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Application of HBO for combined heat and power economic dispatch problem with the presence of green energy sources

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Abstract
This paper implemented a novel meta-heuristic method named the Heap-Based optimizer (HBO) to determine the optimal solutions for the combined heat and power economic load dispatch considering green energy sources (GES-CHPED). In the paper, the real effectiveness of HBO is test by four cases. Besides, particle swarm optimization (PSO) is also applied to compare the results with that of HBO. The results obtained in all study cases indicated that the HBO is much more effective than PSO over all compared aspects. When compared with other methods, it demonstrates HBO is a stable and reliable computing method. Besides, the contribution of green energy sources (GES) is also clarified in the way of solving the original combined heat and power economic load dispatch.

Keywords: Meta-heuristic algorithm; combined heat and power economic dispatch; Heap-Base optimizer; load demand

1. Introduction

The combined heat and power problem (CHPED) is to reuse the large amount of heat caused by driving thermal generators and to minimize total electricity generating expenditure (TEGE). The implementation of this purpose in practice is known as the co-generation method.

A large number of research papers have been published to solve the CHPED problem. In particular, some typical studies can be listed, such as: Twofold programing approach (TPA) [1], Double phase computing approach (DPCA) [2], the enhanced ant colony searching approach (EACA) [3], the evolutionary-based approach (EBP) [4], Genetic mechanism-based approach (GMP) and other modified versions [6–8], Harmonic mechanism-based approach (HMA) and its improved versions [9–11], Particle swarm method and its revised versions [12–14], Bee swarm algorithm (BSA) [15], the combination of Bat optimizer (BO) and Bee swarm-based artificial model (BSAM) [15], Serial second order programing approach (SSOP) [16], Mesh dynamic searching approach (MDS) [17], Mesh direct searching mechanism approach (MDSA) [18, 19]. Immune system-based artificial model (ISA) [20], Lagrange operator with varied gradient operator [21], Teaching-learning mechanism approach (TLMA) [22], Whale hunting behavior approach (WHB) [23], Highly enhanced deep learning (HEDL) [24].

In this paper, the original CHPED is modified by incorporating the presence of GES to form GES-CHPED problem. Besides, a novel meta-heuristic approach called the Heap-Base optimizer (HBO) [25] is implemented to handle the GES-CHPED problem. According to the authors, the theoretical ability of HBA is very strong through the results from dealing with a lot of benchmark functions. In summary, the following are the novelties of this paper:

- The GES-CHPED problem is completely solved with no violations of all related constraints.
- HBO has been successfully implemented to solve the GES-CHPED problem as an effective computing method.

2. Problem formula

2.1 Objective function

The main objective function of the CHPED problem and the GES-CHPED problem is to minimize the total electricity generating expenditure (TEGE).

It is assumed that the generating sources of the system include *I* electricity generators, *K* heat generators, and *J* combined generators. The mathematical expression of the objective function is described as follows:

$$\text{Minimize TEGE} = \sum_{i=1}^{I} FE_{ei}(P_i) + \sum_{k=1}^{K} FE_{hk}(H_k) + \sum_{j=1}^{J} FE_{cj}(P_{cj}, H_{cj}) \quad (1)$$

The fuel expenditure (FE_e) of the electricity generator is formulated closely by a second order below

$$FE_{ei}(P_i) = a_{1i} + b_{1i}P_i + c_{1i}P_i^2; \;\; i = 1,\ldots,I \quad (2)$$

where a_{1i}, b_{1i} and c_{1i} are fuel utilization factors of the electricity generator *i*. P_i is the power generated by the electricity generator *i*.

The fuel expenditure (FE_h) of heat generator is given by

$$FE_{hk}(H_k) = a_{2k} + b_{2k}H_k + c_{2k}H_k^2; \;\; i = 1,\ldots,K \quad (3)$$

where a_{2k}, b_{2k} and c_{2k} are fuel utilization factors of the heat generator *k*. H_k is the amount of heat generated by the heat generator *k*.

The fuel expenditure (FE_c) of the combined generator is presented by equation below:

$$FE_{cj}(P_{cj}, H_{cj}) = a_{3j} + b_{3j}P_{cj} + c_{3j}P_{cj}^2 + a_{4j}H_{cj} + b_{4j}H_{cj}^2 + c_{4j}H_{cj}P_{cj}; \;\; i = 1,\ldots,J \quad (4)$$

where P_c and H_c are the amount of power and heat generated by the combined generators *j*. a_{3j}, b_{3j}, c_{3j}, a_{4j}, b_{4j} and c_{4j} are the fuel utilization factors of the combined generators *j*

2.2 Constraints

Several constraints on the GES-CHPED problem are considered as the generator working constraints and the balance constraints. The description of each constraint is depicted as follows:

2.2.1 The generator working constraints

2.2.1.1 The electricity generator's working constraint: The amount of power output from each generator must be located between the minimum and maximum boundaries as below:

$$P_{i,\min} \le P_i \le P_{i,\max} \quad (5)$$

2.2.1.2 The heat generator working constraint: The heat power output is limited by.

$$H_{k,\min} \le H_k \le H_{k,\max} \quad (6)$$

2.2.1.3 The combined generator working constraint: The working constraint of a combined generator is separated into electricity and heat terms. These terms are presented in equations (7) and (8) below:

$$P_{cj,\min}(H_{cj}) \le P_{cj} \le P_{cj,\max}(H_{cj}) \quad (7)$$

$$H_{cj,\min}(P_{cj}) \le H_{cj} \le H_{cj,\max}(P_{cj}) \quad (8)$$

2.2.2 The power balance constraints

In this constraint, the amount of power output from the supply side and the amount of power consumed by demand side must be equal. In case of considering power loss caused by the transmission lines and the presence of GES, the expression of power balance constraint is given below:

$$P_{DS} + P_{Loss} - \sum_{i=1}^{I} P_i - \sum_{j=1}^{J} P_{cj} - P_{GE} = 0 \quad (9)$$

where P_{DS} is load demand; P_{GE} is power output of GE plant; P_{Loss} is power loss and it is given by

$$P_{Loss} = \sum_{i=1}^{I+J}\sum_{j=1}^{I+J} P_i B_{ij} P_j + \sum_{i=1}^{I+J} B_{0i} P_i + B_{00} \quad (10)$$

Where, P_i and P_j are respectively the amount of power bumped into node *i* and node *j*; B_{ij}, B_{0i} and B_{00} are loss factors from loss matrix

2.2.3 The heat balance constraints

To secure the whole system's operation, the volume of heat generated by the supplied side and the volume of heat required by the demand side (H_D) must be equal:

$$H_D - \sum_{j=1}^{N_{cg}} H_{cgj} - \sum_{k=1}^{N_{ph}} H_{phk} = 0 \quad (11)$$

3. The Applied HBO Algorithm

Like other state-of-the-art meta-heuristic algorithms, HBO also requires several common parameters, such as population (*NP*) and maximum iterations (l_{max}).

The process of updating solutions of HBO is implemented by

$$M_{q,new}^{d} = \begin{cases} M_q^d, & SL \le SL_1 \\ EF + \rho\omega\left|EF - M_q^d\right|, & SL_1 < SL \le SL_2 \\ M_{RP} + \rho\omega\left|M_{RP} - M_q^d\right|, & SL_2 < SL \le SL_3 \text{ and } Fit(M_{RP}) < Fit(M_q) \\ M_q + \rho\omega\left|M_{RP} - M_q^d\right|, & SL_2 < SL \le SL_3 \text{ and } Fit(M_{RP}) \ge Fit(M_q) \end{cases} \quad (13)$$

$$; q = 1, \ldots, NP; \; d = 1, \ldots, Dim$$

Where, $M_{q,new}^{d}$ and M_q^d are the *qth* new and old solutions; M_{RP} is random solution in population; SL is a random value inside the interval of 0 and 1; *EF* is a predetermined value; *Dim* is the number of dimension of variables; ρ and ω are amplifying operators, and they are presented as shown in equations (14,15); SL_1, SL_2 and SL_3 are probability values obtained roulette wheel and they are given by equations (16-18)

$$\omega = 2z - 1 \quad (14)$$

Where, *z* is a random value in [0,1]

$$\rho = \left| 2 - \frac{\left(l.\,mod \left(\frac{l_{max}}{EF} \right) \right)}{\frac{l_{max}}{4EF}} \right| \quad (15)$$

where l is the current iteration

$$SL_1 = 1 - \frac{l}{l_{max}} \quad (16)$$

$$SL_2 = SL_1 + \frac{1 - SL_1}{2} \quad (17)$$

$$SL_3 = SL_2 + \frac{1 - SL_1}{2} = 1 \quad (18)$$

4. Numerical results

In this section, HBO and PSO are implemented to determine the optimal solutions for CHPED and GES-CHPED problems. All system specifications are presented in [13]. The values of power demand and heat demand are 175 MW and 110 MWth, respectively. The real effectiveness of both HBO and PSO is assessed over four different cases of *NP* and l^{max}. In case 1, *NP* is 50 and l^{max} is 50. Similarly, 50 and 100 are for Case 2, 50 and 150 are for Case 3, and 50 and 200 are for Case 4, respectively. The entire work is conducted on a personal computer with a 2.60 GHz central processing unit (CPU) and 8 GB of random-access memory (RAM). The results obtained by HBO and PSO in two systems in which System1 does not consider GES and System 2 considers GES. The details for two systems will be given in subsections 4.1 and 4.2 below:

4.1 System 1

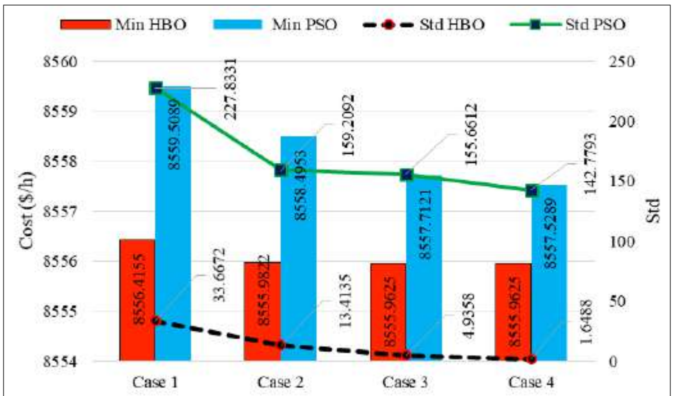

Fig 1: The results obtained by HBO and PSO over four cases of *NP* and l^{max}

Figure 1 presents the results obtained by HBO and PSO in terms of minimum cost value and standard deviation (Std). The red bars represent the minimum cost values reached by HBO (Min.HBO), while the blue ones describe the minimum cost values produced by PSO (Min.PSO). The black dashed line shows the values of Std in four cases given by HBO, while the green line reports the Std values obtained by PSO. As seen in the figure, Min cost and Std of HBO decreased from case 1 to case 4. The best cost of HBO is $ 8555.9625 and it is also the best value for the problem. That of PSO does not reach this value. In relation to Std, that of HBO decreased in all cases and was less than that of PSO.

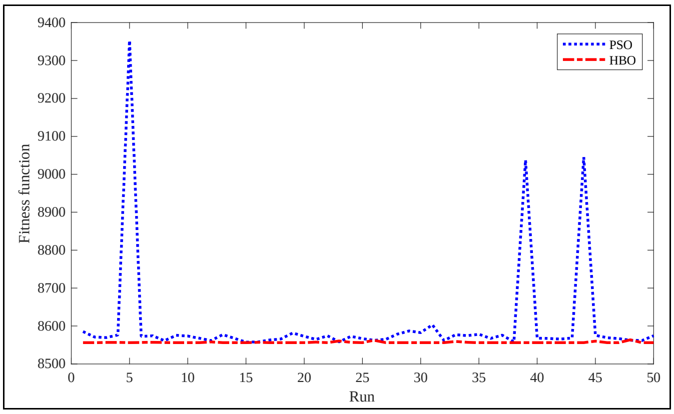

Fig 2: The fitness values obtained by HBO and PSO after 50 independent runs

The fitness values of HBO and PSO after 50 independent runs are plotted in Figure 2. From the observation, it is easy to conclude HBO is more reliable and stable than PSO.

Table 1: Results comparison of PSO and HBO with other previous studies

Method	Min. cost ($/h)	Method	Min. cost ($/h)
GWPSO [13]	8555.9625	LR-SSMU-CSS [21]	8555.9625
GWPSO-CD [13]	8555.9625	LR-SSMU- SSBS [21]	8555.9625
MADS-PSO [18]	8629.4156	PSO	8557.5289
MADS-DACE [18]	8555.9625	HBO	8555.9625

Table 1 compares the results of PSO, HBO, and other methods. The Min.cost of HBO is better than the results reached by MADS-PSO [18] and PSO. HBO's value is $8555.9625 ($/h), while the values reported by MADS-PSO and PSO are 8629.4156 ($/h) and 8557.5289 ($/h), respectively. Besides, HBO reached the same Min.cost value as the other remaining methods.

4.2 System 2

In this section, a green energy resource with a 30MW power output is installed in the original system. Other parameters related to power and heat demand remained the same as in the original system. In addition, this section only applied HBO over four cases of *NP* and l^{max}. These parameters remain the same as in section 4.1.

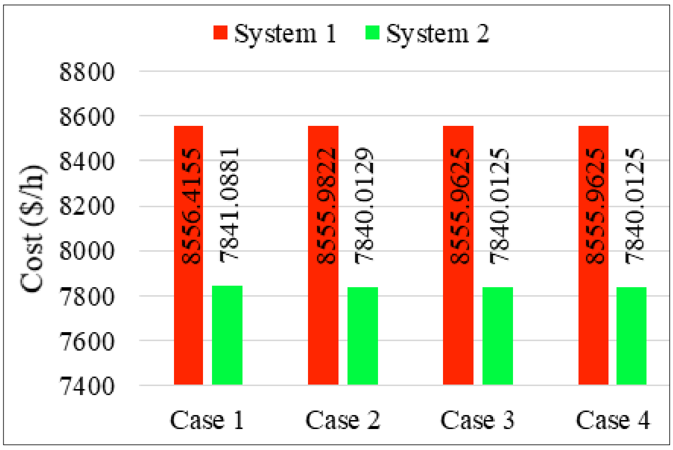

Fig 3: The cost values obtained by two situations with/without GES

In Figure 3, the best cost of HBO for System 2 is from $7841.0881 in Case 1 to $7840.0125 in Case 4. The best value for system 2 is $7840.0125. The result indicates the cost value has significantly dropped while GES is integrated into the system. The cost of system 2 is less than that of system 1 by $715.95.

5. Conclusion

This paper introduces a novel meta-heuristic method called HBO for solving the GES-CHPED problem. The real performance of HBO is assessed with different pairs of control parameters. When compared with PSO and other methods, HBO is completely outstanding in all aspects. The results also indicated that the installation of GES into the system significantly reduced the cost.

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