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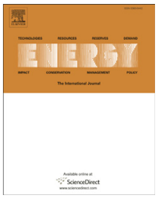

A new algorithm for combined dynamic economic emission dispatch with security constraints

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ABSTRACT

The primary objective of CDEED (combined dynamic economic emission dispatch) problem is to determine the optimal power generation schedule for the online generating units over a time horizon considered and simultaneously minimizing the emission level and satisfying the generators and system constraints. The CDEED problem is bi-objective optimization problem, where generation cost and emission are considered as two competing objective functions. This bi-objective CDEED problem is represented as a single objective optimization problem by assigning different weights for each objective functions. The weights are varied in steps and for each variation one compromise solution are generated and finally fuzzy based selection method is used to select the best compromise solution from the set of compromise solutions obtained. In order to reflect the test systems considered as real power system model, the security constraints are also taken into account. Three new versions of DHS (differential harmony search) algorithms have been proposed to solve the CDEED problems. The feasibility of the proposed algorithms is demonstrated on IEEE-26 and IEEE-39 bus systems. The result obtained by the proposed CSADHS (chaotic self-adaptive differential harmony search) algorithm is found to be better than EP (evolutionary programming), DHS, and the other proposed algorithms in terms of solution quality, convergence speed and computation time.

1. Introduction

The primary objective of CDEED (combined dynamic economic emission dispatch) problem is to determine the optimal power generation schedule for the online generating units over a time horizon and at the same time minimizing the emission level and satisfying the security constraints (transmission line flow limit and load bus voltage limits), generator constraints and spinning reserve capacity constraints simultaneously. The US Clean Air Act Amendments of 1990 mandates a significant reduction of NO_x and SO_2 emissions from 1980 levels [1]. These environmental constraints forced the utilities to modify their design or operational methodology to decrease the atmospheric emissions from the electrical power plants. The methods available to control the emissions, are installing emission control equipments in power plant, switching to lower sulfur coal, fuel switching, replacing the aged fuel-burners with newer ones and emission dispatch. Out of these methods, the emission dispatch method is an attractive method, in which both the objectives (cost and emission) are minimized simultaneously. In the past decades, many conventional techniques such as LP (linear programming) [2], NLP (non-linear programming) [3], QP (quadratic programming) [3], and LR (Lagrange relaxation) [4] have been proposed to solve the ELD (economic load dispatch) problems. These techniques often use approximations to limit complexity of the problem. The solution obtained from these methods is normally inferior in solution quality since they usually get stuck at the local optimal solution. To overcome this difficulty, in the recent past, stochastic search optimization algorithms such as PSO (particle swarm optimization) [5], SA (simulated annealing) [6], DE (differential evolution) [7], AIS (artificial immune system) [8], ECE (enhanced cross-entropy method) [9], HHS (hybrid swarm intelligence based harmony search) [10], EAPSO (enhanced adaptive particle swarm optimization) [11], BCO-SQP (bee colony optimization and sequential quadratic programming) [12], SOA-SQP (seeker optimization algorithm-sequential quadratic programming) [13], improved PSO method [14] and ICA (imperialist competitive

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algorithm) [15] have been used to solve the DED (dynamic economic dispatch) problems without emission and security constraints. NPAHS (Harmony search method with a new pitch adjustment rule) [16], CQGA (chaotic quantum genetic algorithm) [17], EFA (enhanced firefly algorithm) [18], SALCSSA (self-adaptive learning charged system search algorithm) [19] and FSALPSO (fuzzy self-adaptive learning particle swarm optimization) [20] methods have been used to solve DED problems with emission constraints. Vaisakh et al. [21] recently have applied bacterial foraging PSO-DE algorithm to solve DED with security and spinning reserve capacity constraints. In the literature, no research works were done to solve the DED problems with both emission and security constraints. So in this paper, an attempt is made to solve the DED problems with both emission and security constraints along with other conventional constraints. Heuristic methods normally do not always guarantee the global optimal solution but they generally provide a reasonable solution, which is sub-optimal or a value near to global optimal solution. HS (harmony search) algorithm was proposed by Geem et al. [22] which is a new meta-heuristic optimization algorithm. It imitates the music improvisation process of the music players to improvise the pitches of their instruments so as to obtain better harmony. The uniqueness of HS algorithm is, it will consider all the existing solution vectors in the HM (harmony memory) matrix to generate a new solution vector. This property increases the exploration power of the HS algorithm to produce better solutions. It is also proved that the performance of HS algorithm is better than GA (genetic algorithm), EP (evolutionary programming), IFEP (improved fast evolutionary programming), PSO (particle swarm optimization) and DE (differential evolution) algorithms [23–25]. It has been observed that in the complex and multi-modal fitness landscapes the performance of HS algorithm is inferior because it may trap in the local optima or show faulty convergence. In 2007, Mahdavi et al. [26] proposed an improved IHS (improved HS algorithm), in which the control parameters PAR (pitch adjustment rate) and bw (band width) are dynamically varied with respect to the iteration number to generate better harmony vector than HS algorithm. Mahammed and Mahdavi [27] in 2008 proposed GHS (global-best harmony search) algorithm, in this algorithm some concepts borrowed from particle swarm intelligence are used to enhance the performance of HS algorithm. Prithwish Chakraborty et al. [28] in 2009 proposed a new hybrid algorithm called DHS (differential harmony search) algorithm. The DED (dynamic economic dispatch) problem itself is a hard problem to solve, when the objective function of emission is added further to it, then the problem becomes more complicated than before and it needs a very efficient algorithm to generate accurate solution for this problem. To solve this problem, three versions of DHS (differential harmony search) algorithms are proposed. They are CDHS (chaotic differential harmony search) algorithm, SADHS (Self-adaptive differential harmony search) algorithm and CSADHS (chaotic self-adaptive differential harmony search) algorithm. In the CDHS algorithm, the mutation constant F value is chaotic variables generated using logistic map and in every generation the value of F is changed. The F value in the proposed SADHS algorithm is generated using random variable generation method and it is varied using a self-adaptive mechanism. In the CSADHS algorithm, the F value is generated using logistic map and self-adaptive mechanism is introduced to change the value of F during the run of the algorithm. In order to demonstrate the effectiveness of the proposed algorithms, they are applied on IEEE-26 bus and IEEE-39 bus system to solve the CDEED problem with generator, security, spinning reserve capacity constraints. The result obtained by the proposed CSADHS algorithm is found to be better than EP, DHS and the other proposed algorithms in terms of solution quality, convergence speed and computation time. The performance metrics tests are also executed to ascertain the quality of the solution obtained in all case studies considered.

2. Bi-objective CDEED problem

The bi-objective CDEED problem is represented as a single objective optimization problem by assigning different weights for each objective functions. The mathematical expression for CDEED problem is given in (1) [29,30]

$$F_t = \sum_{i=1}^{N} (w{*}F_1 + h{*}(1-w){*}F_2) \tag{1}$$

The letter 'h' is called penalty factor or scaling factor. The scaling factor is multiplied with the emission function to get an equivalent cost value in $/hr. The calculation of h value is given in Ref. [31]. The value of weighing factor w indicates which objective function is given more importance. The problem becomes classical DED problem, when $w = 1$ that minimizes only the fuel cost. The problem becomes pure DEmD (dynamic emission dispatch) problem when $w = 0$, which minimizes only the emission level. In CDEED problem, the value of w is decreased in steps from 1 to 0, for each w value, a compromise solution will be generated. The weight assigned for each objective functions in (1) are such that the summation of weights should be equal to one [32,33]. Finally fuzzy based selection method is utilized to select the BCS (best compromise solution) from the set of compromise solutions obtained for each variation of w value. As the value of w decreases, the fuel cost value increases and the emission value decreases.

3. Fuzzy based selection of BCS (best compromise solution)

Choosing a best compromise solution from the obtained Pareto optimal set is important in decision making process. The fuzzy membership approach is used to find a best compromise solution. Due to imprecise nature of the decision maker's judgment the ith objective function f_i of individual k is represented by a membership function μ_i^k defined as follows [20,34]:

$$\mu_i^k = \begin{cases} 1 & f_i \le f_i^{\min} \\ \dfrac{f_i^{\max} - f_i}{f_i^{\max} - f_i^{\min}} & f_i^{\min} < f_i < f_i^{\max} \\ 0 & f_i \ge f_i^{\max} \end{cases} \tag{2}$$

where $f_i^{\min}$ and $f_i^{\max}$ are the minimum and maximum value of ith objective function among all non-dominated solutions, respectively for each non-dominated solution k, the normalized membership function μ^k is calculated as

$$\mu^k = \frac{\sum_{i=1}^{N} \mu_i^k}{\sum_{k=1}^{p} \sum_{i=1}^{N} \mu_i^k} \tag{3}$$

where p is the total number of non-dominated solutions. The best compromise solution is having maximum value of μ^k.

4. Problem formulation

4.1. Objective functions

The objective functions considered in the CDEED problem are as follows:

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