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An efficient harmony search with new pitch adjustment for dynamic economic dispatch

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ABSTRACT

A simple yet efficient harmony search (HS) method with a new pitch adjustment rule (NPAHS) is proposed for dynamic economic dispatch (DED) of electrical power systems, a large-scale non-linear real time optimization problem imposed by a number of complex constraints. The new pitch adjustment rule is based on the perturbation information and the mean value of the harmony memory, which is simple to implement and helps to enhance solution quality and convergence speed. A new constraint handling technique is also developed to effectively handle various constraints in the DED problem, and the violation of ramp rate limits between the first and last scheduling intervals that is often ignored by existing approaches for DED problems is effectively eliminated. To validate the effectiveness, the NPAHS is first tested on 10 popular benchmark functions with 100 dimensions, in comparison with four HS variants and five state-of-the-art evolutionary algorithms. Then, NPAHS is used to solve three 24-h DED systems with 5, 15 and 54 units, which consider the valve point effects, transmission loss, emission and prohibited operating zones. Simulation results on all these systems show the scalability and superiority of the proposed NPAHS on various large scale problems.

1. Introduction

Dynamic Economic Dispatch (DED) is an important part of the power system operation, which determines the optimal generation schedule of on-line generators, to meet the predicted load demand over a time horizon, while meeting various power system and environment constraints and requirements [1]. In comparison with conventional economic dispatch which is scheduled and operated at a fixed time, the unexpected variation in load demands makes it a challenging problem in real time power system operation. Apart from the operating limits, power balance constraints, valve-point effects, power transmission losses, and ramp-up and ramp-down constraints have added complexities to the DED problem.

Dynamic economic dispatch was first introduced in 1971 by Bechert and Kwanty [2] in order to overcome the disadvantage of static optimization. Since then, mathematical tools, such as dynamic programming [3,4], gradient algorithm [5], interior point quadratic programming method [6], Lagrange relaxation [7], nonlinear programming [8,9], and Maclaurin series based Lagrangian (MSL) [10] have been employed to solve the problem. These methods have a few distinctive merits, such as requiring less computing time and having fewer parameters to adjust. Further, the error boundary and optimality of the methods can be given mathematically. However, a common issue is that these methods cannot guarantee the convergence to the global minimum and the performance may be affected by the initial solutions. Methods like the Lagrange relaxation and gradient methods are only applicable to convex objective functions. While for real-world DED problems, there exist several nonlinear characteristics including prohibited zones, ramp rate limits, and non-smooth or non-convex cost functions due to the valve-point effect. Therefore, the cost function needs to be linearized or simplified in order that these analytic approaches can be employed. As a result, large errors can be produced and the resultant dispatch solutions may not be satisfactory. Dynamic programming imposes no restriction on the characteristics of the objective function, but it suffers from the curse of dimensionality problem and is computationally very expensive for large scale DED problems.

In recent years, meta-heuristic techniques such as genetic algorithm (GA), evolutionary programming (EP), simulated annealing (SA), particle swarm optimization (PSO) and differential evolution (DE) have attracted a lot of attention in solving DED problems due

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to their ability to handle complex optimization problems. For example, Ongsakul and Tippayachai developed a parallel microGA based on merit order loading solutions (PMGA-MOL) for constrained DELD problems [11], and SA was applied in Ref. [12]. Yuan et al. proposed a modified DE to solve the DED problem with valve-point effect [13] and an adaptive dynamic parameter control mechanism was introduced in Ref. [1]. An artificial immune system (AIS) algorithms based on clonal selection was employed in Ref. [14] and a method based on the Pattern Search was proposed in Ref. [15], which considered both the ramp rate limits and transmission loss. Other methods have also been reported, such as the quantum based GA (QGA) [16], PSO with adaptive parameter mechanism (APSO) [17], improved chaotic particle PSO (ICPSO) [18], enhanced cross-entropy (ECE) [19], BF-NM [20] and artificial bee colony (ABC) algorithm [21]. Despite a lot of progresses have been made on meta-heuristic approaches for the DED problem, there is still much room to improve on their searching capability, stability and convergence characteristics. For instance, it is difficult to set several efficient control parameters for SA, and the corresponding computational time is considerably long for complex problems. Conventional PSO and GA may suffer from premature convergence and other algorithms may have complex operation structures which may significantly restrict their global searching ability and computational efficiency. Therefore, it is vital to develop new fast and effective meta-heuristic algorithms which can be applicable for large scale DED problems.

The harmony search (HS), a new intelligent optimization technique developed by Geem et al. [22] in recent years has found a number of successful applications in some real world problems [23–25]. HS has also been used for static economic load dispatch problems [26–29]. Although HS is able to identify the high performance regions in the solution space, it does not have a good local searching capability [30] and several design parameters have to be chosen for each specific problem. To enhance the fine tuning capability and to reduce the number of design parameters, several variants have been proposed. An adaptive strategy for setting parameters namely IHS was introduced in [30]. Global-best harmony search (GHS) combined with the concept of global best in PSO was proposed [31]. Self-adaptive global best harmony search (SGHS) [32] was proposed which combines the aforementioned two improvements. Further, the explorative harmony search (EHS) was investigated in [33]. All these HS variants have shown their superiority in different application case studies, but their computational efficiency has not yet been verified on large-scale optimization problems, including the DED problems. A harmony search combined with the operation strategy of PSO (HHS) [34] was proposed for the DED problem. However, during the searching process, some information is required from PSO, including the best solutions and velocity of individuals, which may increase the computation time and introduce extra design parameters.

This paper proposes a novel yet simple harmony search method with a new pith adjustment rule, namely NPAHS for the DED problem. To enhance the performance and overcome the premature convergence, the new pith adjustment rule uses the mean value information of the population to both improve the diversity of the solutions and to accelerate the convergence. It is noticed that most methods reported in literatures ignore the requirement that the scheduling solutions for the last interval time during the whole scheduling period should meet the ramp rate limits, which is important in practical economic dispatch. Only in Ref. [15], a handling method was mentioned, though no details were given. This ignorance should be considered in real world applications, as the dispatches for the last interval time of the current scheduling period and the first interval time of the next scheduling period should also meet the ramp rate limits for the sake of smooth transition between two consecutive scheduling cycles. To address this requirement, an effective constraint and boundary handling technique, including the determination of output limits for the last interval time is proposed in this paper.

Further, the ever increasing public awareness of environmental protection and stricter legislations has demanded power system operators to improve the operational strategies to reduce pollutant and atmospheric emissions from thermal power plants. In addition to conventional DED, the dynamic economic emission dispatch (DEED) is also addressed in this paper, in which both the emissions and the fuel cost are considered. Similar to the literatures [15,20,35,36], weight setting method is employed to convert the multi-objective DEED into a single-objective problem.

To evaluate the performance of the proposed NPAHS, 10 benchmarks including unimodal, multimodal and discontinuous types with 100 dimensions and three DED problems are used. The performance of NPAHS is compared with HS, IHS, GHS and SGHS. Apart from four variants of HS, several other popular methods including CLPSO [37], PSO-CF [38], DE [39], CoDE [40] and GA [41], are also tested.

The remainder of this paper is organized as follows. Section 2 presents the problem formulation of DEED. Section 3 describes the proposed harmony search algorithm (NPAHS), and its implementation for the DEED problem. Sections 4 and 5 present the results of the proposed NPAHS on benchmark problems as well as on three power systems. Section 6 concludes the paper.

2. Problem formulation

The dynamic economic emission dispatch (DEED) aims to determine the optimal generation levels of all on-line units during a specified period of time (e.g. 24 intervals a day) so as to minimize the total fuel cost and emissions subject to a number of equality and inequality constraints. In this paper, valve-point effects, prohibited operating zones and transmission losses are considered. The overall problem can be mathematically formulated as follows:

2.1. Objective function

2.1.1. Fuel cost

In reality, the steam valves in large steam turbines introduce the valve-point effect and a sharp increase of fuel loss needs to be added to the fuel cost curve [42]. To model the fuel cost taking into account the valve-point effect will inevitably lead to non-smoothness of the cost function and multiple local optimal points in the solution space. The fuel cost (F_C) with valve-point effect is given as follows:

$$F_C = \sum_{t=1}^{T}\sum_{j=1}^{N} a_j P_{j,t}^2 + b_j P_{j,t} + c_j + \left|d_j \sin\left(e_j\left(P_{j\,\min} - P_{j,t}\right)\right)\right| \tag{1}$$

where a_j, b_j, c_j, d_j and e_j are the fuel cost coefficients of the unit j, $P_{j\,\min}$ is the minimal output of the jth unit, $P_{j,t}$ is the output power of unit j at interval t, N is the number of units in the power system for optimization, T denotes the total number of intervals during the scheduling period.

2.1.2. Emission

To reduce the amount of the atmospherical pollutants released into the air, the emission is also introduced into the objective function [43]. The quantitative expression of the emission (F_E) can be formulated as