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Optimizing the Harmony Search Algorithm for Combined Heat and Power Economic Dispatch in American English

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Abstract

Achieving optimal utilization of multiple combined heat and power (CHP) systems is a complex problem that requires powerful methods for resolution. This paper presents a harmony search (HS) algorithm to address the economic dispatch issue in CHP (CHPED). The recently developed meta-heuristic HS algorithm has been successfully employed in a wide range of optimization problems. The method is demonstrated through a test case from existing literature and a new one proposed by the authors. Numerical results indicate that the proposed algorithm can identify superior solutions compared to traditional methods, and that the Harmony Search algorithm can be effectively applied to CHPED-related problems.

Introduction

Combined heat and power (CHP) generation units, which operate at high efficiency levels and provide both heat and power to customers, are playing an increasingly important role in energy production [1]. The very best CHP units can achieve fuel conversion efficiencies of nearly 90%, while even the most modern combined cycle plants can only reach efficiencies between 50 and 60%. For most CHP units, the heat production capacity depends on the power generation and vice versa. This mutual dependency between heat and power generation complicates the integration of CHP units into the heat and power economic dispatch. Therefore, the general objective of CHP economic dispatch (CHPED) is to find the optimal point of power and heat generation with minimal fuel cost, ensuring that both heat and power demands are well satisfied while the CHP units operate within a bounded heat versus power plane [2].

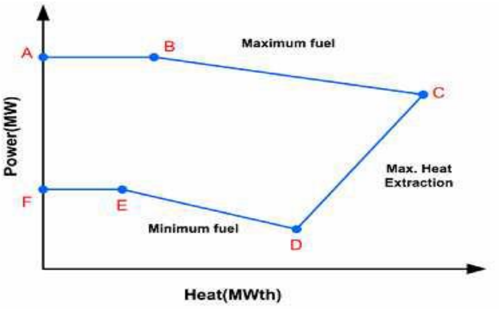

Figure 1: The operating heat-power regions for a cogeneration unit

CHPED Problem Formulation

The power and heat supply system consists of conventional thermal generators (power-only units), CHP units and heat-only units. The power output of power-only units [3] and the heat output of heat-only units are constrained by their respective upper and lower capacity limits. The heat-power relationship for the CHP unit is delineated by boundary curve ABCDEF, as illustrated in Figure 1 [4,5]. In the system being considered, power is generated by power-only units and CHP units, whereas heat is produced by CHP units and heat-only units [6,7].

Objective function: fuel cost of units

$$F_{fuel} = \sum_{i=1}^{N_p} f_i(P_i) + \sum_{j=1}^{N_c} f_j(P_j, h_j) + \sum_{k=1}^{N_h} f_k(h_k) \tag{1}$$

$f_i\ (P_i)$, $f_j\ (P_j, h_j)$, $f_k\ (h_k)$ are the respective fuel costs functions of the power-only unit, CHP unit and heat-only unit, these cost functions are usually smooth quadratic. However, to model a more realistic cost of units, the valve-point effects need to be considered. P_i , P_j are the power generation of the power-only and CHP units respectively; h_j, h_k are heat production of CHP and heat-only units, respectively; N_p, N_c, N_h are the respective numbers of the above three kinds of units [8].

Constraints

Two types of constraints are considered in CHPED problems: equality and inequality constraints. The former are the power and heat balance constraints that cover the total heat and power demands (including real power losses in transmission lines). And the latter constraints reflect the limits on heat and power generated by each unit. These constraints are concluded as follows [9,10].

Power production equilibrium constraint

$$\sum_{i=1}^{N_p} P_i + \sum_{j=1}^{N_c} P_j = P_D + P_L \tag{2}$$

Where P_D is the power demand of the system; P_L is the system power transmission loss that can be calculated by the B-coefficient loss formula as shown in the following [3,6,11]:

$$P_L = \sum_{i=1}^{N_p+N_c} \sum_{j=1}^{N_p+N_c} P_i B_{ij} P_j \tag{3}$$

Where B_{ij} is the loss coefficient for the network branch connected between power generation units i and j.

Heat production equilibrium constraint

$$\sum_{j=1}^{N_c} h_j + \sum_{k=1}^{N_h} h_k = H_D \tag{4}$$

Where H_D is the heat demand of the system.

The capacity limits of each unit

$$P_i^{min} \le P_i \le P_i^{max}\ , \quad i = 1,2,\dots\dots,Np \tag{5}$$

$$P_j^{min}(h_j) \le P_j(h_j) \le P_j^{max}(h_j)\ , \quad j = 1,2,\dots,Nc \tag{6}$$

$$h_j^{min}(P_j) \le h_j(P_j) \le h_j^{max}(P_j)\ , \quad j = 1,2,\dots,Nc \tag{7}$$

$$h_k^{min} \le h_k \le h_k^{max}, \quad k = 1,2,\dots,Nh \tag{8}$$

Harmony Search to solve the Economic Dispatch Problem

Recently, Geem et al. [12] proposed a new HS meta-heuristic algorithm that was inspired by a musical process of searching for a perfect state of harmony. Harmony in music is analogous to the optimization solution vector, and the musician's improvisations are analogous to local and global search schemes in optimization techniques. The HS algorithm does not require initial values for the decision variables. Furthermore, instead of a gradient search, the HS algorithm uses a stochastic random search that is based on the harmony memory, considering rate and pitch adjusting rate so that derivative information is unnecessary [13].

In the HS algorithm, musical performances seek a perfect state of harmony determined by aesthetic estimation, as the optimization algorithms seek a best state (i.e., global optimum) determined by the objective function value. It has been successfully applied to various optimization problems in computation and engineering fields [14].

The optimization procedure of the HS algorithm consists of

- Steps 1–5, as follows [15]:

- Step 1: Initialize the optimization problem and algorithm parameters.

- Step 2: Initialize the harmony memory (HM).

- Step 3: Improvise a new harmony from the HM.

- Step 4: Update the HM.

- Step 5: Repeat Steps 3 and 4 until the termination criterion has been satisfied.

$$\boldsymbol{HM} = \begin{bmatrix} \boldsymbol{x_1^1} & \boldsymbol{x_2^1} & \dots & \boldsymbol{x_N^1} \\ \boldsymbol{x_1^2} & \boldsymbol{x_2^2} & \dots & \boldsymbol{x_N^2} \\ . & . & \dots & . \\ . & . & \dots & . \\ \boldsymbol{x_1^{HMS}} & \boldsymbol{x_2^{HMS}} & \dots & \boldsymbol{x_N^{HMS}} \end{bmatrix} \begin{matrix} \Rightarrow \boldsymbol{f(x^1)} \\ \Rightarrow \boldsymbol{f(x^2)} \\ \Rightarrow \dots\dots\dots \\ \\ \Rightarrow \boldsymbol{f(x^{HMS})} \end{matrix} \tag{9}$$

A detailed explanation of these steps can be found in [15,16], summarized in the following:

Step 1. Initialize the optimization problem and HS algorithm parameters. First, the optimization problem is specified as follows:

Minimize $f(x)$ subject to $x_i \epsilon X_i$, $i = 1, \dots, N$.

$f(x)$ is the objective function, x is the set of each decision variable (x_i); X_i is the set of the possible range of values for each design variable (continuous design variables), that is $x_{i\,lower} \le X_i \le x_{i\,upper}$, where $x_{i\,lower}$ and $x_{i\,upper}$ are the lower and upper bounds for each decision variable; and N is the number of design variables. In this context, the HS algorithm parameters that are required to solve the optimization problem are also specified in this step. The number of solution vectors in harmony memory (HMS) that is the size of the harmony memory matrix, harmony memory considering rate (HMCR), pitch adjusting rate (PAR), and the maximum number of searches (stopping criterion) are selected in this step. Here, HMCR and PAR are parameters that are used to improve the solution vector. In this context, both are defined in Step 3.

Step 2. Initialize the harmony memory (HM). HM is a memory location where all the solution vectors (sets of decision variables) are stored. In Step 2, the HM matrix, shown in Eq. 9, is filled with randomly generated solution vectors using a uniform

distribution,

Step 3. Improvise a new harmony from the HM. A new harmony vectors $x' = (x'_1, \dots, x'_N)$ is generated based on three rules: (a) memory consideration, (b) pitch adjustment, and (c) random selection. Generating a new harmony is called 'improvisation'.

In the memory consideration, the value of the first decision variable (x'_1) of the new vector is chosen from any value in the specified HM range $(x'_1, \dots, x_N^{HMS})$. The values of the other decision variables $(x'_2, \dots, x_N^{HMS})$ are chosen in the same manner. The HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the HM, while $(1 - HMCR)$ is the rate of randomly selecting one value from the possible range of values.

$$x'_i \leftarrow \begin{cases} x'_i \in \{x_i^1; x_i^2; \dots.; x_i^{HMS}\} w.p. HMCR \\ x'_i \in X_i \dots\dots\dots\dots w.p. (1 - HMCR). \end{cases} \tag{10}$$

Afterwards every component obtained by the memory consideration is examined to determine whether it should be pitch-adjusting. This operation uses the PAR parameter, which is the rate of pitch adjustment as follows:

$$Pitch\ adjuseting\ decision\ for\ x'_i \leftarrow \tag{11}$$

$$\begin{cases} yes\ \ with\ probability\ PAR \\ NO\ \ with\ probability\ (1-PAR) \end{cases}$$

The value of (1_PAR) sets the rate of doing nothing. If the pitch adjustment decision for x_i' is yes, then x_i' is replaced as follows:

$$x_i' \leftarrow x_i' \pm r.bw \qquad (12)$$

Where bw is an arbitrary distance bandwidth, r is a random number generated using uniform distribution between 0 and 1.

Step 3. HM consideration, pitch adjustment or random selection is applied to each variable of the New Harmony vector in turn.

Step 4. Update the HM. If the new harmony vector, $(x_1', \dots, x_N')$ is better than the worst harmony in the HM, judged in terms of the objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

Step 5. Repeat Steps 3 and 4 until the termination criterion has been satisfied.

Table 1: Comparing the results of HS algorithm with other methods

Method	HS	ALHN	GA
P1 (MW)	0.887	0.0	0.0
P2 (MW)	46.0268	159.9994	159.23
P3 (MW)	103.32	40	39.95
H2 (Mth)	1.7629	39.9993	40.77
H3 (Mth)	1.7952	75	75.06
H4 (Mth)	14.3787	0.0	0.0
Cost ($)	9230.2	9257.05	9267.2

Case Study and Analysis of Optimization Results

This paper reports on the implementation and solving of the proposed HS algorithm based CHPED problem in the program personal Matlab 7.1.

The proposed method was applied to a test system [17,18] consisting of one conventional thermal generator, two cogeneration units and a heat only unit. System data containing valve point effects coefficients of fuel cost equations and B loss coefficients are obtained from Basu [19]. The feasible operating regions of the two cogenerations units are given in Fig. 3 and Fig. 4. The system power demand PD and the heat demand HD are 200 MW and 115 MTh respectively.

The fitness function of the CHPED problem is:

$$Min \left\{ F_{total} = \sum_{i=1}^{np} F_i(p_i) + \sum_{j=1}^{n_c} F_j(h_j, p_j) + \sum_{k=1}^{n_h} F_k(h_k) \right\} \qquad (13)$$

The active power transmission loss PL [3] can be calculated using the network loss formula as:

$$P_L = \sum_{i=1}^{N_p+N_c} \sum_{j=1}^{N_p+N_c} P_i B_{ij} P_j \qquad (14)$$

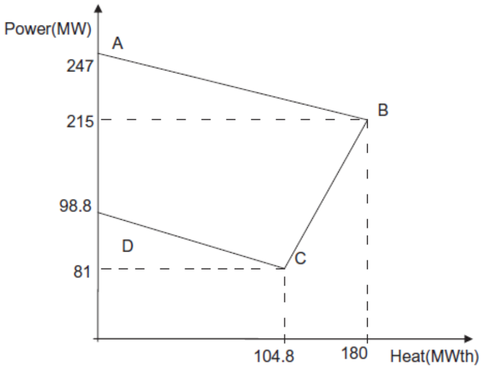

Figure 2: Operating regions of the first cogeneration unit

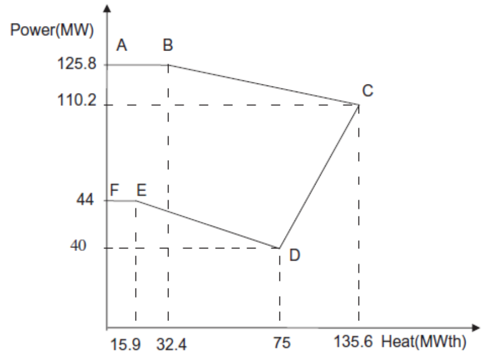

Figure 3: Operating regions of the second cogeneration unit

A. Only Power units:

$$F_1(P_1) = 50P_1 \tag{15}$$

B. Cogeneration units:

$$F_2(P_{2,}H_2) = 2650 + 14.5P_2 + 0.0345P_2^2 + 4.2H_2 + 0.03H_2^2 + 0.031P_2H_2 \tag{16}$$

$$F_3(P_3, H_3) = 1250 + 36P_3 + 0.0435P_3^2 + 0.6H_3 + 0.027H_3^2 + 0.011P_3H_3 \tag{17}$$

C. Only Heating units:

$$F_4(H_4) = 23.4h_4 \tag{18}$$

Subjected to be equality constraints:

$$P_1 + P_2 + P_3 = P_D \tag{19}$$

$$H_2 + H_3 + H_4 = H_D \tag{20}$$

And the inequality constraints:

$$0 \le P_1 \le 150\ MW \tag{21}$$

$$0 \le H_4 \le 2695.2\ \ MWth \tag{22}$$

The results obtained from the proposed Harmony Search Algorithm are compared with the Genetic Algorithm (GA) [17] and Augmented Lagrange Hopfield Network (ALHN) [18]. The resulting production costs were used to compare the performance of the HS with those of other methods. The parameters finally selected for the algorithm - for which consistent and superior results with minimum CPU time were found - are as shown in Table 1.

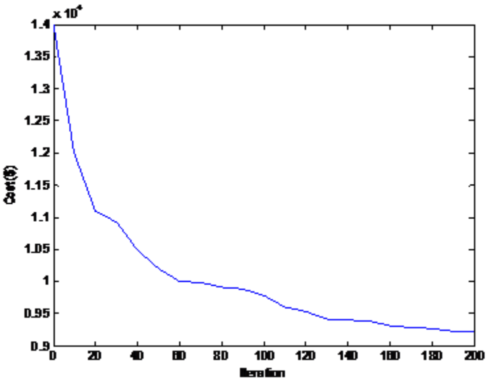

Figure 4: Cost convergence

Conclusion

This paper presents a novel approach based on Harmony Search algorithm optimization for solving the combined heat and power economic dispatch problem. Compared with other methods, this approach evidently provides better performance in terms of optimal solution and computation effort.

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