International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-4, April2021
ISSN: 2395-3470
www.ijseas.com

A Novel Meta-Heuristic Method For Solving Combined Heat And Power Economic Dispatch Problem

Nguyen Anh Tang[1], Ta Minh Cuong [2], Nguyen Minh Duc Cuong [3*]

Faculty of electrical & electronics engineering, Ly Tu Trong College, Ho Chi Minh city, Vietnam
Email: [1] anhtangnguyen@gmail.com, [2] taminhcuong@gmail.com, [3] duccuongltt@gmail.com
*Corresponding Author

Abstract

This paper applies a new metaheuristic algorithm called Heap-Based optimizer (HBO) for solving the combined heat and power economic load dispatch problem (CHPED). The HBO is inspired based on simulating the interaction in a group of people working together inside an organization with a specific order to achieve their common goal. The performance of HBO is assessed through different cases. Even both power demand and heat demand are continuously increased in each case, the optimal results given by HBO in all case studies are quite impressive while comparing with the other methods. Hence, HBO is a very promising method for solving the optimization problem.

Key words: Meta-heuristic algorithm; combined heat and power economic dispatch; Heap – Base optimizer; load demand.

1. Introduction

The combined heat and power problem (CHPED) is now become one of the top considered problem. The main goal needed to achieve while solving the CHPED problem is to minimize total fuel cost for running different type of generators. The idea of combining heat and power is to make use of a huge volume of heat extracted during the operating process of thermal power plant. In practice, this idea is implemented under the name called the co-generation technology. The benefits that this technology offers are improving the productivity of thermal power plant substantially over the conventional one, optimizing the use of fossil fuel such as oil, coal, nature gas, etc. and, therefore, mitigating the negative effects to environment.

By acknowledging the important role of the CHPED problem, there are lot of studies proposed to solve this problem such as Dual programming (DP) [1], Two-layer algorithm [2], the improved ant colony search algorithm (IACS) [3], Evolutionary programming (EP) [4], Genetic algorithm (GA) and its improved versions [6-8], harmonic search algorithm (HSA) and its modified versions [9-11], particle swarm optimization (PSO) and its improved versions [12-14], Bee colony optimization (BCA) [15], The hybridizing Bat algorithm (BA) and Artificial bee colony (ABC) [15], The sequential quadratic programming (SQP) [16], Mesh adaptive direct search algorithm (MASA) [17], Direct search method (DSM) [18], Artificial immune system (AIS) [20], Lagrange relaxation with surrogate sub-gradient multiplier updates [21], Teaching learning based optimization (TLBO) [22], Whale optimization algorithm (WOA) [23], and Deep reinforce learning (DRL) [24].

In this research a new meta-heuristic named Heap – Base optimizer (HBO) [25] is applied to determine the optimal results for CHPED problem. Previously, this new algorithm have proved its high performance though different testing function performed by the author.

The main contribution of the study can be summarized as follows:

- A new method is successfully applied to solve the CHPED problem.
- The optimal results reached by the HBO is noticeably better than the similar ones reported from other methods though different case of studies.
- During the whole process of solving the CHPED problem all complicated constraint involved are satisfied.

2. Problem formula

2.1. Objective function

The objective function of the problem is presented as follows:

$$\text{Minimize TFCC } = \sum_{i=1}^{N_{dp}} FC_{dpi}(P_{dpi}) + \sum_{k=1}^{Nph} FC_{phk}(H_{phk}) + \sum_{j=1}^{N_{cg}} FC_{cgj}(P_{cgj}, H_{cgj}) \quad (1)$$

- The fuel cost of power generator is described approximately as a quadratic function as below

$$FC_{dpi}(P_{dpi}) = a_{dpi} + b_{dpi}P_{dpi} + c_{dpi}P_{dpi}^2 \quad (2)$$

where a_{dpi}, b_{dpi} and c_{dpi} are the fuel consumed coefficients of the dedicated power generator *i*. P_{dpi} is the power generated by dedicated power generator *i*.

- The fuel cost for heat generator is also described in the same form as the power dedicated generator one.

$$FC_{phk}(H_{phk}) = a_{phk} + b_{phk}H_{phk} + c_{phk}H_{phk}^2 \quad (4)$$

where a_{phk}, b_{phk} and c_{phk} are fuel coefficients of the heat generator *k*. H_{phk} is the amount of heat generated by the heat generator *k*.

- The fuel cost mathematical expression of the combined generator is a combination of the two separate quadratic functions as below:

$$FC_{cgj}(P_{cgj}, H_{cgj}) = a_{cgj} + b_{cgj}P_{cgj} + c_{cgj}P_{cgj}^2 + k_{cgj}H_{cgj} + l_{cgj}H_{cgj}^2 + m_{cgj}H_{cgj}P_{cgj} \quad (5)$$

where P_{cgj} and H_{cgj} are the amount of power and heat generated by the combined generators *j*. a_{cgj}, b_{cgj}, c_{cgj}, k_{cgj}, l_{cgj} and m_{cgj} are the fuel coefficients of the combined generators *j*

2.2. Constraints

There are two types of constraint that need to impose strictly in CHPED problem: the operating constraints of generators and the equivalent constraints. These types of constraint are described in details in the next-subsection below:

2.2.1. The operating constraints of generators

The operating constraint for the dedicated power generator is modeled as follows:

$$P_{dpi,\min} \le P_{dpi} \le P_{dpi,\max} \quad (6)$$

Similarly, the operating constraint of heat generator is all about the amount of heat produced and its mathematical model is described as follows:

$$H_{phk,\min} \le H_{phk} \le H_{phk,\max} \quad (9)$$

Finally, the constraints belonging combined generator are regarding the ability to producing the bulk of heat and power within its restrictions. The mathematical expression of this constraints is presented as below

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

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

2.2.2. The equivalent constraints

This constraint is about the relationship between the amount of consumed by load, the total power produced by all generators in system and the amount of power loss in transmission lines. This relationship is illustrated by the Equation (10) below:

$$P_D + P_L - \sum_{i=1}^{N_{dp}} P_{dpi} - \sum_{j=1}^{N_{cg}} P_{cgj} = 0 \tag{10}$$

And, the power loss is calculated by using the Equation 11 below

$$P_L = \sum_{i=1}^{Ndp+Ncg} \sum_{j=1}^{Ndp+Ncg} P_i B_{ij} P_j + \sum_{i=1}^{Ndp+Ncg} B_{0i} P_i + B_{00} \tag{11}$$

Where, P_i and P_j are respectively represented for the power bulk injected at node i and node j; B_{ij}, B_{0i} and B_{00} are loss coefficients picked up from loss matrix

2.2.3. The heat equivalent constraints

Similar to the power balance constraint, this constraints depict the correlation between the heat supply side and the consuming side that they must be equal. The constraint is formulated as follows:

$$H_D - \sum_{j=1}^{N_{cg}} H_{cgj} - \sum_{k=1}^{N_{ph}} H_{phk} = 0 \tag{12}$$

3. The HBO

3.1. Initialization

In this step, the important parameters need to set such as the staff number or population size (*Pop*); dimension (*d*); upper (S_{max}) and lower boundary (S_{min}) of variables, the utilized-determined parameter (*UD*), quantity of managers (*qm*); maximum number of iterations (*Max_iter*);
The initial population is generated randomly as follows:

$$S_i = S_{min} + rd(S_{max} - S_{min}) \quad with\ i = 1, 2, \dots, Pop \tag{9}$$

Each solution S_i is a term of the general matrix (*S*) and the fitness value of each solution is a term of the fitness matrix (*F*). *M* and *F* are expressed as follows:

$$S = [S_i]\ with\ i = 1, 2, \dots, Pop \tag{10}$$

$$F = [F_i]\ with\ i = 1, 2, \dots, Pop \tag{11}$$

3.2. Update procedure

The whole update procedure is described in details at below:

3.2.1. The formulation of the interaction between staffs and their direct manager

In any company or organization every action for work implemented by staff is affected directly by their direct upper manager. This relationship is formulated as a mathematic equation as follows:

$$S_i^d(t+1) = UM^d + \varepsilon\delta^d\left|UM^d - S_i^d(t)\right| \qquad (12)$$

Where, *S* represents for a feasible solution or it can be considered as a specific particle of Population (*Pop*). *d* is the dimension or the quantity of variables of the problem considered, *i* is the particle i^{th} of the population and *i* = 1, 2, … *Pop*. *t* is the current iteration and *t* = 1, 2, …, *Max_iter* with *Max_iter* is the maximum number of iteration. *UM* is the direct upper manager. ε, δ^d are the designed parameters, respectively. Both ε and δ^d are determined as the equations below:

$$\delta^d = 2r_0 - 1 \qquad (13)$$

Where, r_0 is a random value in [0,1]

$$\varepsilon = \left|2 - \frac{\left(t \bmod \frac{Max\_iter}{UD}\right)}{\frac{Max\_iter}{4UD}}\right| \qquad (14)$$

Where *UD* is utilized-determine parameter. By experiments, *UD* is set by $\frac{Max\_iter}{25}$ in other to achieve the stable computational performance.

3.2.2. The formulation of the interaction between staffs

In the process of complete a particular task ordered each staff not only affected by their direct upper manager but also sometime they need to collaborate or ask for support from their colleague… This interaction is depicted as a mathematic model as follows:

$$S_i^d(t+1) = \begin{cases} S_{rsp}^d + \varepsilon\delta^d\left|S_{rsp}^d - S_i^d(t)\right|, & f(S_{rsp}) < f(S_i^d(t)) \\ S_i^d + \varepsilon\delta^d\left|S_{rsp}^d - S_i^d(t)\right|, & f(S_{rsp}) \geq f(S_i^d(t)) \end{cases} \qquad (15)$$

Where, S_{rsp} is random selection partner that a staff S_i chooses to collaborate with in order to complete their own task.

3.2.3. The formulation of the contribution of each staff

In this section, the contribution of each staff is represented by S_i^d and the mathematic model of this section is described briefly as follows:

$$S_i^d(t+1) = S_i^d(t) \qquad (16)$$

It can be viewed from the Equation 5 that the update new variables process of each particle at the next iteration is unchanged. This behavior according to the developer that it can support to regulate the variation ratio of a particle in its update new variables process

3.2.4. The orientation of entire update new variable process

Each component of P_{hc} is calculated following the equations bellows:

$$P_{hc1} = 1 - \frac{t}{Max\_iter} \quad (17)$$

$$P_{hc2} = P_{hc1} + \frac{1 - P_{hc1}}{2} \quad (18)$$

$$P_{hc2} = P_{hc2} + \frac{1 - P_{hc1}}{2} = 1 \quad (19)$$

While these harmonic choosing parameters are determined completely, the final step about update process of HBO is clarified as follows:

$$S_i^d(t+1) = \begin{cases} S_i^d(t), \quad P_0 \leq P_{hc1} \\ UM^d + \varepsilon\delta^d \left| UM^d - S_i^d(t) \right|, P_{hc1} < P_0 \leq P_{hc2} \\ S_{rsp}^d + \varepsilon\delta^d \left| S_{rsp}^d - S_i^d(t) \right|, P_{hc2} < P_0 \leq P_{hc3} \ and \ f(S_{rsp}) < f(S_i^d(t)) \\ S_i^d + \varepsilon\delta^d \left| S_{rsp}^d - S_i^d(t) \right|, P_{hc2} < P_0 \leq P_{hc3} \ and \ f(S_{rsp}) \geq f(S_i^d(t)) \end{cases} \quad (20)$$

3.3. Checking and correcting new solution

Checking new solutions can be performed as follows:

$$S_i^{new} = \begin{cases} S_{min} \ if \ S_i^{new} < S_{min} \\ S_{max} \ if \ S_i^{new} > S_{max} \end{cases} \quad (21)$$

3.4. Validating the quality of new solution

The main job of this section is validating the quality of new solution. Each new solution will be validated its quality through the new fitness value given by the fitness function feature by the problem considered. This work is modelled following the equation below:

$$F^{new} = [F_i^{new}] \ with \ i = 1, 2, \dots, Pop \quad (22)$$

3.5. Comparing and saving the better solution

In this step the new fitness value of new solution will be compared with the old one at the previous iteration. The solutions with better quality will replace the old ones and they will be utilized for the next iteration. This procedure is formulated as below:

$$M_i = \begin{cases} M_i^{new} \ if \ F_i^{new} < F_i \\ M_i \quad else \end{cases} \quad (23)$$

$$F_i = \begin{cases} F_i^{new} \ if \ F_i^{new} < F_i \\ F_i \ if \ F_i^{new} > F_i \end{cases} \quad (24)$$

4. Numerical results

In this section, the HBO is applied to solve the CHPED in the system with the specific information is described in Table B1. Besides, performance of HBO is evaluated through three separate cases with different load parameters for each case. Specifically, case 1 with the value of power demand and heat demand are 175 MW and 110MWth, respectively while these value for Case 2 are 200 MW and 115MWth, respectively and finally 225 MW and 125MWth for Case 3. In each case the quantity of maximum iteration (Maxiter) is varied from 75 to 150.

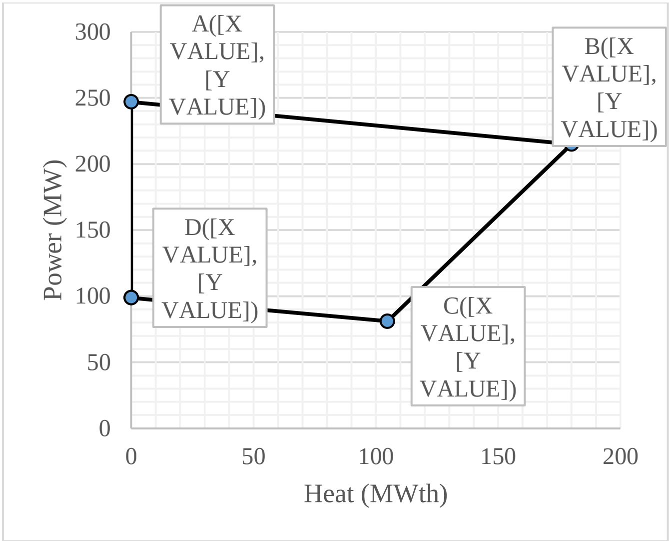

Figure 1: The feasible working zone of the combined generator

4.1. *Case 1: Power demand 175 MW and Heat demand 110 MWth*

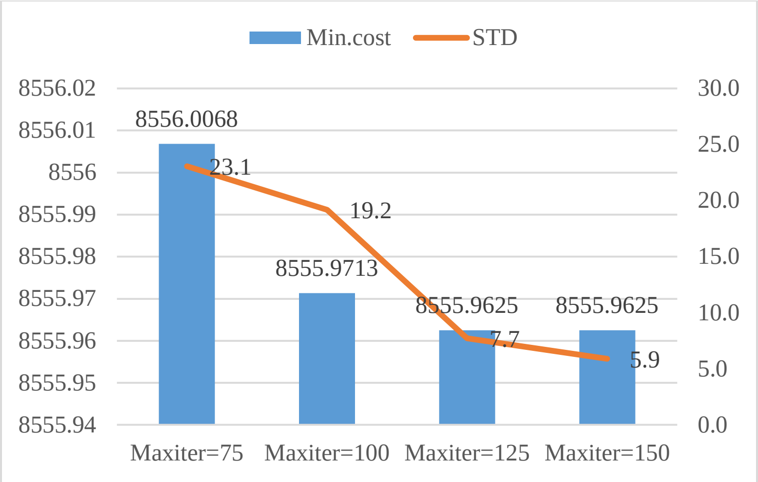

Figure 2: The value of Min.cost and STD for Case 1

Figure 2 above presents the Minimum cost value (Min.cost) and the STD value reached by HBO with different quantity of maximum iteration (Maxiter). Specifically, the blue bar presents for the Min.cost value and the orange line illustrated of the STD value. It easy to come to a general conclusion that while increasing the number of Maxiter both Min.cost and STD value are better. And, this conclusion is one more time proved by data given by the Figure 3 below. Explicitly, both Mean cost value (Mean.cost) and Maximum cost value (Max.cost) decreases while the quantity of iteration becomes larger.

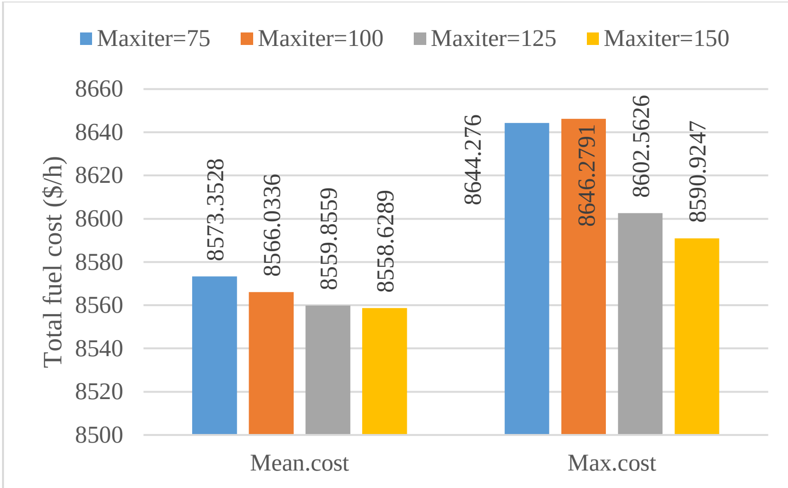

Figure 3: The value of Mean.cost and Max.cost for Case 1

Table 1: The comparison of Min.cost value given by HBO with the other methods

Method	Min. cost ($/h)
LCPSO [13]	8555.9625
LCPSO-CD [13]	8555.9625
LWPSO [13]	8555.9626
LWPSO-CD [13]	8555.9625
GCPSO [13]	8555.9625
GCPSO-CD [13]	8555.9625
GWPSO [13]	8555.9625
GWPSO-CD [13]	8555.9625
MADS-LHS [18]	8622.0748
MADS-PSO [18]	8629.4156
MADS-DACE [18]	8555.9625
LR-SSMU-CSS [21]	8555.9625
LR-SSMU- SSBS [21]	8555.9625
HBO	8555.9625

While HBO placed among many other methods to evaluate its performance, the Min.cost value given by HBO is better than the similar ones reached by the MADS-LHS [18] and the MADS-PSO [18]. The Min.cost values reported by remaining methods in Table 1 are equal the number reached by HBO.

4.2. Case 2: Power demand 200MW and Heat demand 115 MWth

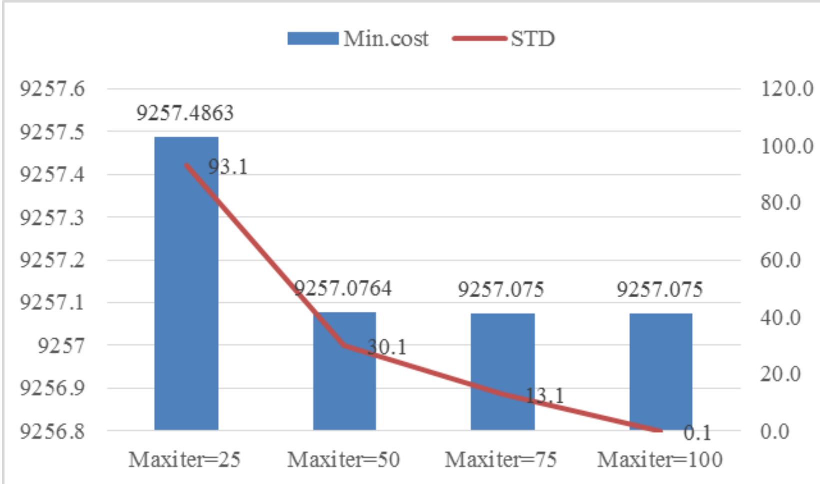

Figure 4: The value of Min.cost and STD for Case 2

In this case the HBO is run with the Maxiter varied from 25 to 100. Similar to case 1, the blue bar represented for the Min.cost value is become shorter while the quantity of Maxiter is increased. In addition the increasing of Maxiter value makes the SDT value become better. Specifically, the optimal value of Min.cost can be reached after 75 iteration with the STD value is 13.1. However, while the maximum quantity of iteration increased up to 100, the Min.cost obtained is still unchanged but the STD in this situation is only 0.1. This value of STD is every impressive for a meta-heuristic.

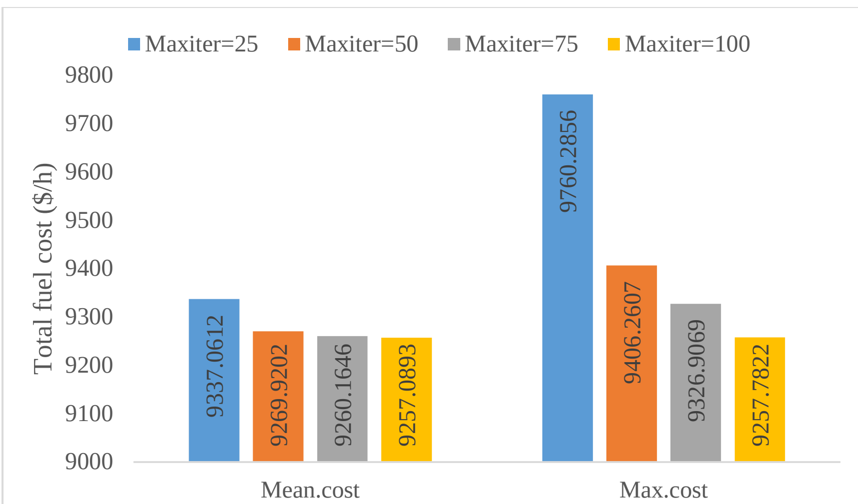

Figure 5: The value of Mean.cost and Max.cost for Case 2

Figure 5 above reports the value of Mean.cost and Max.cost with different case of Maxiter. Specifically, the quantity of maximum iteration is also regulated in the interval of 25 and 100. In term of the Mean.cost, the difference caused by increasing Maxiter is only viewed clearly in case of the quantity of maximum iteration varied from 25 to 50. After that, the differences between 50, 75 and 100 of Maxiter are still have but not much. Regarding the Max.cost, this value is also decreased as the quantity of Maxiter increased. For all of the situations with different values of Maxiter, the decrease of Max.cost can be viewed clearly.

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-4, April2021
ISSN: 2395-3470
www.ijseas.com

Table 2: The comparison of Min.cost value given by HBO with the other methods for Case 2

Method	Min. cost ($/h)
LR [2]	9,257.10
IACSA [3]	9,452.20
EP [4]	9,257.10
IGA-MU [5]	9,257.08
GA [7]	9,267.20
HSA [9]	9,257.07
LCPSO [13]	9257.075
LCPSO-CD [13]	9257.075
LWPSO [13]	9257.075
LWPSO-CD [13]	9257.075
GCPSO [13]	9257.075
GCPSO-CD [13]	9257.075
GWPSO [13]	9257.075
GWPSO-CD [13]	9257.075
MADS–LHS [18]	9277.1311
MADS–PSO [18]	9301.3567
MADS–DACE [18]	9257.0754
NDS[19]	9,257.07
LRSS [21]	9,257.07
HBO	9257.075

Table 2 above presents a larger comparison about the HBO performance with many other methods. In this case, the competitive ability regarding searching for the Min.cost value of HBO is repeatedly proved. Specifically, the Min.cost value reached by HBO is 9257.075 ($/h) while the similar values reported from LR [2], IACSA [3], EP [4], IGA-MU [5], GA [7], HAS [9], MADS-LHS [18], MADS-PSO [18], NDS [19] and LRSS [21] are respectively 9257.10 ($/h), 9452.20 ($/h), 9257.10 ($/h), 9257.08 ($/h), 9267.20 ($/h), 9257.07 ($/h), 9277.1311 ($/h), 9301.3567 ($/h), 9257.0754 ($/h), 9257.07 ($/h), 9257.07 ($/h).

4.3. Case 3: Power demand 225 MW and Heat demand 125 MWth

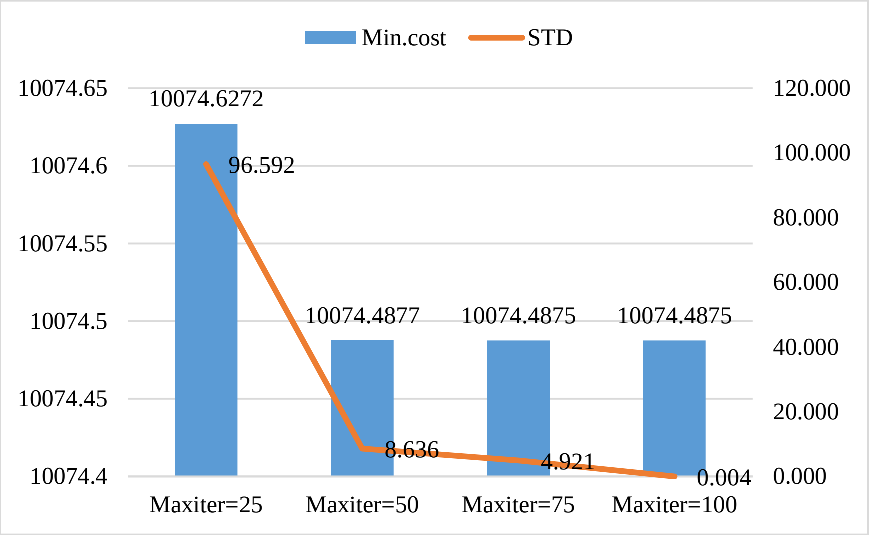

Figure 6: The value of Min.cost and STD for Case 3

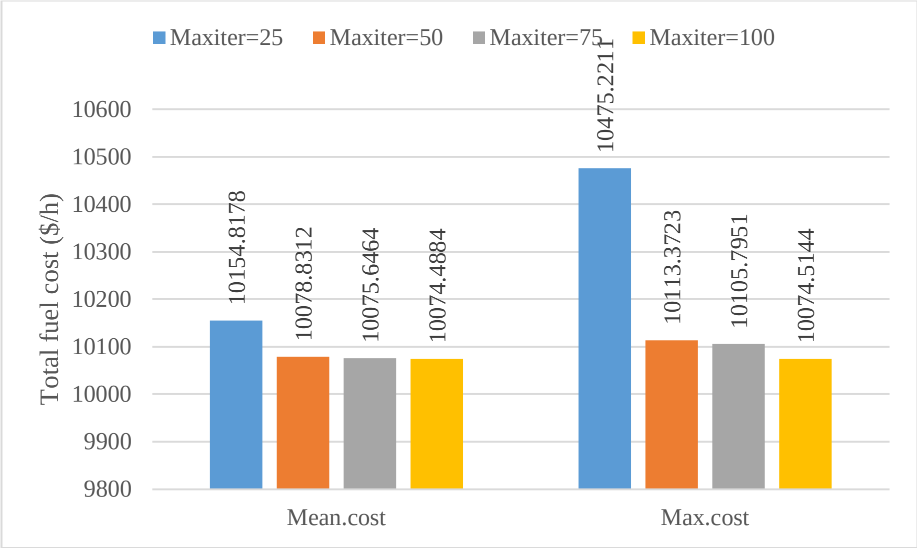

Figure 7: The value of Mean.cost and Max.cost for Case 3

The observation from both Figure 6 and Figure 7 show that the more quantity of Maxiter increases the more value in term of Min.cost, Mean.cost and Max.cost decrease. Specifically, there is a slightly decrease of Min.cost at Maxiter 50 comparing with the case of 25. The optimal value of Min.cost reach at Maxiter 75. In addition, the SDT value decrease dramatically form 96.592 down to 8.636 while the Maxiter increases from 25 to 50. And, at the Maxiter 100, the value of STD showed at Figure 1 is only 0.004. In the Mean.cost, the decrease of this value is only clear while the quantity of Maxiter increases from 25 to 50, for the next increase of Maxiter, the decrease still exists but it is not noticeable. In term of the Max.cost, this value decreases dramatically from 10475.2211 ($/h) down to 10113.3723 ($/h) while the quantity of Maxiter increases from 25 to 50. When the quantity of Maxiter becomes greater the Max.cost continuously goes down. However, the rate of decrease is not the same as the circumstance that Maxiter increases from 25 to 50.

Table 3: The comparison of Min.cost value given by HBO with the other methods for Case 3

Method	Min. cost ($/h)
LCPSO [13]	10074.4875
LCPSO-CD [13]	10074.4875
LWPSO [13]	10074.4875
LWPSO-CD [13]	10074.4875
GCPSO [13]	10074.4875
GCPSO-CD9 [13]	10074.4875
GWPSO [13]	10074.4875
GWPSO-CD [13]	10074.4875
MADS-LHS [18]	10101.4753
MADS-PSO [18]	10101.8942
MADS-DACE [18]	10074.4875
LR-SSMU-CSS [21]	10,074.49
LR-SSMU- SSBS [21]	10,074.49
HBO	10074,4875

The Table 3 above presented the Min.cost value given by HBO and many other methods. It is clear to see that in this case both the power demand and heat demand is increased up to 225 MW and 125 MWth, respectively but HBO still performs better than several other methods such as MADS-LHS [18], MADS-PSO [18], MADS-DACE [18], LR-SSMU-CSS [21], LR-SSMU-SSBS [21]. The remaining other methods in Table 3 report the same value of Min.cost as the one reached by HBO.

5. Conclusion

In this study a new meta – heuristic algorithm called HBO is applied to solve the CHPED problem successfully. The performance of HBO is evaluated through different case of studies. In each testing case, the optimal values given by HBO are always more competitive than several other methods even while the power demand and heat demand are continuously increased from low to high. Therefore, the authors have come to the conclusion that the HBO is a high performance method for solving such CHPED problem. This paper shows a bright beginning for applied HBO to deal with a typical problem in power system. Currently, the performance of HBO is quite good, but to be frankly, the results given by HBO do not show a huge difference with most methods as compared. In the future, HBO can be continuously improved and modified in order to deal with a range of large-scale optimal problems with more complicated constraints involved. In addition, the new version of HBO will be expected to show a big performance leap while comparing with the other meta-heuristic methods.

References

[1] Rooijers, F. J., & van Amerongen, R. A. (1994). Static economic dispatch for co-generation systems. *IEEE Transactions on Power Systems*, *9*(3), 1392-1398.
[2] Guo, T., Henwood, M. I., & Van Ooijen, M. (1996). An algorithm for combined heat and power economic dispatch. *IEEE Transactions on Power Systems*, *11*(4), 1778-1784.
[3] Song, Y. H., Chou, C. S., & Stonham, T. J. (1999). Combined heat and power economic dispatch by improved ant colony search algorithm. *Electric Power Systems Research*, *52*(2), 115-121.
[4] Wong, K. P., & Algie, C. (2002). Evolutionary programming approach for combined heat and power dispatch. *Electric Power Systems Research*, *61*(3), 227-232.
[5] Su, C. T., & Chiang, C. L. (2004). An incorporated algorithm for combined heat and power economic dispatch. *Electric Power Systems Research*, *69*(2-3), 187-195.
[6] Subbaraj, P., Rengaraj, R., & Salivahanan, S. (2009). Enhancement of combined heat and power economic dispatch using self - adaptive real-coded genetic algorithm. *Applied energy*, *86*(6), 915-921.
[7] Song, Y. H., & Xuan, Q. Y. (1998). Combined heat and power economic dispatch using genetic algorithm based penalty function method. *Electric machines and power systems*, *26*(4), 363-372.
[8] Zou, D., Li, S., Kong, X., Ouyang, H., & Li, Z. (2019). Solving the combined heat and power economic dispatch problems by an improved genetic algorithm and a new constraint handling strategy. *Applied energy*, *237*, 646-670.
[9] Vasebi, A., Fesanghary, M., & Bathaee, S. M. T. (2007). Combined heat and power economic dispatch by harmony search algorithm. *International Journal of Electrical Power & Energy Systems*, *29*(10), 713-719.
[10] Khorram, E., & Jaberipour, M. (2011). Harmony search algorithm for solving combined heat and power economic dispatch problems. *Energy Conversion and Management*, *52*(2), 1550-1554.
[11] Javadi, M. S., Nezhad, A. E., & Sabramooz, S. (2012). Economic heat and power dispatch in modern power system harmony search algorithm versus analytical solution. *Scientia Iranica*, *19*(6), 1820-1828.
[12] Ramesh, V., Jayabarathi, T., Shrivastava, N., & Baska, A. (2009). A novel selective particle swarm optimization approach for combined heat and power economic dispatch. *Electric Power Components and Systems*, *37*(11), 1231-1240.
[13] Nguyen Trung, T., & Vo Ngoc, D. (2016). Improved particle swarm optimization for combined heat and power economic dispatch. *Scientia Iranica*, *23*(3), 1318-1334.
[14] Chen, X., Li, K., Xu, B., & Yang, Z. (2020). Biogeography-based learning particle swarm optimization for combined heat and power economic dispatch problem. *Knowledge-Based Systems*, *208*, 106463.
[15] Basu, M. (2011). Bee colony optimization for combined heat and power economic dispatch. *Expert Systems with Applications*, *38*(11), 13527-13531.

[16] Murugan, R., Mohan, M. R., Rajan, C. C. A., Sundari, P. D., & Arunachalam, S. (2018). Hybridizing bat algorithm with artificial bee colony for combined heat and power economic dispatch. *Applied Soft Computing*, *72*, 189-217.
[17] Chapa, M. G., & Galaz, J. V. (2004, June). An economic dispatch algorithm for cogeneration systems. In *IEEE Power Engineering Society General Meeting, 2004.* (pp. 989-994). IEEE.
[18] Hosseini, S. S. S., Jafarnejad, A., Behrooz, A. H., & Gandomi, A. H. (2011). Combined heat and power economic dispatch by mesh adaptive direct search algorithm. *Expert Systems with Applications*, *38*(6), 6556-6564.
[19] Chen, C. L., Lee, T. Y., Jan, R. M., & Lu, C. L. (2012). A novel direct search approach for combined heat and power dispatch. *International Journal of Electrical Power & Energy Systems*, *43*(1), 766-773.
[20] Basu, M. (2012). Artificial immune system for combined heat and power economic dispatch. *International Journal of Electrical Power & Energy Systems*, *43*(1), 1-5.
[21] Sashirekha, A., Pasupuleti, J., Moin, N. H., & Tan, C. S. (2013). Combined heat and power (CHP) economic dispatch solved using Lagrangian relaxation with surrogate subgradient multiplier updates. *International Journal of Electrical Power & Energy Systems*, *44*(1), 421-430.
[22] Roy, P. K., Paul, C., & Sultana, S. (2014). Oppositional teaching learning based optimization approach for combined heat and power dispatch. *International Journal of Electrical Power & Energy Systems*, *57*, 392-403.
[23] Nazari-Heris, M., Mehdinejad, M., Mohammadi-Ivatloo, B., & Babamalek-Gharehpetian, G. (2019). Combined heat and power economic dispatch problem solution by implementation of whale optimization method. *Neural Computing and Applications*, *31*(2), 421-436.
[24] Zhou, S., Hu, Z., Gu, W., Jiang, M., Chen, M., Hong, Q., & Booth, C. (2020). Combined heat and power system intelligent economic dispatch: A deep reinforcement learning approach. *International Journal of Electrical Power & Energy Systems*, *120*, 106016.
[25] Askari, Q., Saeed, M., & Younas, I. (2020). Heap-based optimizer inspired by corporate rank hierarchy for global optimization. *Expert Systems with Applications*, *161*, 113702.