Electrical Power and Energy Systems 82 (2016) 58–66

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Combined heat and power economic dispatch using exchange market algorithm

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ARTICLE INFO

Article history:
Received 2 May 2015
Received in revised form 6 March 2016
Accepted 7 March 2016
Available online 19 March 2016

Keywords:
Combined heat and power
Non-convex
Exchange market algorithm
Valve-point

ABSTRACT

Combined heat and power economic dispatch (CHPED) is one of the critical issues in power systems, playing key role in economic performance of the system. CHPED is a challenging optimization problem of non-linear and non-convex type. Thus, evolutionary and heuristic algorithms are employed as effective tools in solving this problem. This paper applies newly proposed exchange market algorithm (EMA) on CHPED problem. EMA is a powerful and robust algorithm. With two powerful absorbing operators pulling solutions toward optimality and two smart searching operators, EMA is able to extract optimum point in optimization problem. In order to examine the proposed algorithm's capabilities and find optimum solution for CHPED problem, several test systems considering valve-point effect, system power loss and system constraints are optimized. The obtained results prove high capability of EMA in extracting optimum points. The results also show that this algorithm can be utilized as an efficient and reliable tool in solving CHPED problem.

Introduction

In conventional thermal generating units, all of the produced heat energy is not converted to the electric power and a considerable fraction of the power is lost as heat loss. Combined heat and power (CHP) as a cogeneration system can lead to the simultaneous production of heat and electric power from one fuel source. Thus, supplying simultaneous heat and power required for customers is possible [1,2]. In CHP system, output energy of a generating unit can be utilized as input energy for the other system. The use of CHP system is, therefore, can increase fuel efficiency up to 90% [3], decrease production cost by 10–40% [4] and environmental pollution by 13–18% [5]. In order to effectively utilizing of cogeneration units, economic dispatch problem is solved for optimal combination of output heat and power of generating units to satisfy the heat and power demand in system. That is, the economic dispatch problem with cogeneration units called the CHP economic dispatch (CHPED) problem is solved [6].

The aim of solving CHPED problem is to determine optimal heat and power of generating units with the minimized cost of total system and satisfied constraints of problem. In addition, the heat and power demand should be met. The presence of heat-power feasibility constraints of cogeneration units may result in more complicated ED problem in comparison to conventional economic dispatch problems [7,8]. In recent two decades, much research has been reported in literature for solving CHPED problem using mathematical methods and optimization algorithms. In [9], a two-level strategy was proposed to solve CHPED problem. The lower level determines the outputs of units under given Lagrangian multipliers, and the upper level updates the multipliers by a Newton-based iterative process. The procedure is repeated until the heat and power demands are met. In [10], CHPED problem was divided into subproblems: heat dispatch and power dispatch. These two subproblems were correlated in heat-power feasible operation region for CHP units. Afterwards, Lagrangian relaxation algorithm was utilized to solve this problem. In [11], Makkonen and Lahdelma proposed a mixed integer programming model to solve CHP problem. In order to accelerate optimization process, the problem is divided into two hourly subproblems and a customized branch-and-bound algorithm was applied to solve these subproblems. All mentioned techniques could successfully solve CHPED problem assuming a convex fuel cost. However, generating units have non-convex fuel cost in practice leading to inability of the aforementioned techniques in solving non-convex CHPED problem. Heuristic algorithms can optimize various problems by generating random numbers without considering complexity and constraints of the problem. Thus, various intelligent techniques,

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http://dx.doi.org/10.1016/j.ijepes.2016.03.004
0142-0615/

including improved ant colony search algorithm [12], evolutionary programming [13] genetic algorithm [14], harmony search algorithm [15] and multi objective particle swarm optimization [16] have been proposed to successfully solve CHPED problem with convex and non-convex fuel cost function.

Heuristic algorithms have an operator for generating random number and another operator for absorbing random numbers toward optimum numbers. In other words, heuristic algorithms find optimum points in optimization problems by generating random numbers. Due to their randomized structure, evolutionary algorithms may encounter with problems and constraints such as trapping in local minima and, in turn, premature convergence, inability to extract optimum-neighborhood points and convergence to non-matched solutions in each program run [17].

Exchange market algorithm as a heuristic algorithm was first proposed by N. Ghorbani and E. Babaei in 2014. Inspired by human intelligence and the process of trading shares in stock market, EMA is proposed mainly to solve optimization problems. EMA's structure is same as the other optimization algorithms in terms of generating random numbers. However, this has two simultaneous intelligent operators generating random numbers and two efficient operators absorbing random numbers towards optimal numbers. This leads to the best-generated numbers. Thus, some of drawbacks and issues in other optimization algorithms mentioned above are highly obviated [18].

EMA is a population-based algorithm inspired by stock market in which a number of stocks are selected by shareholders. Then, they make decisions on the selected stocks based on their own policies. In the proposed algorithm, two market states are available per program run: (1) balanced market, where the algorithm absorbs individuals toward elite person, (2) oscillated market, where the algorithm produces random numbers. In this algorithm, the fitness of individuals is evaluated after each market state. Then, they are ranked based on their conditions and placed in different groups.

Considering high capability of EMA in finding optimum point, this algorithm can be applied on various CHPED problems including power-only units, CHP units, and heat-only units with valve-point effect, system power loss and operational constraints. The results obtained by this technique are compared with those of obtained by intelligent methods. These results show the superiority of the proposed algorithm over the other intelligent techniques.

The rest of this paper is organized as follows. Section "Problem formulation": gives the formulation of the CHPED problem; Section "Exchange market algorithm": explains the EMA; Section "Exchange market algorithm implementation pattern in solving CHPED problem": shows implementation pattern of EMA in solving CHPED problem; Section "Numerical studies": shows implementation of the proposed algorithm to the test systems and obtained results; and Section "Conclusion" gives our conclusions.

Problem formulation

Authors in [12–15] formulated CHPED problem constraints in details. In general, the aim of solving CHPED problem is to determine the generating unit power and heat production such that the system's production cost is minimized while the power and heat demands and other constraints are met appropriately.

Objective function

The objective function of CHPED problem is given by:

$$\min \sum_{i=1}^{N_p} C_i(P_i^p) + \sum_{j=1}^{N_c} C_j(P_j^c, H_j^c) + \sum_{k=1}^{N_h} C_k(H_k^h)\,(\$/h) \tag{1}$$

where C_i, C_j and C_k are production cost of the power-only, GHP and heat-only units, respectively. N_p, N_c, N_h are the number of above mentioned units, respectively. i, j and k are the indices used for power-only, CHP and heat-only units, respectively. In Eq. (1), H and P indicate the heat and power output of unit, respectively. The production cost of different unit types are defined as:

$$C_i(P_i^p) = \alpha_i(P_i^p)^2 + \beta_i P_i^p + \gamma_i \quad (\$/h) \tag{2}$$

$$C_j(P_j^c, H_j^c) = a_j(P_j^c)^2 + b_j P_j^c + c_j + d_j(H_j^c)^2 + e_j H_j^c + f_j H_j^c P_j^c \quad (\$/h) \tag{3}$$

$$C_k(H_k^h) = a_k(H_k^h)^2 + b_k H_k^h + c_k \quad (\$/h) \tag{4}$$

where $C_i(P_i^p), C_j(P_j^c, H_j^c)$ and $C_k(H_k^h)$ are cost function of the power-only, CHP and heat-only units, respectively. α_i, β_i and γ_i stand for cost coefficients of ith conventional thermal unit. a_j, b_j, c_j, d_j, e_j and f_j are cost coefficients of jth CHP unit. In Eq. (3), a_k, b_k and c_k show the cost coefficients of kth heat-only unit. P_i^p and P_j^c are the power outputs of power and CHP units. H_j^c and H_k^h are the heat production by cogeneration and heat-only units.

In a practical generation unit, steam-valve admission effects lead to the ripple in the production cost. In order to model this effect more accurately, a sinusoidal term is added to the quadratic cost function. In this case, Eq. (5) is used to show the valve-point effects in cost function of power units instead of Eq. (2).

$$C_i(P_i^p) = \alpha_i(P_i^p)^2 + \beta_i P_i^p + \gamma_i + |\lambda_i \sin(\rho_i(P_i^{p\,\min} - P_i^p))| \quad (\$/h) \tag{5}$$

where λ_i and ρ_i are the cost coefficients of power unit i for reflecting valve-point effects [19].

Equality and inequality constraints

In order to balance the supply and demand, the power equality constraint should be met. Total generated power of the power-only and CHP units should be equal to total system demand which can be evaluated by Eq. (6). If there are power losses in the system, they should be added to the system demand power.

$$\sum_{i=1}^{N_p} P_i^p + \sum_{j=1}^{N_c} P_j^c = P_d \tag{6}$$

$$\sum_{i=1}^{N_p} P_i^p + \sum_{j=1}^{N_c} P_j^c = P_d + P_{loss} \tag{7}$$

$$P_{loss} = \sum_{i=1}^{N_p}\sum_{m=1}^{N_p} P_i^p B_{im} P_m^p + \sum_{i=1}^{N_p}\sum_{j=1}^{N_c} P_i^p B_{ij} P_j^c + \sum_{j=1}^{N_c}\sum_{n=1}^{N_c} P_j^c B_{in} P_n^c \tag{8}$$

where P_d is the system demand. Parameter P_{loss} is the power losses of transmission line and a function of units output power evaluated by Eq. (8). Total generated heat of cogeneration and heat units should be equal to total system demand heat in order to balance the heat demand:

$$\sum_{j=1}^{N_c} H_j^c + \sum_{k=1}^{N_h} H_k^h = H_d \tag{9}$$

where H_d is the system heat demand.

The outputs of electricity units and heat units are restricted by their own upper and lower boundaries. The power and heat outputs of cogeneration units should be placed in feasible operation region. Fig. 1 illustrates the heat-power feasible operation region of a CHP unit. The inequality constraints of each generating unit in the CHPED problem are given by:

$$P_i^{p\,\min} \leqslant P_i^p \leqslant P_i^{p\,\max} \quad i = 1, 2, \ldots, N_p \tag{10}$$