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Environmental/economic dispatch using multi-objective harmony search algorithm

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ABSTRACT

This paper presents a new multi-objective harmony search (MOHS) algorithm for environmental/economic dispatch (EED) problem. The EED problem is formulated as a non linear and constrained optimization problem with competing and non-commensurable objectives. The two competing objectives, fuel cost and emission, were optimized simultaneously using the proposed MOHS algorithm. The MOHS algorithm uses a non dominated sorting and ranking procedure with dynamic crowding distance to develop and maintain a well distributed Pareto-optimal set. The proposed algorithm has been tested on the standard IEEE 30 bus and 118 bus systems. Simulation results are compared with the fast non dominated sorting genetic algorithm (NSGA-II) method. The results clearly show that the proposed method is able to produce a well distributed Pareto-optimal solutions than the NSGA-II method.

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1. Introduction

The basic objective of economic dispatch (ED) problem is to schedule the committed generating units to meet the system load demand at minimum operating cost while satisfying the various system equality and inequality constraints. However, the optimum schedule obtained by solving ED problem may not be the best, in the case of environmental constraints are considered. The passage of clean air act amendments in 1990 forced the utilities to reduce the emission from fossil fuel fired thermal station [1]. Therefore, in addition to fuel cost, emission must also be considered as an objective.

Environmental/economic dispatch (EED) is a multi-objective problem having two conflicting objectives, i.e., minimum fuel cost and the minimum emission, which need to be solved simultaneously. Many methods have been reported in the literature to solve EED problem [2]. In linear programming [3], one objective is considered at a time. This does not give any information about trade-off between objectives. In another way, this multi-objective EED problem was converted into a single objective problem by giving a suitable weights to the objective function [4,5]. Unfortunately, this method requires multiple runs to find a Pareto-optimal set. Ref. [6] treated the emission as a constraint and reduced the multi-objective problem to a single objective one. The trade-off relation between the two objectives is difficult in this method. To avoid this difficulty, ϵ-constraint method was proposed in [7]. In this method, most preferred objective is considered and other objective as constraints in the allowable range ϵ. This may also result in a weak non-dominated solutions.

Recently, multi-objective evolutionary algorithms (MOEA) which use Pareto based approach, have been reported to solve the EED problem [8,9]. Most MOEAs reported in the literature use non-dominated sorting and ranking (NSGA), strength pareto evolutionary approach and fast non-dominated sorting and ranking (NSGA-II) approach to obtain a Pareto-optimal set. Since, evolutionary algorithms use a group of population in their search, a multiple Pareto-optimal set can, in principle, be obtained in a single simulation run. Initially, genetic algorithm (GA), which uses any of the above Pareto approach, has been used to handle multi-objective EED problem. More recently, the other evolutionary algorithms particle swarm optimization (PSO) [10,11], differential evolution (DE) [12–14] and biogeography based optimization (BBO) [15] have been extended using Pareto based approach to handle the multi-objective EED problem. The most preferred approach is NSGA-II proposed by Deb et al. [16] because of a less number of computation and maintaining diversity. Though NSGA-II possesses the elitism, non-dominated sorting and ranking with crowding distance, it still falls in maintaining a uniformity in Pareto-optimal set. To overcome this, dynamic crowding distance (DCD) based strategy has been recently proposed [17]. In this paper, fast non-dominated sorting and ranking with DCD strategy has been used to determine and maintain a well distributed Pareto-optimal set.

Harmony search (HS) algorithm has been recently developed [18] in an analogy with an improvisation process where musicians always try to polish their pitches to obtain a better harmony. Music

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improvisation process is similar to the optimum design process which seeks to find optimum solution. The pitch of each musical instrument determines the certain quality of harmony, just like the objective function assigned to the set of variables. In this paper, HS algorithm is extended using fast non dominated sorting and ranking with DCD strategy to find a Pareto-optimal solutions for EED problem with two competing objectives. Finally, a fuzzy based mechanism is used to find a compromise solution from the Pareto-optimal front. This multi-objective harmony search (MOHS) algorithm has been tested on the standard IEEE 30 bus and 118 bus test systems for competing and non-commensurable objectives. For comparison purpose, the EED problem was also solved by the NSGA-II method. Simulation results clearly show the robustness of the MOHS method to obtain a well distributed Pareto-optimal solutions than NSGA-II method.

2. EED Problem formulation

The objective of EED problem is to minimize the two competing objectives, i.e., fuel cost and emission, simultaneously, while satisfying several equality and inequality constraints. This problem can be formulated as follows:

2.1. Objective functions

2.1.1. Minimization of fuel cost

This objective is to minimize the total fuel cost F_T of the system. The fuel cost curves of the thermal generators are modeled as quadratic functions and can be represented as

$$F_T = \sum_{i=1}^{N_G} (a_i + b_i P_i + c_i P_i^2) \quad \$/\mathrm{h} \tag{1}$$

where a_i, b_i, c_i are the fuel cost coefficients of the i th generator, P_i is real power output of the i th generator and N_G is the total number of generators in the system.

2.1.2. Minimization of emission

The total emission E, in (ton/h), of sulphur oxides SO_x and nitrogen oxides NO_x from fossil-fueled thermal stations can be mathematically modelled as

$$E = \sum_{i=1}^{N_G} 10^{-2} (a_i + \beta_i P_i + \gamma_i P_i^2) + \zeta_i \exp(\lambda_i P_i) \tag{2}$$

where α_i, β_i, γ_i, ζ_i and λ_i are the emission coefficients of the i th generator.

2.2. Constraints

2.2.1. Power balance constraints

The total power generated must meet the total system load P_D and transmission line losses P_L. It can be defined as

$$\sum_{i=1}^{N_G} (P_i) - P_D - P_L = 0 \tag{3}$$

The transmission line losses P_L is a function of generator power outputs and can be represented using B-coefficients:

$$P_L = \sum_{i=1}^{N_G} \sum_{j=1}^{N_G} P_i B_{ij} P_j + \sum_{i=1}^{N_G} B_{0i} P_i + B_{00} \tag{4}$$

2.2.2. Generation capacity constraints

The real power output of each generator is constrained by lower and upper limits, i.e.,

$$P_i^{\min} \le P_i \le P_i^{\max}, \quad i = 1, 2, \cdots, N_G \tag{5}$$

where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum power output of i th generator, respectively.

2.3. Problem formulation

The EED problem is formulated as a constrained multi-objective optimization problem and is given as follows

$$\text{Minimize} \quad [F, E] \tag{6}$$

Subject to

$$\sum_{i=1}^{N_G} (P_i) - P_D - P_L = 0 \tag{7}$$

$$P_i^{\min} \le P_i \le P_i^{\max}, \quad i = 1, 2, \cdots, N_G \tag{8}$$

3. Multi-objective optimization

Many real world optimization problems involve simultaneous optimization of several conflicting objectives. Multi-objective optimization problems with such conflicting objectives give rise to a set of optimal solution, rather than a single optimal solution. Because, no solution can be considered to be better than other solutions with out a information. These set of optimal solutions are called as a Pareto-optimal solutions [19].

A general multi-objective optimization problem consists of multiple objectives to be optimized simultaneously and the various equality and inequality constraints. This can be generally formulated as

$$\text{Min} \quad f_i(x), \quad i = 1, 2, \cdots, N \tag{9}$$

$$\text{Subject to:} \begin{cases} g_j(x) = 0, & j = 1, 2, \cdots, M \\ h_k(x) \le 0, & k = 1, 2, \cdots, K \end{cases} \tag{10}$$

where f_i is the i th objective function, x is a decision vector that represents a solution, N is the number of objective functions, M and K are the number of equality and inequality constraints, respectively.

For a multi-objective optimization problem, any two solutions x_1 and x_2 can have any one of two possibilities, one dominates other or none dominates other. In a minimization problem, with out loss of generality, solution x_1 dominates x_2 if the following conditions are satisfied.

$$1. \quad \forall i \in \left\{1, 2, \cdots, N\right\} : f_i(x_1) \le f_i(x_2) \tag{11}$$

$$2. \quad \exists j \in \left\{1, 2, \cdots, N\right\} : f_j(x_1) < f_j(x_2) \tag{12}$$

If any one of the above conditions is violated, then the solution x_1 does not dominate x_2. If x_1 dominates the solution x_2, x_1 is called as the non-dominated solution. The solutions that are non- dominated within the entire search space are denoted as Pareto-optimal solutions.

4. Harmony search algorithm

The harmony search (HS) algorithm, proposed by Geem et al. [18], is a nature inspired algorithm, mimicking the improvisation of music players. The harmony in music is analogous to the optimization solution vector, and the musician's improvisations are analogous to the local and global search schemes in optimization techniques. The HS algorithm uses a stochastic random search,

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