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Bee colony optimization for combined heat and power economic dispatch

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ABSTRACT

This paper presents a novel optimization approach to the combined heat and power economic dispatch problem by using bee colony optimization algorithm. The algorithm is a swarm-based algorithm inspired by the food foraging behavior of honey bees. The performance of the proposed algorithm is validated by illustration with a test system. The results of the proposed approach are compared with those of particle swarm optimization, real-coded genetic algorithm and evolutionary programing techniques. From numerical results, it is seen that bee colony optimization based approach is able to provide a better solution at a lesser computational effort.

1. Introduction

The conversion of fossil fuel into electricity is an inefficient process. Even the most modern combined cycle plants are between 50% and 60% efficient. Most of the energy wasted in the conversion process is heat. The principle of combined heat and power, known as cogeneration, is to recover and make beneficial use of this heat and as a result the overall efficiency of the conversion process is increased. Combined heat and power generation has higher energy efficiency and less green house gas emission as compared with the other forms of energy supply. Recently, cogeneration units have been extensively used in utility industry. The heat production capacity of most cogeneration units depends on the power generation and vice versa. The mutual dependencies of heat and power generation introduce a complication in the integration of cogeneration units into the power economic dispatch. The objective of the combined heat and power economic dispatch (CHPED) is to find the optimal point of power and heat generation with minimum fuel cost such that both heat and power demands and other constraints are met while the combined heat and power units are operated in a bounded heat versus power plane.

Non-linear optimization methods, such as dual and quadratic programming (Rooijers & Van Amerongen, 1994), and gradient descent approaches, such as Lagrangian relaxation (Guo, Henwood, & van Ooijen, 1996), have been applied for solving CHPED. However, these methods cannot handle nonconvex fuel cost function of the generating units.

The advent of stochastic search algorithms has provided alternative approaches for solving CHPED problem. Improved ant colony search algorithm (Song, Chou, & Stonham, 1999), evolutionary programming (Wong & Algie, 2002) Genetic algorithm (Su & Chiang, 2004), harmonic search algorithm (Vasebi, Fesanghary, & Bathaee, 2007) and multiobjective particle swarm optimization (Wang & Singh, 2008) have been applied to solve CHPED problem. But these methods did not consider transmission loss.

Swarm intelligence (Bonabeau, Dorigo, & Theraulaz, 1999; Camazine et al., 2003; Eberhart, Shi, & Kennedy, 2001), a branch of natural inspired algorithms, focuses on the behavior of insect in order to develop some meta-heuristics algorithms. Bee colony optimization (BCO) algorithm (Karaboga, 2005) is a new member of swarm intelligence and it mimics the food foraging behavior of honey bees. This algorithm is simple, robust and capable to solve difficult combinatorial optimization problems.

This paper proposes BCO algorithm for solving the CHPED problem. Here, transmission loss is considered. In order to show the validity of the proposed approach, the developed algorithm is illustrated on a test system (Guo et al., 1996). Results obtained from the proposed approach are compared with those obtained from particle swarm optimization (PSO), real-coded genetic algorithm (RCGA) and evolutionary programming (EP). The comparison shows that the proposed BCO based approach achieves lower production cost and CPU time.

2. Formulation of CHPED problem

The system under consideration has conventional thermal generators, cogeneration units, and heat-only units. Fig. 1 shows the heat–power feasible operation region of a combined cycle cogeneration unit. The feasible operation is enclosed by the boundary curve ABCDEF. Along the boundary curve BC, the heat capacity increases as the power generation decreases, the heat capacity declines along the curve CD.

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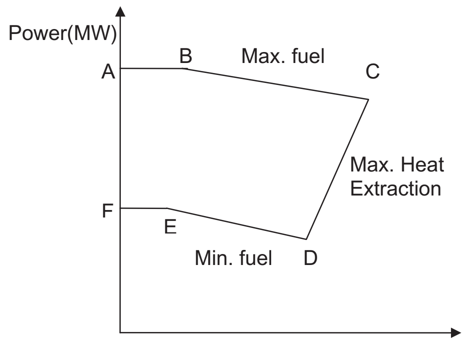

Fig. 1. Heat-power feasible operation region for a cogeneration unit.

The power output of the power units and the heat output of heat units are restricted by their own upper and lower limits. The power is generated by conventional thermal generators and cogeneration units while the heat is generated by cogeneration units and heat-only units. The CHPED problem is to determine the unit power and heat production so that the system's production cost is minimized while the power and heat demands and other constraints are met. It can be mathematically stated as:

$$\text{Minimize} \quad \left[\sum_{i=1}^{\alpha} F_{ti}(P_i) + \sum_{i=\alpha+1}^{\beta} F_{ci}(P_i, H_i) + \sum_{i=\beta+1}^{n} F_{hi}(h_i)\right]. \quad (1)$$

Subject to the equilibrium constraints of electricity and heat production, and the capacity limits of each unit:

$$\sum_{i=1}^{\alpha} P_i + \sum_{i=\alpha+1}^{\beta} P_i = P_D + P_L, \quad (2)$$

$$\sum_{i=\alpha+1}^{\beta} H_i + \sum_{i=\beta+1}^{n} H_i = H_D, \quad (3)$$

$$P_i^{\min} \leqslant P_i \leqslant P_i^{\max} \quad i \in 1, 2, \ldots, \alpha, \quad (4)$$

$$P_i^{\min}(H_i) \leqslant P_i \leqslant P_i^{\max}(H_i) \quad i \in \alpha+1, \alpha+2, \ldots, \beta, \quad (5)$$

$$H_i^{\min}(P_i) \leqslant H_i \leqslant H_i^{\max}(P_i) \quad i \in \alpha+1, \alpha+2, \ldots, \beta, \quad (6)$$

$$H_i^{\min} \leqslant H_i \leqslant H_i^{\max} \quad i \in \beta+1, \beta+2, \ldots, n. \quad (7)$$

The active power transmission loss P_L can be calculated by the network loss formula:

$$P_L = \sum_{i=1}^{\beta} \sum_{j=1}^{\beta} P_i B_{ij} P_j, \quad (8)$$

where F_{ti}, F_{ci}, F_{hi} are the respective fuel characteristics of the conventional thermal generators, cogeneration units and heat-only units. P is the unit power generation. H is the unit heat production. $i \in [1, 2, \ldots, \alpha]$ denotes conventional thermal generators. $i \in [\alpha+1, \alpha+2, \ldots, \beta]$ denotes cogeneration units. $i \in [\beta+1, \beta+2, \ldots, n]$ denotes heat-only units. The operation ranges of conventional thermal generators and heat- only units are expressed in Eqs. (4) and (7) and those for cogeneration units are in Eqs. (5) and (6). The heat and power outputs of the cogeneration units are non-separable and one output will affect the other. H_D and P_D are the system heat and power demands respectively. B_{ij} the loss coefficient for a network branch connected between generators i and j. $P^{\min}$ and $P^{\max}$ are the unit power capacity limits. $H^{\min}$ and $H^{\max}$ are the unit heat capacity limits. $P^{\min}(H)$, $P^{\max}(H)$, $H^{\min}(P)$ and $H^{\max}(P)$ are the linear inequalities that define the feasible operating region of the cogeneration units.

3. The bee colony optimization

Social insects have lived on earth for million of years, building nests, organizing production and procuring food. The colonies of social insects are very flexible and can adapt well to the changing environment. This flexibility allows the colony of social insects to be robust and maintain its life in spite of considerable disturbances. The dynamics of the social insect population is a result of the different actions and interactions of individual insects with each other as well as with their environment. The interactions are executed via multitude of various chemical and/or physical signals. The final product of different actions and interactions represents social insect colony behavior. The examples of interaction between individual insects in the colony of social insects are bee dancing during the food procurement, ants' pheromone secretion and performance of specific acts which signal the other insects to start performing the same action. These communication systems between individual insects contribute to the formation of swarm intelligence.

3.1. Bees in nature

A colony of honey bees can extend itself over long distances and in multiple directions simultaneously to exploit a large number of food sources. A colony prospers by deploying its foragers to good fields. In principle, flower patches with plentiful amounts of nectar can be collected with less effort and should be visited by more bees whereas patches with less nectar should receive fewer bees. The foraging process begins in a colony by scout bees that are sent to search for promising flower patches. Scout bees move randomly from one patch to another. When they return to the hive, those scout bees that found a patch which is rated above a certain quality threshold deposit their nectar and go to the dance floor to perform a dance known as waggle dance. This dance is essential for colony communication and contains three pieces of information regarding a flower patch: the direction in which it will be found, its distance from the hive and its quality rating. This information helps the colony to send it bees to flower patches precisely. After waggle dancing on the dance floor, the dancer goes back to the flower patch with follower bees that are waiting inside the hive. More follower bees are sent to more promising patches. This allows the colony to gather food quickly and efficiently. While harvesting from a patch, the bees monitor its food level. If the patch is still good enough as a food source, then it will be advertised in the waggle dance and more bees will be recruited to that source.

3.2. Bee colony optimization algorithm

Bee colony optimization (BCO) algorithm is proposed by Karaboga for numerical optimization in 2005. This algorithm mimics the food foraging behavior of honey bees. In BCO algorithm, the colony of bees consists of two groups, scout and employed bees. The scout bees seek a new food source and the employed bees look for a food source within the neighborhood of the food source in their memories. Both scout and employed bees share their information with other bees within the hive.

Fig. 2 shows the flowchart of Bee Colony Optimization algorithm. The algorithm starts with n_s scout bees randomly distributed in the search space. The nectar amounts of sites visited by n_s scout bees are calculated. Sites (m) that have the highest nectar amounts are chosen for neighborhood search. Recruit n_b bees for each selected site to explore neighborhood search. The nectar amounts of all ($n_b \times m$) sites are calculated. Select m sites which have the highest nectar amounts from ($n_b \times m$) sites to form the next bee population.