Energy 93 (2015) 1711–1718

Contents lists available at ScienceDirect

Energy

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

# Cuckoo optimization algorithm with penalty function for combined heat and power economic dispatch problem

Mohamed Arezki Mellal [a,*], Edward J. Williams [b,c]

[a] Faculty of Engineering Sciences (FSI), M'Hamed Bougara University, Boumerdes 35000, Algeria
[b] Industrial and Manufacturing Systems Engineering Department, College of Engineering and Computer Science, University of Michigan, Dearborn 48126, USA
[c] Decision Sciences, College of Business, University of Michigan, Dearborn 48126, USA

ARTICLE INFO

*Article history:*
Received 25 October 2014
Received in revised form
27 December 2014
Accepted 2 October 2015
Available online 19 November 2015

*Keywords:*
Economic dispatch
Combined heat and power
Cuckoo optimization algorithm with penalty function

ABSTRACT

The CHPED (combined heat and power economic dispatch) is a complex engineering optimization problem. The goal is to minimize the system production costs by taking into consideration different kind of constraints. This research investigates the first implementation of a prevailing bio-inspired metaheuristic called the cuckoo optimization algorithm which is powered by a penalty function (PFCOA) for solving the CHPED problem. Two case studies of the CHPED are presented and the results are compared to those obtained by several other optimization techniques applied in the literature. It has been proven that the implemented PFCOA is superior.



## 1. Introduction

The quotidian dependence of people for electrical power and useful heat pressures researchers to develop combined systems to meet aggregate demand. The main idea is to integrate co-generation units producing both heat and power simultaneously. With increasing fuel prices, the CHPED (combined heat and power economic dispatch) is a fundamental issue in power systems. Basically, the CHPED is an optimization problem whose objective is to minimize the total cost of heat and power co-generation while considering all operating constraints [1,2]. The literature shows that several researches have been proposed to deal with the CHPED optimization problem. The methods used can be divided into three categories: Nonlinear optimization methods (e.g., dual and quadratic programming), gradient descent approaches (e.g., Lagrangian relaxation), and evolutionary computation techniques (e.g., GA (genetic algorithms), PSO (particle swarm optimization), and ABC (artificial bee colony)).

The works of Rooijers & Van Amerongen [3] and Guo et al. [4] are considered the oldest and most popular papers dealing with the CHPED optimization problem. The authors applied dual/quadratic programming and Lagrangian relaxation, respectively. The limitation of these methods for handling the different kinds of the considered constraints motivates most researchers to move towards AI (artificial intelligence) optimization methods, also referred as evolutionary computation techniques. A detailed review on the application of AI to the CHPED problem could take up the whole paper. By the way, in this section, we will cite a nonexecutive overview of papers and a comprehensive summary is presented later. Song and Xuan [5] successfully employed genetic algorithms with a penalty function (GA_PF). In Ref. [6], Su and Chiang proposed an incorporated algorithm consisting of improved genetic algorithm with multiplier updating (IGA_MU). The DE (differential evolution) and its improved version (IDE) were implemented by Karimzadeh [7] and Najafi et al. [8], respectively. A SPSO (selective particle swarm optimization) for the CHPED problem was proposed by Ramesh et al. [9]. It should be noted that relatively new evolutionary computation techniques were successfully applied, such as: IWO (invasive weed optimization algorithm) [10], FSS (fish school search) [11], MGSOA (modified group search optimization) [12], ISFLA (improved shuffled frog leaping algorithm) [7], and FA (firefly algorithm) [13].

The aim of the present work is to introduce the first implementation of a modern evolutionary computation technique for the CHPED problem, namely the cuckoo optimization algorithm

* Corresponding author.
*E-mail addresses:* mellal.mohamed@gmail.com, mellal-mohamed@umbb.dz (M.A. Mellal).

http://dx.doi.org/10.1016/j.energy.2015.10.006
0360-5442/

inspired by the lifestyle of a distinguished bird called the cuckoo. The algorithm is powered by a penalty function for handling the constraints (PFCOA). The rest of the paper is organized as follows. Section 2 presents the general mathematical model expressing the CHPED optimization problem. Section 3 describes the concept of the employed cuckoo optimization algorithm with penalty function (PFCOA). Two case studies consisting of four and five units respectively with numerical results and discussion confirming the effectiveness of the proposed method are highlighted in Section 4. Finally, Section 5 draws conclusions of this research.

## 2. Optimization formulation of CHPED problem

From a mathematical point of view, the CHPED problem is a nonconvex and nonlinear optimization problem. The objective is to find the optimal allocation of power and heat generation with minimum total production cost such that both total heat and power demands and other constraints are met while the optimal points should be within the feasible operating regions (i.e., combined heat and power units are operated in a bounded heat versus power plane). Fig. 1 shows the feasible operating region of a combined cycle co-generation unit enclosed by the boundary curve MNOPQR, as described in Refs. [2,4,14–18].

Basically, the CHPED optimization problem can be formulated as follows:

Objective function

$$\text{Minimize}\quad f_{\text{cost}} = \sum_{i=1}^{n_p} \text{cost}_i(P_i) + \sum_{j=n_p+1}^{n_p+n_c} \text{cost}_j(H_j, P_j) + \sum_{k=n_p+n_c+1}^{n_p+n_c+n_h} \text{cost}_k(H_k) \tag{1}$$

Subject to equality constraints of the power and heat demands

$$\begin{aligned} &\sum_{i=1}^{n_p} P_i + \sum_{j=n_p+1}^{n_p+n_c} P_j = P_d \\ &\sum_{j=n_p+1}^{n_p+n_c} H_j + \sum_{k=n_p+n_c+1}^{n_p+n_c+n_h} H_k = H_d \end{aligned} \tag{2}$$

and inequality constraint of the capacity limits

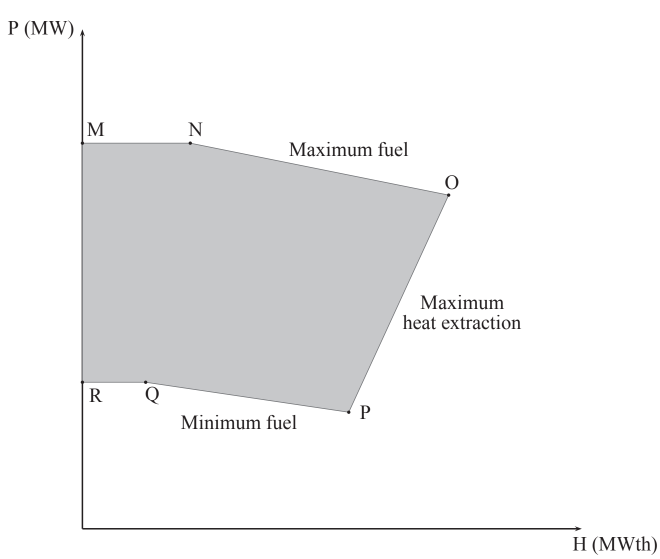


**Fig. 1.** Feasible operating region of a co-generation unit.

$$\begin{aligned} &P_i^{\min} \le P_i \le P_i^{\max}, \;\; i = 1, \ldots, n_p \\ &P_j^{\min}(H_j) \le P_j \le P_j^{\max}(H_j), \;\; j = n_p + 1, \ldots, n_p + n_c \\ &H_j^{\min}(P_j) \le H_j \le H_j^{\max}(P_j), \;\; j = n_p + 1, \ldots, n_p + n_c \\ &H_k^{\min} \le H_k \le H_k^{\max}, \;\; k = n_p + n_c + 1, \ldots, n_p + n_c + n_h \end{aligned} \tag{3}$$

where *cost* is the unit production cost; $P$ is the unit power generation; $H$ is the unit heat production; $H_d$ and $P_d$ are the heat and power demands, respectively; $i$, $j$ and $k$ are the indices of conventional power units, co-generation units and heat-alone units, respectively; $n_p$, $n_c$ and $n_h$ are the numbers of the kinds of units; $P^{\min}$ and $P^{\max}$ are the unit power capacity limits and $H^{\min}$ and $H^{\max}$ are the unit heat capacity limits.

## 3. Implementation of cuckoo optimization algorithm with penalty function for CHPED problem

The COA (cuckoo optimization algorithm) was inspired by the reproduction cycle of the bird cuckoo after the pioneer works of Rajabioun [19] in 2011. The cuckoo has the ability to lay its eggs in the nests of other species of birds by mimicking the pattern and color of the host birds' eggs. Some eggs are recognized as intruder and destroyed by the host birds. The cuckoos' chicks are fed by the host bird; however, some of them starve as they eat more than their own chicks. Therefore, the mature cuckoos seek the best habitat and migrate toward goal. The COA has been successfully applied for different engineering optimization problems, such as: multivariable controller design [19], replacement of components subject to technological obsolescence in industrial plants [20,21], statistical process control [22], advanced machining processes [23], determination of the warranty period [24], and multi-pass turning operations [25].

Basically, in this paper the PFCOA is implemented for the non-convex CHPED problem as follows:

**Step 1:** Initialization: a random of initial population of cuckoos starts laying eggs in their habitat as given by:

$$\text{Habitat} = [P_1, (P_2, H_2), (P_3, H_3), (P_4, H_4), \ldots, (P_N, H_N), H_{N+1}] \tag{4}$$

where $P_1$ is the conventional power unit, ($P_2$, $H_2$) is the co-generation unit 2, ($P_3$, $H_3$) is the co-generation unit 3, ($P_N$, $H_N$) is the co-generation unit $N$, and $H_{N+1}$ is the heat-alone unit.

**Step 2:** Allocation: a random number of eggs is attributed to each cuckoo within a bounded number.

**Step 3:** ELR (Eggs laying radius): the cuckoos start laying eggs within their respective distance given by:

$$\text{ELR} = \alpha \times \frac{\textit{Number of current cuckoos' eggs}}{\textit{Total number of eggs}} \times (\text{var}_{hi} - \text{var}_{low}) \tag{5}$$

where $\alpha$ is a positive integer, $var_{hi}$ and $var_{low}$ are the upper limit and the lower limit for variables, respectively.

**Step 4:** Eggs recognition: destroy some eggs.

**Step 5:** Growing: the eggs not destroyed hatch and the cuckoos' chicks grow.