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Multi-elite guide hybrid differential evolution with simulated annealing technique for dynamic economic emission dispatch

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ABSTRACT

This paper proposes an improved multi-objective differential evolutionary algorithm named multi-objective hybrid differential evolution with simulated annealing technique (MOHDE-SAT) to solve dynamic economic emission dispatch (DEED) problem. The proposed MOHDE-SAT integrates the orthogonal initialization method into the differential evolution, which enlarges the population diversity at the beginning of population evolution. In addition, modified mutation operator and archive retention mechanisms are used to control convergence rate, and simulated annealing technique and entropy diversity method are utilized to adaptively monitor the population diversity as the evolution proceeds, which can properly avoid the premature convergence problem. Furthermore, the MOHDE-SAT is applied on the thermal system with a heuristic constraint handling method, and obtains more desirable results in comparison to those alternatives established recently. The obtained results also reveal that the proposed MOHDE-SAT can provide a viable way for solving DEED problems.

1. Introduction

Dynamic economic dispatch (DED) is an important task in the power system operation, it allows for more advanced treatment of economic dispatch (ED), and the main goal is to operate electric power systems at minimum total fuel cost while satisfying system inequality and equality constraints [1]. However, the increasing public awareness of environmental protection has forced to improve the operational strategy for reducing pollutant emission of thermal units, several strategies must be taken to reduce the atmospheric emissions, they often include installation of cleaning equipment, switching to low emission fuels, replacement of aged fuel-burners with clearer ones and emission dispatch. The first three choices require installation of new equipment and/or modifications of the existing ones that need considerable capital outlay, which can be considered only as long-term options [2–4].

Then emission dispatch becomes another crucial objective in the power dispatch, and DED has been extended to environmental/economic dispatch (DEED) problem, which needs to optimize the fuel cost and pollutant emission simultaneously. However, the consideration of pollutant emission will increase the fuel cost, DEED can be taken as a multi-objective problem (MOP) with non-commeasurable and contradictory objectives, many approaches and methods have been proposed to solve this problem [5–9].

In conventional way, the DEED problem is converted into a single objective by linear combination with given objective weights [10–13], literature [14] presents DED based on a simulated annealing (SA) technique for the determination of the global or near global optimum dispatch solution, literature [15] proposes Maclaurin series based Lagrangian method (MSL) to solve the DED problem for generating units with valve-point effect, considering the ramp-rate limits and spinning reserve constraint, Pattern search (PS) and Particle swarm optimization (PSO) methods are presented to solve DEED problem with linear-weighted methods [16,17]. Though it can improve the optimization mechanism and obtain some satisfactory results, it has three drawbacks: (i) It may fall into local optima, and lead to premature convergence problem; (ii) It takes a series of separate runs to obtain Pareto-optimal solutions; (iii) The objective weight can be difficult to obtain in reality.

Afterwards, some multi-objective evolutionary algorithms have been proposed to optimize these objectives simultaneously and produce a set of non-dominated solutions for decision-making, such as niched Pareto genetic algorithm (NPGA) [18], non-dominated sorting genetic algorithm II (NSGA-II) [19], strength Pareto evolutionary algorithm (SPEA) [20], multi-objective particle swarm optimization (MOPSO) [21–23], and multi-objective differential evolution (MODE) [24], and so on. In this paper, an improved multi-objective differential evolutionary algorithm is proposed to solve this DEED problem.

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Differential evolution (DE) was originally proposed by Storn and Price for optimization problems over the continuous space [25], it is a simple yet powerful population based direct search algorithm for optimizing problems using real value parameters. In comparison to other evolutionary algorithm, DE is more ease of use and higher speed of evolutionary convergence. Within a short span of about fifteen years, DE has been widely used to solve single objective global optimization problems owe to its simple optimization structure, great robustness and fast convergence rate. Due to its high efficiency for dealing with single objective problems, DE has been extended to solve those MOPs in the continuous domain. Pareto differential evolution was initially proposed by Abbass with applying DE to MOPs [26], and then achieved good results by Madavan's Pareto differential evolution approach (PDEA) [27]. Then Xue et al. introduced multi-objective differential evolution (MODE) with its individual fitness using pareto-based ranking [28], Rolic and Filipic's differential evolution for multi-objective optimization (DEMO) obtained good results with its efficient population update strategy [29]. Though these methods can obtain a set of desirable results, they also fall into premature convergence problem that all evolutionary algorithms suffer.

In this paper, an improved multi-objective differential evolutionary algorithm is proposed to solve the DEED problems. The orthogonal initialization is implemented to enlarge the search scale before the population evolution, and the annealing technique is used to control the population diversity in the mutation operator adaptively, which can avoid premature convergence problem to certain degree. In additional, a new diversity metric of Pareto front is also integrated into the external archive set to control the diversity distribution, which can provide the most representative non-dominated solutions for decision-making. Furthermore, the proposed algorithm is applied on the thermal system for solving the DEED problem, and obtains the satisfactory non-dominated schemes and trade-offs of DEED problem.

This paper is organized as follows: the problem formulation of DEED is shown in Section 2, the basic principles of multi-objective optimization are introduced in Section 3, the proposed multi-objective differential evolutionary algorithm and the implementation of the proposed algorithm are presented in Section 4 and Section 5, and the obtained results of case study are given in Section 6.

2. Problem formulation

The DEED problem is to minimize the fuel cost and pollutant emission synchronously while satisfying various equality and inequality constraints of physical requirement and system load demand of thermal units, which are shown as follows:

2.1. Minimization of fuel cost

The objective of ED is to minimize the total fuel cost of thermal power system, which is presented as the summation of fuel cost in N generating units for T intervals over the given dispatch horizon, it can be described as follows [17]:

$$\min F_1 = \sum_{t=1}^{T}\sum_{i=1}^{N}[f_i(P_{i,t})] \tag{1}$$

where F_1 denotes the total fuel cost of thermal power system, $f_i(P_{i,t})$ represents the thermal cost of the ith thermal unit at the tth time interval, $P_{i,t}$ is the generated power in the ith thermal unit at tth time interval, T is the length of total dispatch period, N is the number of thermal units.

Traditionally, the generator cost curve is presented in form of quadratic functions of thermal power, which is represented as follows [17]:

$$f_i(P_{it}) = a_i + b_iP_{it} + c_i{P_{it}}^2 \tag{2}$$

where a_i, b_i, c_i are the coefficients of fuel cost in the ith thermal unit. However, since the wire drawing effects will occur when steam admission valve starts to open, the above presentation cannot reflects the sharp increase of fuel cost in reality. For modeling the DEED problem accurately, the generator cost curves of thermal power unit can be represented by quadratic functions with sine components of valve loading effects [19]:

$$f_i(P_{it}) = a_i + b_iP_{it} + c_iP_{it}^2 + \left|d_i \sin(e_i(P_{i,\min} - P_{it}))\right| \tag{3}$$

where a_i, b_i, c_i, d_i, e_i are the coefficients of the ith thermal unit, $P_{i,\min}$ is the minimum output of the ith thermal unit.

2.2. Minimization of emission rate

As more concern about pollutant emission of thermal units, the emission rate of harmful substance becomes the focus of environmental problem. Due to the main effects of harmful substance caused by the nitric oxide (NO_x), the emission rate of nitric oxide is often taken as another objective in the power dispatch [30]. And the total emission rate of thermal system is presented as follows [19]:

$$\min F_2 = \sum_{t=1}^{T}\sum_{i=1}^{N}e_i(P_{it}) \tag{4}$$

where $e_i(P_{it})$ represents the emission rate of the ith thermal unit at tth dispatch interval, it is often described as [19]:

$$e_i(P_{it}) = \alpha_i + \beta_iP_{it} + \gamma_i{P_{it}}^2 + \zeta_i \exp(\lambda_iP_{it}) \tag{5}$$

where α_i, β_i, γ_i, ζ_i, λ_i are the coefficients of emission rate at the ith thermal unit.

2.3. Constraints

(1) System load balance constraint [17]:

$$\sum_{i=1}^{N}P_{it} = P_{Dt} + P_{Lt} \tag{6}$$

where P_{Dt} denotes the system load at tth dispatch interval, P_{Lt} represents the transmission loss at tth time interval, it also can be expressed as follows:

$$P_{Lt} = \sum_{i=1}^{N}\sum_{j=1}^{N}P_{it}B_{ij}P_{jt} + \sum_{i=1}^{N}B_{0i}P_{it} + B_{00} \tag{7}$$

where B_{ij}, B_{0i} and B_{00} are loss coefficients of generation units.

(2) Power generation limits [17]:

$$P_{i,\min} \le P_{it} \le P_{i,\max}, \quad i = 1, 2, \ldots, N, \quad t = 1, 2, \ldots, T \tag{8}$$

where $P_{i,\min}$, $P_{i,\max}$ are the minimum and maximum outputs of the ith thermal unit.

(3) Generating unit ramp rate limits [17]:

To ensure the thermal output on the feasible domain, the ramp limits are described as below:

$$\begin{cases} P_{it} - P_{i,t-1} \le UR_i \\ P_{i,t-1} - P_{it} \le DR_i \end{cases} \quad i = 1, 2, \ldots, N, \quad t = 1, 2, \ldots, T. \tag{9}$$

where UR_i, DR_i are the up-ramp and down-ramp limits of the ith thermal unit.