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# A harmony-genetic based heuristic approach toward economic dispatching combined heat and power

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ABSTRACT

The Combined Heat and Power Economic Dispatch (CHPED) problem seeks to determine the heat and power production to minimize the system production costs and satisfy the heat–power demands and capacity constraints. This study examines the combined heat and power dispatching needs of cogeneration plants, and investigates the performance of an evolutionary computing approach which is based on both genetic algorithm (GA) and harmony search (HS). Experimental results were conducted for an extensive comparison with GA and HS to confirm the superior performance of this hybrid approach in cost minimization and computation times. The output results indicate that the proposed algorithm is capable of managing the CHPED problem and yields high-quality solutions.

## 1. Introduction

Economic dispatch determine the short-term optimal output of a number of electricity generation facilities to meet the system load at the lowest possible cost, and is one of the main optimization problems for electrical power system operation. The energy wasted in the conversion process from fossil fuels to electricity is often released into the environment as waste heat. Inefficient conversion processes not only waste resources, but also pollute the environment. Growing concern about the environmental impact has drawn attention to integrate environmental criteria into energy decision-making problems [12]. The principle of combined heat and power (cogeneration) involves the recovery and reuse of heat, thereby considerably increasing the overall efficiency of the energy conversion process. Economic dispatch minimizes the total cost of energy cogeneration and complies with the operational constraints of available resources. When one or more units produce both electricity and heat, the reciprocal dependencies of heat and power generation introduce a complication in the integration of cogeneration units into the economic dispatch of power system. Therefore, the Combined Heat and Power Economic Dispatch (CHPED) problem seeks to determine the heat and power production levels which minimize system production costs and satisfy the heat–power demands and capacity constraints [11,15,17,18].

The difficulty of solving CHPED lies in the constraints imposed by the mutual dependencies of heat–power capacity, which contributes to the difficulty of determining a feasible solution [14]. The mutual dependencies of heat–power capacity were mostly modeled as nonlinear constraints, which present an inherent difficulty for optimization algorithms. Several metaheuristic optimization algorithms with stochastic techniques were employed to solve complex optimization problems and were found to be powerful for engineering applications [5,6]. Stochastic methods require no mathematical structure of the problem to be optimized and are generally applicable. The evolutionary computation techniques such as genetic algorithm [14], harmony search [17], mesh adaptive direct search algorithm [13], particle swarm optimization [2], and the recently developed Firefly algorithm [19] have successfully been applied to the CHPED problem. Methods for solving the CHPED problem have been reviewed and discussed in the literature [5,13,19] systematically and thoroughly.

The genetic algorithm (GA), first proposed by Holland [10], is a stochastic optimization technique based on the natural selection of the evolution mechanism that tends to move toward optimizing the behavior of a system. In general, it iteratively constructs a population of strings called chromosomes, and has a reproductive process that allows parent chromosomes to breed a new population as the next generation. The offspring reproduced by two randomly selected parents inherits a number of characteristics from both parents. The chromosomes evolve through successive iterations (generations) until a predetermined number of iterations is reached, or the fitness value converges. The GA was applied successfully to various optimization problems, and its capabilities of easily modeling and solving difficult problems were proven.

The GA may offer solutions to overcome the difficulty experienced in nonlinear programming. However, the GA is known to

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suffer from non-convergence or early-convergence in a number of problems. The GA involves a powerful resolving process, as long as the representation of chromosomes is well-defined, a suitable crossover method is adopted, and a rich gene pool is initialized. A rich gene pool provides wider variety of gene species, and well-defined chromosomes and a suitable crossover method facilitate the reproduction of offspring. Several methods of crossover are proposed in the literature, such as single-point crossover, two-point crossover, and cut-and-splice crossover. In addition, other crossover methods have been designed for ordered chromosomes, including partially mapped crossover, cycle crossover, and order crossover. Although the crossover procedure based on two parents is more biological, researchers, including Eiben et al. [4] and Ting [16], suggest that more than two parents may be superior for yielding a quality solution. A novel approach to generating a new population is required to locate optimal solutions. Therefore, this study proposes a hybrid optimization approach by combining the features of both GA and harmony search (HS), which retains the features of GA, and simultaneously avoids the non-convergence or early-convergence deficiency. This method may present a superior alternative to address than the GA.

This study adopts the concept of the harmony search (HS) algorithm to devise a new crossover mechanism to improve GA. The HS was developed to mimic the music improvisation process in which musicians in an ensemble continue to polish their pitches to obtain superior harmony [7]. The HS algorithm has been successfully applied to a wide variety of optimization problems, such as vehicle routing problems [8], network design problems [1], and power economic load dispatch problems [3]. A new solution that differs from the GA was developed by cloning fragments of other solutions in HS. The concept behind this cloning scheme was used and adjusted in the proposed HSGA algorithm when generating fresh populations, allowing those populations created by the new crossover method to approach the optimum.

The objective of this research is to investigate the performance of the HSGA in solving the CHPED problem to meet demand constraints of power plants and to minimize their production costs. The performance of conventional approaches of GA and HS are presented and used for comparison purposes. Section 2 presents the formulation of the CHPED problem in a nonlinear program model. Section 3 provides a detailed description of HSGA. Its dispatching results and that of GA and HS are provided in Section 4. Finally, conclusions are presented in Section 5.

## 2. Combined Heat and Power Economic Dispatch (CHPED)

From a mathematical programming point of view, the CHPED problem falls into the category of nonlinear programming, in which constraints describe the consequences of decisions made for heat production affecting the decisions of power production, and vice versa. The core of its formulation is the consideration of interactions between heat and power production. However, this difficult problem can be expressed in a nonlinear optimization model as if they are actually decoupled.

In this particular case, the objective was to develop an economic dispatch scheme to minimize the total cost of cogeneration and satisfy the operational constraints. To build the cost minimization model for this CHPED, we followed the notations and modeling of Vasebi et al. [17] in defining the following parameters and variables:

| | |
|---|---|
| $C$ | Total heat and power production cost |
| $c$ | Unit production cost |
| $p$ | Unit power generation |
| $h$ | Unit heat production |
| $H_D$ | System heat demands |
| $P_D$ | System power demands |
| $i$ | Index of conventional power units |
| $j$ | Index of cogeneration units |
| $k$ | Index of heat-only units |
| $n_p$ | Number of power units |
| $n_c$ | Number of cogeneration units |
| $n_h$ | Number of heat units |
| $p^{\min}$ | Minimum of unit power capacity |
| $p^{\max}$ | Maximum of unit power capacity |
| $h^{\min}$ | Minimum of unit heat capacity |
| $h^{\max}$ | Maximum of unit heat capacity |

The CHPED is formulated as a nonlinear program model to minimize the total production cost as follows:

$$\min \quad C = \sum_{i=1}^{n_p} c_i(p_i) + \sum_{j=1}^{n_c} c_j(h_j p_j) + \sum_{k=1}^{n_h} c_k(h_k) \tag{1}$$

$$\text{s.t.} \quad \sum_{i=1}^{n_p} p_i + \sum_{j=1}^{n_c} p_j = P_D \tag{2}$$

$$\sum_{j=1}^{n_c} h_j + \sum_{k=1}^{n_h} h_k = H_D \tag{3}$$

$$p_i^{min} \leqslant p_i \leqslant p_i^{max}, \quad i = 1, \ldots, n_p \tag{4}$$

$$p_j^{min}(h_j) \leqslant p_j \leqslant p_j^{max}(h_j), \quad j = 1, \ldots, n_c \tag{5}$$

$$h_j^{min}(p_j) \leqslant h_j \leqslant h_j^{max}(p_j), \quad j = 1, \ldots, n_c \tag{6}$$

$$h_k^{min} \leqslant h_k \leqslant h_k^{max}, \quad k = 1, \ldots, n_h \tag{7}$$

The power outputs and heat outputs are restricted by their own upper and lower capacity limits, as shown in (4) and (7). Moreover, for cogeneration units, their power capacity limits are functions of the unit heat production and their heat capacity limits are functions of the unit power generation [9,17], as shown in (6) and (7). The difficulty in solving the cost-minimization model arising in the CHPED is caused by the mutual dependencies of production constraints.

## 3. The harmony-genetic algorithm and Frankenstein

HSGA is a combination of genetic algorithms and the harmony search approach. Genetic algorithms are stochastic and population-based search algorithms that determine the locations and values of a set of points in the domain space. The criterion for which new points are generated or old points are discarded is a function of the existing population. The other technique used in HSGA is harmony search [7], which is another well-known heuristic algorithm. The proposed algorithm employs the cloning scheme in HS for generating a new population. The process replaces the original genes with genes obtained from other chromosomes. Unlike the conventional two-parent basis crossover, the newly formed chromosome is called Frankenstein because parts of the new chromosome are reaped selected from other chromosomes rather than inherited conventionally from only two parents, and originates from an open source framework for music composition and improvisation. The offspring Frankenstein offers the algorithm fertile combinations of genes to provide higher probability to approach global optimum. The method used to produce a Frankenstein is to first choose a chromosome as the “noumenon”. The roulette selection method is used to select any one of the chromosomes in the pool (except the nou-