Electrical Power and Energy Systems 56 (2014) 127–139

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Efficient hybrid optimization approach for emission constrained economic dispatch with nonsmooth cost curves

Samir Sayah [a,*], Abdellatif Hamouda [b], Abdelghani Bekrar [c]

[a] University Setif 1, QUERE Laboratory, Electrical Engineering Department, Setif 19000, Algeria
[b] University Setif 1, QUERE Laboratory, Optics and Fine Mechanics Institute, Setif 19000, Algeria
[c] Université de Valenciennes, TEMPO/PSI, Le Mont Houy, 59313, Valenciennes cedex 9, France

ARTICLE INFO

Article history:
Received 30 April 2012
Received in revised form 1 November 2013
Accepted 6 November 2013

Keywords:
Economic dispatch
Emission dispatch
Environmental/economic dispatch
Valve-point loading
Differential evolution
Harmony search

ABSTRACT

Power plants usually operate on the strategy of economic dispatch (ED) regardless of emissions produced. Environmental considerations have become one of the major management concerns. Under these circumstances, the alternative strategy of environmental/economic dispatch (EED) is becoming more and more desirable for not only resulting in great economical benefit, but also reducing the pollutants emission.

Based on the literature survey, few attempts have been made at considering valve-point effects for the realistic environmental/economic dispatch (EED) problem. This paper proposes a new efficient hybrid differential evolution algorithm with harmony search (DE–HS) to solve the multiobjective environmental/economic dispatch (EED) problems that feature nonsmooth cost curves. The proposed approach combines in the most effective way the properties of differential evolution (DE) and harmony search (HS) algorithms. To enhance the local search capability of the original DE method, the fresh individual generation mechanism of the HS is utilized.

Numerical results for three case studies have been presented to illustrate the performance and applicability of the proposed hybrid method. The comparative results with some of the most recently published methods confirm the effectiveness of the proposed strategy to find accurate and feasible optimal solutions for practical EED problems.

1. Introduction

Economic dispatch is a fundamental function in modern power system operation and control. The economic dispatch (ED) problem of power generation involves allocation of power generation to different thermal units to minimize the total fuel cost while satisfying load demand and diverse operating constraints of a power system [1]. However, due to strict governmental regulations on environmental protection, the conventional operation at absolute minimum fuel cost cannot be the only basis for dispatching electric power. Therefore, it is mandatory for electric utilities to reduce pollution from power plants either by design or by operational strategies [2]. The most important emissions considered in the power generation industry due to their effects on the environment are sulfur dioxide (SO_2) and nitrogen oxides (NO_x). The emission of these pollutants affects not only human beings, but harms other life forms as well causing damage to materials and global warming. In these circumstances, the alternative strategy of environmental/economic dispatch (EED) is becoming more and more desirable for not only resulting in great economical benefit, but also reducing the pollutants emission.

Environmental issues add complexity to the solution of the economic dispatch problem due to the nonlinear characteristics of the mathematical models used to represent emissions. In addition, the EED problem can be complicated even further if nonsmooth and nonconvex fuel cost functions are used to model generators, such as valve-point loading effects [3]. All these considerations make the EED problem a highly nonlinear and a multimodal optimization problem. Therefore, conventional gradient based optimization methods are not able to locate or identify the global optimum for this kind of problems and usually result in inaccurate dispatches causing huge loss of revenue over the time. An excellent summary on the various conventional methods and emission models to reduce atmospheric emissions was presented by Talaq et al. [4].

In recent years, new heuristic global search algorithms such as neural networks [5,6], genetic algorithms [7,8], simulated annealing [8], evolutionary programming [9], parallel particle swarm optimization [10], differential evolution [11,12], harmony search [13], fuzzy approach [14] and pareto-based multiobjective procedures [15–18], have facilitated solving the multiobjective environmental/economic dispatch (EED) problem with no restriction on its nonsmooth and nonconvex characteristics. Nevertheless, owing to their drawbacks, these methods cannot guarantee obtaining the global optimal solution in a finite computation time. The main disadvantage of these techniques is the stagnation of search process

* Corresponding author. Tel.: +213 561 295 179; fax: +213 36 92 72 10.
E-mail address: samir_pg04@yahoo.fr (S. Sayah).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.11.001

due to premature convergence into local optimum, particularly for highly nonlinear and a multimodal optimization problem. To overcome the disadvantages of heuristic techniques, some hybridization and combination of these methods have been widely used to solve more effectively EED problems [19,20]. The results reported were promising and encouraging for further research in this direction.

Differential evolution and harmony search algorithms are two of these global optimization techniques, developed recently. Differential evolution (DE) algorithm which is inspired by biological and sociological motivations has been developed and introduced by Storn and Price [21] in 1995. DE algorithm improves a population of candidate solutions over several generations using the mutation, crossover and selection operators in order to reach an optimal solution [22]. In DE, the fitness of an offspring is one-to-one competed with that of the corresponding parent. This one-to-one competition makes convergence speed of DE faster than other evolutionary algorithms. Nevertheless, this faster convergence property yields in a higher probability of searching toward a local optimum or getting premature convergence [23,24].

Proposed by Geem et al. [25] in 2001, the harmony search (HS) method is inspired by the underlying principles of the musicians' improvisation of the harmony. In the HS algorithm, musician improvises the pitches of his/her instrument to obtain a better state of harmony. The pitch of each musical instrument determines the aesthetic quality, just as the objective function value is determined by the set of values assigned to each decision variable [26]. On the other hand, HS is good at identifying the high performance regions of the solution space at a reasonable time. However, recent studies [27–29] have shown that the original HS method has a limitation in dealing with the multimodal and constrained optimization problems.

In order to enhance the convergence rate and to find better results, a hybrid technique combining exploration capacity of DE with exploitation ability of HS (termed DE–HS) [30], is proposed in this paper, for solving complex EED problems. Here, the basic idea is to incorporate the individual generation procedure of HS into the conventional DE algorithm to improve the global search capability, and thus avoiding premature convergence to local minima. The proposed approach has been applied to solve simple EED problems as well as large scale nonconvex EED problems involving valve-point loading effects [31,32].

The performance of the proposed method is tested on three case studies using a six-generator system with smooth fuel cost functions in the first case and nonsmooth fuel cost functions in the second and third cases. Numerical results obtained by the proposed approach were compared with other optimization results reported in the literature recently.

2. Problem description

The main objective of EED is to minimize two conflicting objectives, which are the fuel cost and pollutants emission, while satisfying operating and loading constraints. Generally the problem is formulated as follows:

2.1. Problem objectives

2.1.1. Minimization of fuel cost

Traditionally, the fuel cost curve of each generator is approximated using a simple smooth quadratic function [1] given by:

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 \tag{1}$$

where P_i is the power of generator *i*. a_i, b_i and c_i are the cost coefficients of generator *i*.

However, it is more practical to consider the valve-point loading effects for fossil-fuel-based plants. These effects, which occur as each steam admission valve in a turbine starts to open, produce a rippling effect on the unit's cost curve [3]. Usually, valve-point effect is modeled by adding a recurring rectified sinusoid to the basic quadratic cost curve [3]. Therefore, (1) can be modified as:

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 + |d_i \sin(e_i(P_i^{\min} - P_i))| \tag{2}$$

where d_i and e_i are the coefficients of generator *i* reflecting valve-point effects and $P_i^{\min}$ is the minimum generation limit of unit *i*.

The total fuel cost function *F* ($/h) for the entire power system can then be written as the sum of the fuel cost model for each generator:

$$F = \sum_{i=1}^{ng} F_i \tag{3}$$

where F_i is the fuel cost function of the *i*th generator and *ng* is the number of online generating units to be dispatched.

2.1.2. Minimization of emission

The atmospheric pollutants caused by fossil-fueled thermal units can be modeled separately. However, as an illustration, only NO_x emission reduction is considered, since it is more harmful than other pollutants. The total ton/h or kg/h emission function *E* of these pollutants can be expressed as [18]:

$$E = \sum_{i=1}^{ng} 10^{-2}(\alpha_i + \beta_iP_i + \gamma_iP_i^2) + \omega_i \exp(\mu_iP_i) \tag{4}$$

where α_i, β_i, γ_i, ω_i and μ_i are the emission coefficients of generator *i*.

2.1.3. Total objective function

Economic objective and emission objective are combined with different weightings in a single function. For a specified demand a trade-off curve may then be obtained. The total objective function F_T is then described by [33]:

$$F_T = hF(P_g) + (1 - h)\lambda E(P_g) \tag{5}$$

where *h* is the weighting factor that can be varied between 0 and 1. λ is the price penalty factor ($/kg or $/ton) which blends the emission cost with the normal fuel costs.

The procedure to find out price penalty factor λ for a particular load demand is described in [5]. The values of *h* indicate the relative significance between the two objectives. By varying the value of *h*, the trade-off between the fuel cost and the environmental degradation cost can be determined over the range of *h*. If *h* = 1.0, the solution is that of minimum cost, and if *h* = 0.0 the solution is minimum emissions.

2.2. Problem constraints

2.2.1. Power balance constraint

This constraint is based on the principle of equilibrium between total system generation and total system loads P_D and transmission losses P_L [1]. That is

$$\sum_{i=1}^{ng} P_i = P_D + P_L \tag{6}$$

P_L can be obtained using the *B* matrix loss formula [1], given by:

$$P_L = \sum_{i=1}^{ng}\sum_{j=1}^{ng} P_iB_{ij}P_j + \sum_{i=1}^{ng} P_iB_{i0} + B_{00} \tag{7}$$

where B_{ij}, B_{i0} and B_{00} are the loss coefficients.