f_i(p_i) = a_i + b_i p_i + c_i p_i^2 + |e_i \sin(h_i(p_{i,\min} - p_i))| \tag{3}$$

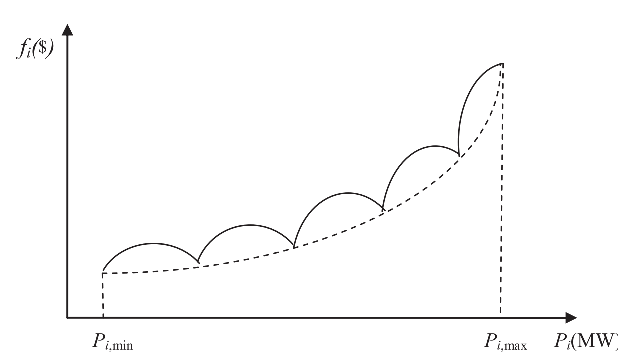

Fig. 1. The performance curve of the thermal unit with valve points.