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# A multiobjective hybrid bat algorithm for combined economic/emission dispatch

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ABSTRACT

In this paper, a multiobjective hybrid bat algorithm is proposed to solve the combined economic/emission dispatch problem with power flow constraints. In the proposed algorithm, an elitist nondominated sorting method and a modified crowding-distance sorting method are introduced to acquire an evenly distributed Pareto Optimal Front. A modified comprehensive learning strategy is used to enhance the learning ability of population. Through this way, each individual can learn not only from all individual best solutions but also from the global best solutions (nondominated solutions). A random black hole model is introduced to ensure that each dimension in current solution can be updated individually with a predefined probability. This is not only meaningful in enhancing the global search ability and accelerating convergence speed, but particularly key to deal with high dimensional systems, especially large-scale power systems. In addition, chaotic map is integrated to increase the diversity of population and avoid premature convergence. Finally, numerical examples on the IEEE 30-bus, 118-bus and 300-bus systems, are provided to demonstrate the superiority of the proposed algorithm.

## 1. Introduction

In power systems, the objective of economic dispatch problem is to seek an optimal schedule for all committed generators to minimize the operating fuel cost while satisfying all kinds of constraints such as load-demand balance constraint and generation capacity constraints [1,2]. However, with the increasing public concern on the environmental problem caused by fossil fuels, it is urgent for us not only to care for economic benefit, but also to tackle the emission problem of fossil fuels [3,4]. Therefore, the emission objective should also be involved.

### 1.1. Literature review and motivation

As a multiobjective optimization problem (MOP), the combined economic/emission dispatch (CEED) problem has been intensively studied by different technologies [3–18], which are mainly classified into two categories [19]:

(i) *Classical optimization methods* Such methods include linear programming [5], weighted sum method [6] and $\varepsilon$–constraints [7], etc. The most popular method among them is weighted sum method, which mainly has two drawbacks: ① This method, as well as other classical method, is not suitable for solving nonconvex and/or nonsmooth problems. ② Only one solution is generated in a single run, that is, if the Pareto Optimal Front (POF) has 100 nondominated solutions, the program must be run 100 times by varying the weights [8,9].

(ii) *Evolutionary algorithm techniques* Many of these algorithms have been successfully introduced to solve the CEED problem, such as GA (genetic algorithm) based algorithm [1,12], PSO (particle swarm optimization) based algorithms [13,14], flower pollination algorithm [15], SMODE [16], FBHPSO-DE [17] and ant colony optimization [18]. These algorithms essentially remove the aforementioned drawbacks of weighted sum method, and are suitable to deal with the nonlinear and nonconvex optimization problem. However, it is well known that evolutionary algorithms have difficulty in dealing with premature convergence problem. For example, genetic algorithm (GA) often suffers from premature convergence problem once the degree of population diversity is sharply decreased [20], and PSO also encounters the same problem when particles trap into local optima [21,22]. Moreover, existing algorithms always have difficulties in dealing with large-scale system. For example, in PSO, all the dimensions of $v_i^t$ or $x_i^t$ are updated simultaneously rather than only for one dimension. In addition, the same parameters are

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applied to the update of $v_i^t$ and $x_i^t$ in each step of iteration. These are harmful to enhance the diversity of $v_i^t$ or $x_i^t$, and limit the performance of PSO especially for high dimensional systems.

As a promising evolutionary algorithm, bat algorithm (BA), proposed in [23], integrates the advantageous of PSO, harmony search and simulated annealing algorithm. Optimization problems about economic dispatch and CEED problem solved by BA have been reported in several literatures. For example, in [24], the economic dispatch problem was realized by chaotic BA, but it is a single objective optimization problem and does not include emission objective. In [25], BA was introduced to deal with the CEED problem, but the price penalty factor was used to convert the MOP to a single-optimization problem, so the POF could not be formed. In [26], a multiobjective BA (SALBA) was applied to dynamic environmental/economic dispatch problem. However, there are several drawbacks in the proposed algorithm: ① All the dimensions of each generated solution are updated simultaneously, that is, it cannot update each single dimension of a solution separately, which is very important for enhancing the global search ability of algorithm. ② The update for velocity, loudness and pulse emission is the same as original BA, which cannot be well suitable to MOP problem. As for the optimization model in [26], several important constraints are not included in the model such as voltage magnitude constraints and line flow constraints. In [27], the CEED problem was solved by BA, but the POF is generated by varying the weights of the two objectives and power flow constraints are not included in the CEED model. In [28], an improved BA was proposed to solve the CEED problem considering the uncertain of wind power, and the local random walk in original BA was replaced by mutation operator. However, it does not change the fact that all the dimensions in a solution are updated simultaneously, which would limit the performance of the proposed algorithm.

### 1.2. Contributions

In this paper, a **Multiobjective Hybrid Bat Algorithm** (MHBA) is proposed to solve the CEED problem including power flow constraints. The main contributions of this paper is listed as follows:

(i) *A new multiobjective hybrid bat algorithm (MHBA) is proposed, which is especially suitable for high dimensional systems.* The performance of MHBA is improved in the following aspects compared with the existing multiobjective BA in [25–29]. ① An elitist nondominated sorting method with external archive [30–32] is introduced to generate POF, which overcomes the drawbacks of weighted sum method. ② In order to increase the learning ability of population, the comprehensive learning strategy [38] is modified to update the velocity. ③ The random walk in original BA is replaced by the random black hole model proposed in [35]. This replacement is meaningful in enhancing the global search ability and accelerating convergence speed. More importantly, in MHBA, each dimension in current solution can be updated individually due to the replacement. This is essentially different from the original BA, and is key for MHBA to obtain better solutions for high dimensional systems compared with other algorithms. ④ To avoid premature convergence and increase the diversity of population, the loudness and pulse emission rate in multiobjective BA are replaced by chaotic map.

(ii) *The CEED of large-scale systems with power flow constraints are effectively solved by the proposed algorithm.* The integrating of random black hole model can greatly increase the random search efficiency, which make MHBA be more suitable for large-scale systems. The reason is given as follows: ① In MHBA, each dimension in current solution is updated individually with a probability $p$, and the update parameter is different for each step. This gives each individual the chance to alter the search direction in every iteration, and hence increases the diversity of solutions. But as for other algorithms, for example, PSO, all the dimensions in velocity $v_i^t$ and position $x_i^t$ are updated simultaneously with the same parameters in each iteration step. ② Each dimension in current solution not only can be absorbed by a black hole, but also can escape from the black hole because the speed of individuals is all remained in the process. This is meaningful in preventing premature convergence problem. ③ Different from the original random black hole model, the effective radius $r_d$ in the model is treated as a piecewise parameter. This is helpful in enlarging search area for individuals at the beginning with a relatively large value of $r_d$, and improving the solution qualities with a relatively small value of $r_d$ for the rest steps of iteration. The IEEE 118-bus system and IEEE 300-bus system are used in the simulation to demonstrate the effectiveness of the proposed algorithm in solving large-scale systems. The results show that RCBA has great advantages in dealing with the CEED of large-scale systems with power flow constraints compared with other algorithms.

The remainder of this paper is organized as follows. Section 2 describes the CEED problem including power flow constraints. Section 3 explores the approaches to improve the performance of BA for MOP and proposes the multiobjective optimization algorithm: MHBA. Section 4 gives the simulation results of the standard IEEE 30-bus system, IEEE 118-bus system and IEEE 300-bus system, and demonstrates the effectiveness of MHBA in dealing with the CEED of large-scale systems compared with other algorithms. Section 5 summarizes several conclusions and gives some future research directions.

## 2. Problem formulation

The CEED problem is aimed at minimizing fuel cost and emission simultaneously while satisfying various equality and inequality constraints. The objectives and constraints of CEED problem are formulated as follows.

### 2.1. Objectives

#### 2.1.1. Objective 1: minimization of fuel cost

The total fuel cost including valve point effects is expressed as below [1]:

$$F(P) = \sum_{i=1}^{N} [a_i P_i^2 + b_i P_i + c_i + |d_i \sin(e_i (P_i^{\min} - P_i))|], \tag{1}$$

where $N$ is the number of generators; $P = (P_1, P_2, ..., P_N)$; $P_i$ and $P_i^{\min}$ are the active power output and the minimum active power output limit of the $i$-th generator, respectively; $F(\cdot)$ is the total fuel cost; $a_i, b_i, c_i, d_i$ and $e_i$ are fuel cost coefficients of the $i$-th generator.

#### 2.1.2. Objective 2: minimization of emission

The main emission caused by fossil fuels, such as nitrogen oxides ($NO_x$) and sulfur oxides ($SO_x$), is described as follow [9]:

$$E(P) = \sum_{i=1}^{N} [10^{-2}(\alpha_i P_i^2 + \beta_i P_i + \gamma_i) + \varepsilon_i \exp(\lambda_i P_i)], \tag{2}$$

where $E(\cdot)$ is the total emission; $\alpha_i, \beta_i, \gamma_i, \varepsilon_i$ and $\lambda_i$ are emission coefficients of the $i$-th generator.

### 2.2. Constraints

#### 2.2.1. Generation capacity constraints

The active power output $P_i$ and reactive power output $Q_i$ of the $i$-th generator should be restricted by lower and upper limits ($i = 1, ..., N$):

$$\begin{cases} P_i^{\min} \leqslant P_i \leqslant P_i^{\max}, \\ Q_i^{\min} \leqslant Q_i \leqslant Q_i^{\max}, \end{cases} \tag{3}$$