RESEARCH ARTICLE OPEN ACCESS

Combined Heat and Power Dispatch Using Grasshopper Optimization Algorithm

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ABSTRACT
This paper presents an optimization algorithm called Grasshopper Optimization Algorithm (GOA) to solve Combined Heat and Power Dispatch (CHPD) or co-generation power system problem. This algorithm is mathematically modeled and mimics the behavior of grasshopper swarms, is nature inspired for solving the optimization problems. The proposed technique is applied for six-unit system with transmission losses and for CHPD. The results shows that the proposed algorithm is capable of obtaining better results efficiently in CHPD problems than the other algorithms in the literature.
***Keywords* –** CHPD, Economic Load Dispatch (ELD), Fire-fly Optimization (FFO), GOA.

Date of Submission: 01-01-2021 Date of Acceptance: 12-01-2021

I. INTRODUCTION

Cogeneration or Combined Heat and Power (CHP) or distributed generation is the consecutive generation of two different forms of energy (mechanical and thermal) from single energy source, have played an important role in the utility industry. CHP differs from conventional plant as the output is only in electrical form whereas CHP generates both electrical and thermal energy which increases the efficiency. Due to efficient use of waste heat, the efficiency of CHP unit is increased to 70% to 80% from 35% to 45% of the conventional case [24]. With higher efficiency it also reduces the emission of gaseous pollutants (SO_x, NO_x, CO, etc.,) by of about 13-18% [24] Different researches were carried out on this area of Combined Heat and Power Dispatch. An algorithm was developed by Rooijers and Van [1] which is related with two levels, lower and upper. Lower level is to solve the given power and head lambdas and the upper level updates the lambda's sensitivity coefficients. The procedure is repeated to meet the heat and power demands. Algorithm for CHPD problem by Tao Guo [2] is divided into the two sub-problems, "Heat dispatch and Power Dispatch". This connection is interpreted with the heat-power unit constraints multipliers in the langrangian functions which leads to the growth of two layer algorithm. Different approaches used for solving CHPD problems are: Genetic Algorithm (GA) based on penalty function method [3], Improver Ant Colony Search Algorithm (IACSA) [4], Integrated Genetic Algorithm and tabu search [6], Harmony Search algorithm [9],GSA [16], PSO [21], Different Evaluation Technique[23], Hybrid DE-SQP Method [24] have been successfully applied to the CHPD problems.

In this paper cogeneration or combined heat and power dispatch problem of the system is solved by using Grasshopper Optimization Algorithm to consider the power production and unit heat to minimize the production cost. The Grasshopper Optimization Algorithm is based on behavior and social interaction of grasshopper and is new optimization method developed by Seyedali Mirjalili [28].

II. PROBLEM FORMULATION

In CHPED there are three types of generating units, CHP, Heat-only and Power-only units. The main objective of CHPED problem is to minimize the fuel cost of the system and to satisfy the constraints.

Minimize,

$$f_{cost} = \sum_{i=1}^{N_p} C_i(P_i) + \sum_{j=1}^{N_b} C_j(P_j, H_j) + \sum_{k=1}^{N_k} C_k(H_k)$$

1) Power Production and Demand Balance Constraint

$$\sum_{j=1}^{N_p} P_i^{PU} + \sum_{j=1}^{N_b} P_j^{CHP} = P_D + P_L \quad ..(i)$$

2) Heat Production and Demand Balance Constraint

$$\sum_{j=1}^{N_p} H_j^{CHP} + \sum_{k=1}^{N_b} H_k^{H} = H_D \quad ..(ii)$$

3) Capacity Limit Constraint

$P_i^{min} \leq P_i \leq P_i^{max} \ldots .\, i = 1,2 \ldots, N$ ..(iii)

III. GRASSHOPPER OPTIMIZATION ALGORITHM

Grasshopper Optimization Algorithm(GOA) was first proposed by Sareni, et al.in 2017 [28].It mimics the behavior and social interaction of grasshopper swarms in nature for solving optimization problems. Meta-heuristic algorithm divides the search process into two phases which are exploitation and exploration.

The main task of Combined Heat and Power economic dispatch is to determine the optimal generating unit of cogeneration plants with minimum operational cost of providing heat and power load demands without violating any system constraints.

The GOA is applied to the cogeneration plant by exploration or by exploitation.

The CHPED problem can be formulated by the following equations;

$$f_{cost} = \sum_{i=1}^{N_p} C_i\,(P_i) + \sum_{j=1}^{N_b} C_j\big(P_j, H_j\big) + \sum_{k=1}^{N_k} C_k(H_k)$$

$$P_L = \sum_{i=1}^{N_p+N_b} \sum_{j=1}^{N_p+N_b} PL_i B_{ij} PL_j \quad ..1$$

1) Grasshopper Position Representation

Position matrix formation is done by real power generations which are decision variables for CHPED problem. The position of the grasshopper in the position matrix is the exact replica of the real power generation of the generators.

Let there are NG generators in the system, the position representation of the grasshopper is then described in the form of vector length NG.

Again, let NP grasshoppers are taken in the search space, the position representation of grasshopper in the matrix s as follows;

$$X_i = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1NG} \\ x_{21} & x_{22} & \cdots & x_{2NG} \\ \cdots & \cdots & x_{ij} & \cdots \\ x_{NP1} & x_{NP2} & \cdots & x_{NPNG} \end{bmatrix} \quad ..2$$

2) Position Initialization

Initialization of each element in the position matrix, occurred randomly with capacity constraints done by equation given below;

$$P_j^{min} \leq P_{ij} \leq P_j^{max} \quad (i=1,2..NP, j=1,2,,NG) \quad ..3$$

$$P_i = P_i^{min} + rand(\,)(P_i^{min} - P_i^{max}) \quad ..4$$

3) Objective function evaluation

To satisfy the given constraints, one of the generators is chosen as a slack generator d and this is obtained by

$$P_d^j = Z^j \quad (i=1,2..NP, j=1,2..NG) \quad ..5$$

Where $Z = P_d - \sum_{i=1, i\neq d}^{NG} P_i$

If there is the violation of the operating limits by the production of the slack generator then it is set by equation below;

$$P_i^j = \begin{cases} P_i^{min}; & P_i^j < P_i^{min} \\ P_i^{max}; & P_i^j > P_i^{max} \\ P_i^j; & P_i^{min} < P_i^j < P_i^{max} \end{cases} \quad ..6$$

(i=1, 2...NG; i≠ d; j= 1, 2...L)

After restraining the value of dependent generator, a penalty term is set up in objective function. Therefore the function is defined by;

$$f^j = F\big(P_i^j\big) + \emptyset \quad ..7$$

4) Seeking Food

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \quad ..8$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad ..9$$

Where $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_p$ shows the food location.

$\vec{X}$ shows the location of grasshopper and t is the current iteration.

The calculation of vectors A and C is done as follows:

$$\vec{A} = 2.\vec{a}.\vec{r}_1.\vec{a} \quad ..10$$

$$\vec{C} = 2.\vec{r}_2.r_3 \quad ..11$$

Where values of '$\vec{a}$'are linearly reduced from 2 to 0 during the course of iterations and r1, r2, r3 are random values ranging in [0, 1].

5) Grasshopper Movement and Updating the position

Grasshoppers reach their comfort zone and eat up the whole vegetation. The location of food is guided by gravity force and wind advection. To reach their comfort zone other grasshoppers must update their position according to the best grasshopper position. The update and best position can be given as follows;

$$\vec{D}_i = |\vec{C}_1.\vec{X}_i - \vec{X}|, \vec{D}_j = |\vec{C}_2.\vec{X}_j - \vec{X}|, \vec{D}_k = |\vec{C}_3.\vec{X}_k - \vec{X}|$$

$$X_1 = \vec{X}_i - \vec{A}_1.(\vec{D}_i), X_2 = \vec{X}_j - \vec{A}_2.(\vec{D}_j), \vec{X}_3 = \vec{X}_k - \vec{A}_3.(\vec{D}_k)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad ..12$$

6) Stopping Criterion

A stochastic optimization approach can be terminated by many criterions at hand. Some of them are maximum no. of iterations, no. of functions evaluations and tolerance. In the present case, maximum no. of iteration is taken for this task.

ALGORITHM

1) Start.
2) Read the thermal generating units characteristics and load demand for ELD problem.
3) Initialize the input parameters for GOA algorithm i.e. search agents, c_{max}, c_{min} maximum iterations, dimension.
4) Initialize the swarm Pi (i=1, 2,...., n).
5) Calculate the fitness of each search agent.
6) T = best search agent.
7) **If** iteration (l) < maximum iterations (L).
8) Update c using,

$$C = \text{Cmax} - \text{iteration}\frac{\text{Cmax} - \text{Cmin}}{\text{Maximum Iteration}}$$

9) For each search agent.
10) Normalize the distance between grasshoppers in [1,4].
11) Update the position of current search agent by the equation.

$$P_i^d = c\left(\sum_{j=1\, j\neq i}^{N} c\frac{ub_d - lb_d}{2} s(|P_j^d - P_i^d|)\frac{P_j^d - P_i^d}{d_{ij}}\right) + \hat{T}_d$$

12) Bring the current search agent back if it goes outside the boundaries.
13) **End for**
14) Update T if there is better solution.
15) Iteration = iteration+1
16) **End If**
17) Return T.

IV. RESULT AND DISCUSSION

Combined Heat and Power Economic Dispatch problem has been solved for one power-only unit, two cogeneration units and a heat-only unit. The numerical example is taken from the literature [21].

The main objective of this method is to minimize the cost of fuel on heat and power demands.

Power-Only unit $C_1 = 50_{p1}$

Cogeneration unit

$$C_2 = 2650 + 14.5_{p2} + 0.0345_{p2^2} + 4.2_{h2} + 0.03_{h2^2} + 0.031_{p_2 h_2}$$

$$C_3 = 1250 + 36_{p_3} + 0.0435_{p3^2} + 0.6_{h3} + 0.027_{h3^2} + 0.011_{p_3 h_3}$$

Heat-Only unit $C_4 = 23.4_{h4}$

Minimize,

$C = \sum_{i=1}^{4} C_i$ I=1,..4

Subject to,
$0 \le p_1 \le 150$ MW
$0 \le h_4 \le 2695.2$ MW
PD = $p_1 + p_2 + p_3$,
HD = $h_2 + h_3 + h_4$

Here, PD = Power demand (200 MW) and
HD = Heat demand (115 MW)

Table 1: Effect of iteration counts on results for CHPD using GOA.

Iteration	**500**	**2000**	**3000**	**6000**
p_1	21.197	4.2469	0.18474	0.19277
p_2	134.34	154.88	159.43	158.62
h_2	48.351	3.0092	28.153	11.668
p_3	44.455	40.867	40.384	41.192
h_3	66.64	111.99	86.848	102.23
h_4	0.00	0.00	0.00	1.0979

Cost Rs/hr	9899.51 5439	9216.01 7783	9200.89 4601	9166.41 3091

Table 1 shows the effect of iteration count on the results of CHPD using GOA. As the iteration increases, the cost of fuel decreases to minimum and the best fuel cost is obtained at 10000 iterations.
Fig.1 shows convergence characteristics of proposed algorithm (Grasshopper Optimization Algorithm) where faster convergence is achieved as the number of population increased from 50 to 500.

Table 2 and fig.2 shows the comparison with other techniques which gives better results as compared to the other techniques in literature.

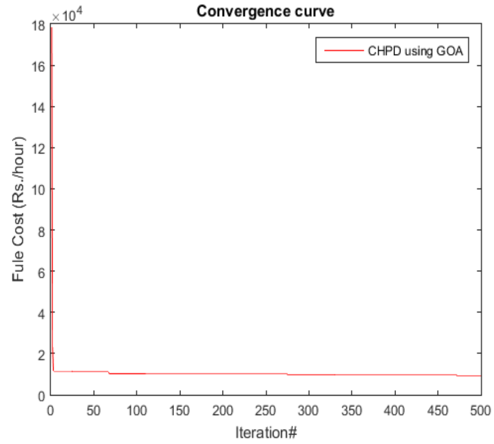

Fig.1: Convergence curve of CHPD using GOA

Table 2: Comparison of CHPD using GOA with other techniques.

Method	**GOA**	**PSO [21]**	**GA_MU [7]**	**LR [2]**	**ACSA [4]**	**GT [6]**	**HS [9]**
Cost	9128.8008	9257.07	9257.07	9257.07	9452.2	9207.6	9257.07
p1	0.27673	0.00	0.00	0.00	0.08	0.00	0.00
p2	159.47	159.99	160.00	160.00	150.9	157.9	160.0
h2	8.392	39.99	39.99	40.00	48.84	26.00	40.00
p3	40.246	40.00	40.00	40.00	49.00	42.08	40.00
h3	106.61	75.00	75.00	75.00	65.79	89.00	75.00
h4	0.00	0.00	0.00	0.00	0.37	0.00	0.00

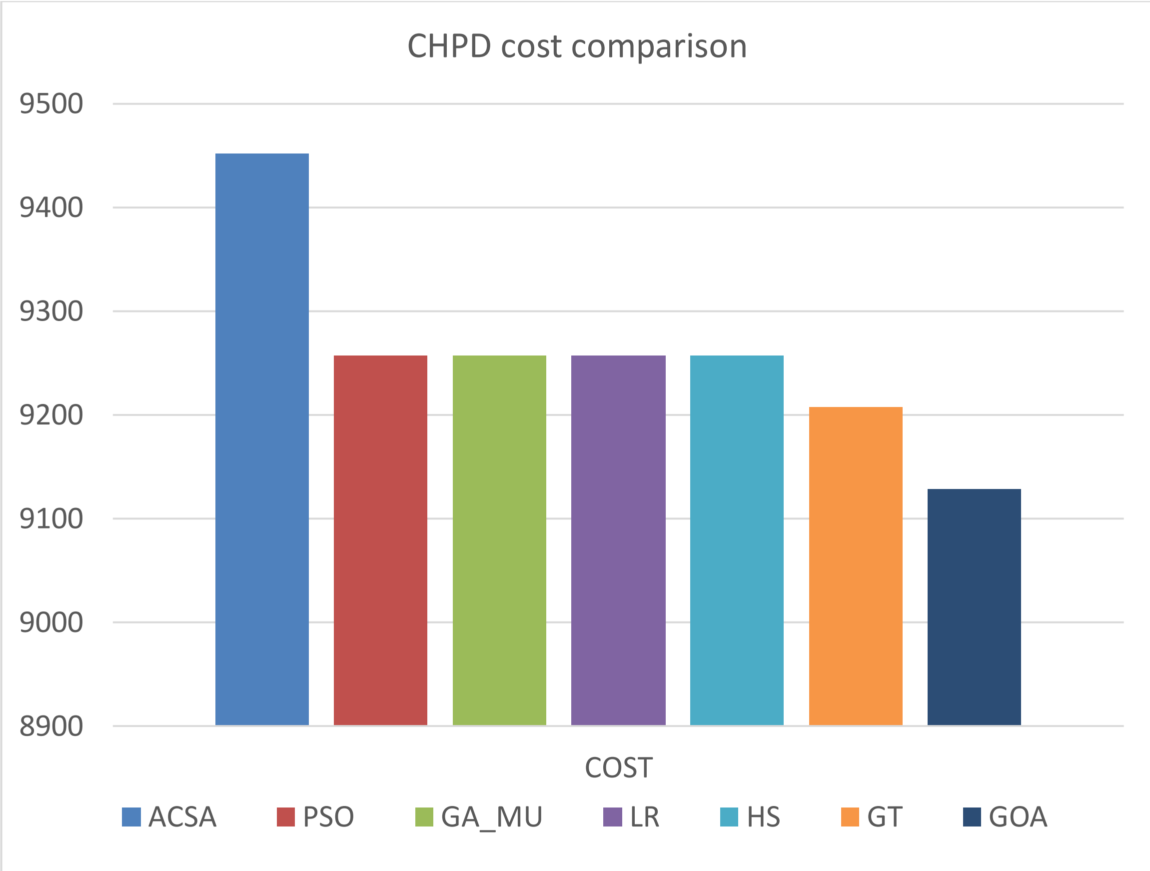

Fig.2: Combined Heat and Power Dispatch cost comparison.

V. CONCLUSION

In this research, optimization technique is being proposed to solve CHPED problem considering ED and CHP dispatch effects for different test cases.

This optimization technique proposed to solve CHPED problem is entitled as Grasshopper Optimization Algorithm(GOA). GOA is the new meta-heuristic technique which is population based and nature-inspired. GOA successfully achieved the optimal solution for ED problem within feasible operating region and for CHP dispatch problem. Results are more effective when compared with the other techniques on large-scale problems in the cogeneration.

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Baljit Singh, et. al. "Combined Heat and Power Dispatch Using Grasshopper Optimization Algorithm." *International Journal of Engineering Research and Applications (IJERA)*, vol.11 (1), 2021, pp 40-46.