HSA FOR COMBINED HEAT AND POWER ECONOMIC DISPATCH

Rasoul Ghadimi[1], Adel Akbarimajd[2], Noradin Ghadimi[3,*]

[1]Ardebil Province Electricity Distribution Co, Ardabil, Iran
[2]Electrical Engineering Department, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil, Iran
[3]Young Researchers and Elite club, Ardabil Branch, Islamic Azad University, Ardabil, Iran

Abstract- This paper presents a Harmony Search Algorithm (HAS) for Combined Heat and Power Economic Dispatch (CHPED) problem. The proposed HSA technique, which is a population based global search and optimization technique, has been developed to solve the CHPED problem. The CHPED problem is formulated as an optimization problem which is solved by the HSA technique that has a strong ability to find the most optimistic results. The effectiveness of these algorithms has been tested on system with four power units, two co-generation units and one heat unit compared to other algorithms such as Real-coded Genetic Algorithm (RGA), Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) techniques for total operating cost. The results show the Particle Swarm Optimization with Improved Inertia Wight is able to achieve a better solution at less computational time.

Keywords: Combined Heat and Power, HAS, Cogeneration.

I. INTRODUCTION

The global energy supply and demand are increasingly dominated by major concerns about multiple factors, most notably climate change, shortage of oil supply and price increase, and rising population levels and per capita energy consumption. Hence it is critically important to find an alternative to fossil fuels, in particular petroleum fuels, from economic, environmental and social perspectives. Renewable energy sources with near zero-emissions such as solar energy, wind, and wave, hydro, and biomass energy offer such an alternative [1,2]. In Fig. 1, the CHP usage in European countries is presented.

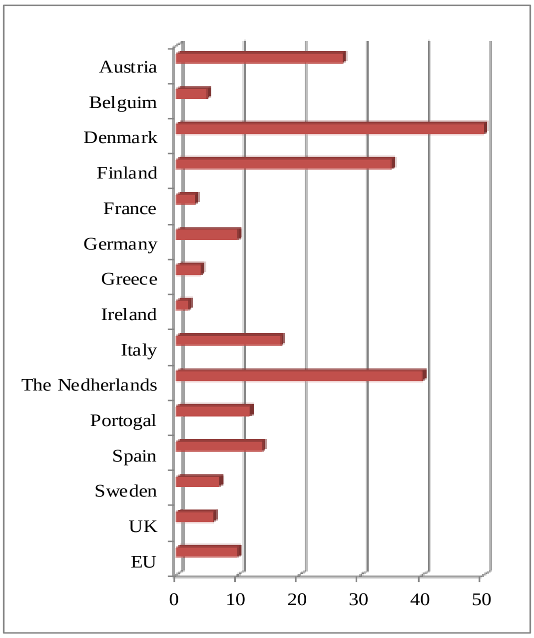

Figure 1. European countries usage for CHP systems

The co-generation units achieve with combined heat and power generation to produce energy with minimum cost and environment. In the other hand, it is important role in energy production technology recently [3]. Also, the heat production capacity for CHP systems depends on power generation and vice versa. Thereupon, the Combined Heat and Power Economic Dispatch (CHPED) problem introduces complexities in the integration of co-generation units into the power system economic dispatch [4, 5]. Figure 2 show challenge for CHP mechanism.

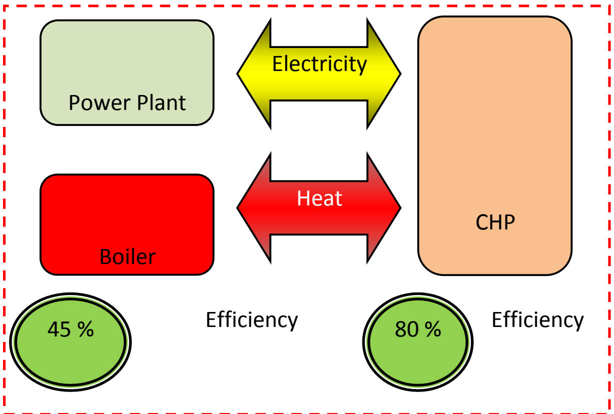

Figure 2. Challenge energy for a CHP system

In the recent researches, global optimization techniques like Genetic Algorithms (GA) [6], Harmony Search Algorithm (HAS) [7], Particle Swarm Optimization (PSO) [8] and Evolutionary

Programming (EP) techniques [9] have been applied for optimal tuning of CHPED based restructure schemes. These evolutionary algorithms are heuristic population-based search procedures that incorporate random variation and selection operators. Although, these methods seem to be good methods for the solution of CHPED parameter optimization problem, However, when the system has a highly epistatic objective function (i.e. where parameters being optimized are highly correlated), and number of parameters to be optimized is large, then they have degraded efficiency to obtain global optimum solution. In order to overcome these drawbacks, a HSA is proposed for solution of the CHPED problem in this paper.

II. CHPED PROBLEM FORMULATION

The propose CHPED problem is an optimization problem like ELD problem, but it is consider some types of produce units such as pure heat units, combined power and heat (co-generation) and conventional power units. The co-generation is role to produce heat and power with feasible operation region according to figure 3, where the boundary curve ABCDEF determines the feasible region. Along the boundary there is a trade-off between power generation and heat production from the unit. It can be seen that along the curve AB the unit reaches maximum output power. In contrast, the unit reaches maximum heat production along the curve CD. Therefore, power generation limits of cogeneration units are the combined functions of the unit heat production and vice versa [7].

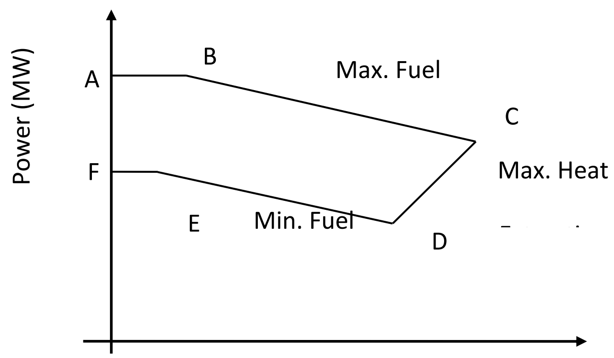

Figure 3. Typical heat-power feasible region for co-generation units.

Mathematically, the problem is formulated as follows

$$\text{Minimize} \quad \sum_{i=1}^{\alpha} F_{ti}(P_i) + \sum_{i=\alpha+1}^{\beta} F_{ci}(P_i, H_i) + \sum_{i=\beta+1}^{n} F_{hi}(h_i) \qquad (1)$$

Subject to

(a) Power balance constraint

$$\sum_{i=1}^{\alpha} P_i + \sum_{i=\alpha+1}^{\beta} P_i = P_D + P_L \qquad (2)$$

(b) Heat balance constraint

$$\sum_{i=\alpha+1}^{\beta} H_i + \sum_{i=\beta+1}^{n} H_i = H_D \qquad (3)$$

(c) Generation and heat limits constraints

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad i \in 1, 2, \ldots, \alpha \qquad (4)$$

$$P_i^{\min}(H_i) \le P_i \le P_i^{\max}(H_i) \qquad i \in 1+\alpha, 2+\alpha, \ldots, \beta \qquad (5)$$

$$H_i^{\min}(P_i) \le H_i \le H_i^{\max}(P_i) \qquad i \in 1+\alpha, 2+\alpha, \ldots, \beta \qquad (6)$$

$$H_i^{\min} \le H_i \le H_i^{\max} \qquad i \in 1+\beta, 2+\beta, \ldots, n \qquad (7)$$

The active power transmission loss P_L can be calculated by the network loss formula:

$$P_L = \sum_{i=1}^{\beta} \sum_{j=1}^{\beta} P_i B_{ij} P_j \qquad (8)$$

III. Harmony Search Algorithm

A. HSA

The brief procedure steps of harmony search for solving optimization problems are described in five steps as shown in following flow chart:

HS procedure can be described as Figure. 4 [10-11].

Step 1: Identify objective function and Equality &

Inequality constraints by using eq

$$\begin{aligned} &Minmize:\{f(x), x \in X\} \\ &s.t \\ &g(x) \geq 0 \\ &h(x) = 0 \end{aligned} \tag{9}$$

Where $f(x)$ is the objective function. Xi is the feasible set. xi is the random choosing parameter. $G(x)$ is the inequality constraint. $h(x)$ is the equality constraint.

Step 2: Initialize harmony memory (*HM*) in this step chooses the initial value of xi from *Xi* parameters and fill them in *HM* matrix randomly.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^1 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \frac{\Delta y}{\Delta x} \tag{10}$$

Step 3: Improvise New Harmony Improvise new xi from harmony memory considers rated (*HMCR*) and pith adjust rated (*PAR*) [12-13].

Step 3.1:.1 Harmony consider rated (*HMCR*)

$$x_i' \leftarrow \begin{Bmatrix} x_i' \in \left\{x_i^1, x_i^2, \ldots, x_i^{HMS}\right\}(HMCR) \\ x_i' \in X_i\,(1-HMCR) \end{Bmatrix} \tag{11}$$

Where x'_i is new value of *xi* *HMCR* is probability of choosing x'_i w.p. means with probability

Step 3.2: Pitch Adjust Rate (*PAR*)

$$x'_i \leftarrow \begin{Bmatrix} Yes, \Pr(PAR) \\ No, \Pr(1-PAR) \end{Bmatrix} \tag{12}$$

Where PAR is probability to shift *xí*

$$x'_i \leftarrow x'_i \pm rand() \times bw \tag{13}$$

Where b*w* is range of *Xi* rand is random number during 0-1. In this step, random choose the value of x'_i. If the value of x'_i is in the range of *Xi* it has probability *HMCR*. If out of condition probability of x'_i is *1−HMCR* and then will check *PAR* if *PAR* of *x 'i* is carry on the condition eq. (11), shift x'_i.

Step 4: Update HM and check the stopping criterion Find value of *f* (x'_i) from substitute x'_i in eq. (10) if value of *f*(x'_i) is better than the worst value of *f*(*x*) in *HM*, substitute x'_i instead the worst *xi* in *HM*.

Step 5: To check the stopping criterion, set the *NI* (Number of iteration) before begins to run the simulation; *HS* can stop calculation instantaneously when *NI* is reached. The aim of this paper is to apply multi objective harmony search for proposed problem. Results show that harmony search can solve this problem intelligently and find a near optimal solution.

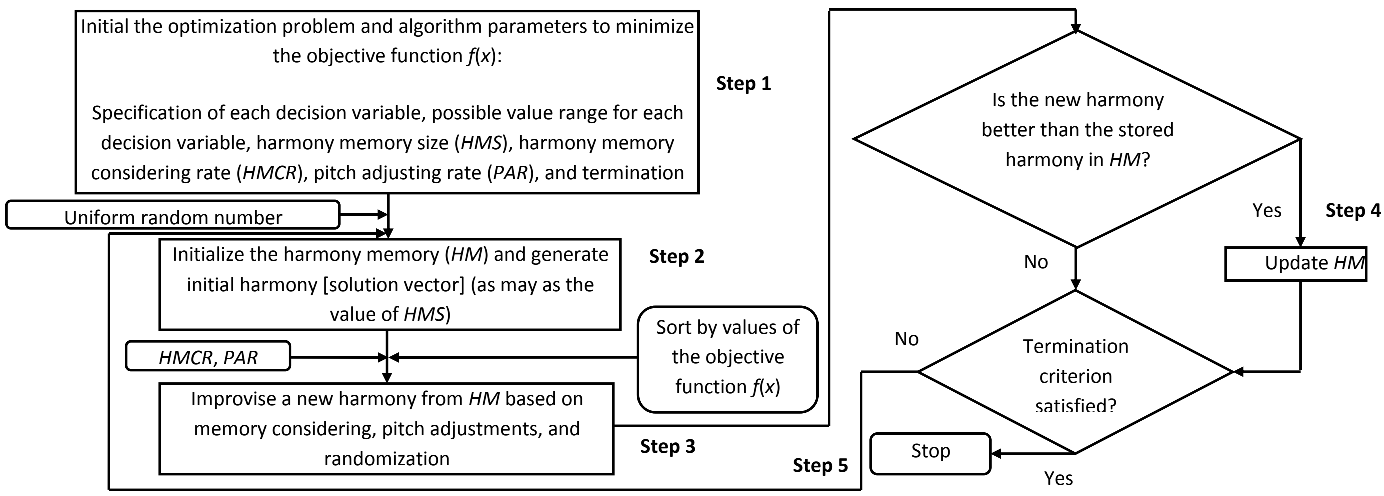

Figure 4. Flowchart of HSA

IV. HSA OPTIMIZATION BASED COMBINED HEAT AND POWER ECONOMIC DISPATCH

The CHPED problem is a nonlinear complex optimization problem with feasible operating zones constraints. In this part, to achieve optimal distribution performance, HSA algorithm is proposed to optimal tune of units under different operating conditions. The sequential steps of the proposed HSA method are given below:

Step 1: In this step, an initial population based on state variable is generated, randomly. That is formulated as:

$$p^k = [P_1, P_2, \dots, P_a, P_{a+1}, P_{a+2}, \dots, P_b, H_{a+1}, H_{a+2}, \dots, H_b, H_{b+1}, H_{b+1}, \dots, H_n]^T \qquad (14)$$

Where, P_a and H_b are the real power outputs of conventional thermal generators and cogeneration units and heat outputs of cogeneration units and heat-only units, respectively. Also, the initial should satisfy the equilibrium equation of heat and power following:

$$\sum_{i=1}^{\alpha} P_i + \sum_{i=\alpha+1}^{\beta} P_i = P_D + P_L$$

$$\sum_{i=\alpha+1}^{\beta} H_i + \sum_{i=\beta+1}^{n} H_i = H_D$$

Step 2: The fitness function to be evaluated is defined as follows:

$$fitness = \frac{1}{\sum_{i=1}^{\alpha} F_{ti}(P_i) + \sum_{i=\alpha+1}^{\beta} F_{ci}(P_i, H_i) + \sum_{i=\beta+1}^{n} F_{hi}(h_i)}$$

Step 3: Each p_{best} values are compared with the other p_{best} values in the population. The best evaluation value among the p-bests is denoted as g_{best}.

Step 4: The member velocity v of each individual x_i is modified according to the velocity update equation.

Step 5: The position of each individual P_i is modified according to the position update equation.

Step 6: If the evaluation value of each individual is better than previous p_{best}, the current value is set to be p_{best}. If the best p_{best} is better than g_{best}, the value is set to be g_{best}.

Step 7: If the number of iterations reaches the maximum, then finish. Otherwise, go to step 2.

The parameters of the proposed HSA method used in the test system example as following; Q = 50; $iter_{max}$ = 100; c_1 = 0.1; c_2 = 0.1; Z = 100; ω_{max} = 1.1; ω_{min} = 0.4.

V. SIMULATION AND RESULTS

The different methods discussed earlier are applied a cases to find out the minimum cost for any demand. The proposed method has been applied to a test system which consists of four conventional thermal generators, two cogeneration units and a heat-only unit. Unit data has been modified from [14]. System data containing coefficients of fuel cost equations, B loss coefficients and heat-power feasible regions are given in below equations. The power and heat demands of the test system are 600 MW and 150 MWth respectively.

(a) Power-only units:

$$F_{t1}(P_1) = 25 + 2P_1 + 0.008P_1^2 + |100\sin\{0.042(P_1^{\min} - P_1)\}|\,\$$$
$$10 \le P_1 \le 75MW$$

$$F_{t2}(P_2) = 60 + 1.8P_2 + 0.003P_2^2 + |140\sin\{0.04(P_2^{\min} - P_2)\}|\,\$$$
$$20 \le P_1 \le 125MW$$

$$F_{t3}(P_3) = 100 + 2.1P_3 + 0.001P_3^2 + |160\sin\{0.038(P_3^{\min} - P_3)\}|\,\$$$
$$30 \le P_1 \le 175MW$$

$$F_{t4}(P_4) = 120 + 2P_4 + 0.001P_4^2 + |180\sin\{0.037(P_4^{\min} - P_4)\}|\,\$$$
$$40 \le P_1 \le 250MW$$

(b) Cogeneration units:

$$F_{t5}(P_5, H_5) = 2650 + 14.5P_5 + 0.001P_5^2 + 4.2H_5 + 0.03H_5^2 + 0.031P_5H_5\,\$$$

The heat-power feasible region of the cogeneration unit is illustrated in Fig. 5.

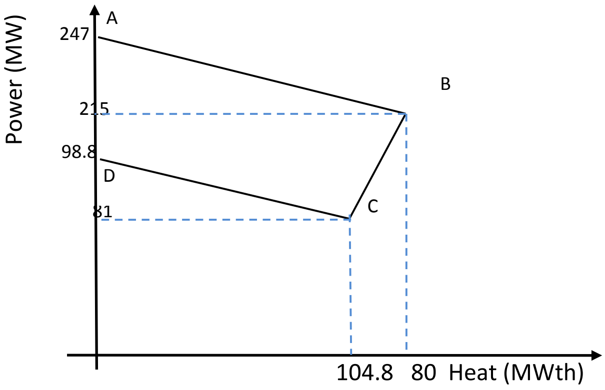

Figure 5. Heat-power feasible operation region for the cogeneration unit 1.

$$F_{t6}(P_6, H_6) = 1250 + 36P_6 + 0.0435P_6^2$$
$$+ 0.6H_6 + 0.027H_6^2 + 0.11P_6H_6 \$$$

The heat-power feasible region of the cogeneration unit is illustrated in Fig. 6.

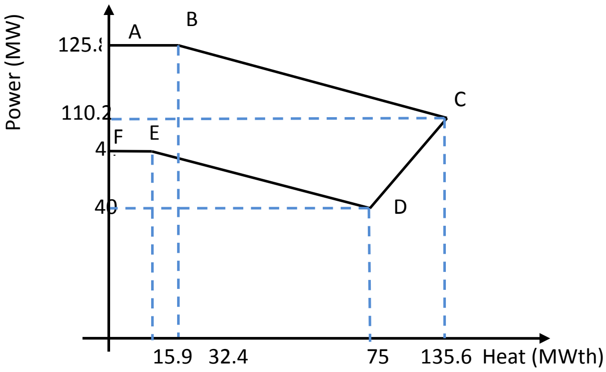

Figure 6. Heat-power feasible operation region for the cogeneration unit 2.

The Network loss coefficients are given below:

$$B = \begin{bmatrix} 49 & 14 & 15 & 15 & 20 & 25 \\ 14 & 45 & 16 & 20 & 18 & 19 \\ 15 & 16 & 39 & 10 & 12 & 15 \\ 15 & 20 & 10 & 40 & 14 & 11 \\ 20 & 18 & 12 & 14 & 35 & 17 \\ 25 & 19 & 15 & 11 & 17 & 39 \end{bmatrix} \times 10^{-7}$$

To validate the proposed HSA based approach, the same test system is solved using Evolutionary Programming (EP), Bee Colony Optimization (BCO) Particle Swarm Optimization (PSO), and Real-Coded Genetic Algorithm (RCGA). Table 1 compares the computational results of this test system obtained from HSA, BCO, EP, PSO and RCGA. It is found that the proposed approach provides lower production cost and CPU time. Fig. 6 shows the cost convergence obtained from propose algorithm. Fig. 7 and Table 1 show the best convergence rate as well as the best solution time among the four is achieved by HSA, followed by BCO, EP. RCGA is the worst performer, followed by PSO.

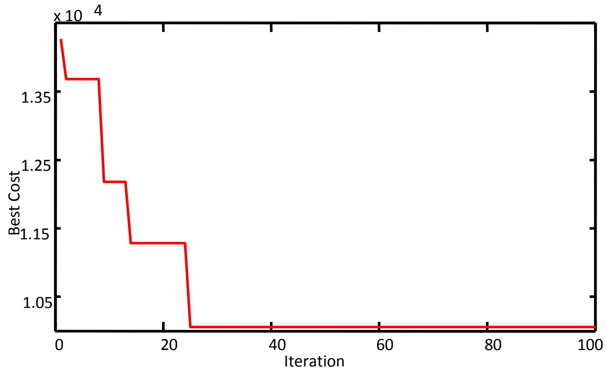

Figure 7. Convergence characteristics of HSA

Table. 1. The best convergence rate as well as the best solution time

	HAS	BCO[15]	EP[15]	PSO[15]	RCGA[15]
P_1 (MW)	25.2489	43.9457	61.3610	18.4626	74.6834
P_2 (MW)	99.1988	98.5888	95.1205	124.2602	97.9578
P_3 (MW)	114.2311	112.9320	99.9427	112.7794	167.2308
P_4 (MW)	210.0159	209.7719	208.7319	209.8158	124.9079
P_5 (MW)	90.3456	98.8000	98.8000	98.8140	98.8008
P_6 (MW)	44.0000	44.0000	44.0000	44.0107	44.0001
H_5 (MWth)	45.0456	12.0974	18.0713	57.9236	58.0965
H_6 (MWth)	35.3219	78.0236	77.5548	32.7603	32.4116
H_7 (MWth)	58.3325	59.8790	54.3739	59.3161	59.4919
P_L (MW)	7.9876	8.0384	7.9561	8.1427	7.5808
Cost ($)	10115	10317	10390	10613	10667
CPU time (s)	3.465	5.1563	5.2750	5.3844	6.4723

VI. CONCLUSIONS

Combined heat and power generation (co-generation) units have an increasingly important role in energy production technology recently in this paper, HSA for Combined Heat and Power Economic Dispatch (CHPED) has been applied to determine the feasible optimal solution. The proposed method convergence rate is really less than in comparison other methods in solving complex mathematical problems. The numerical results demonstrate that the proposed method has better ability in finding optimal answers and possibility of particle placed in local zone. Moreover, the proposed strategy has simple structure, easy to implement and tune and therefore it is recommended to generate good quality and reliable electric energy in the restructured power systems.

REFERENCES

[1] H. V. Larsen, H. Palsson, H. F. Ravn, “Probabilistic production simulation including combined heat and power plants”, Electric Power Systems Research, vol. 48, pp: 45–56, 1998.

[2] R. Lahdelma, H. Hakonen, “An efficient linear programming algorithm for combined heat and power production”, European Journal of Operational Research, vol. 148, pp: 141-151, 2003.

[3] A. Rong, H. Hakonen, R. Lahdelma, “An efficient linear model and optimization algorithm for multisite combined heat and power production”, European Journal of Operational Research, vol. 168, pp: 612-632, 2006.

[4] K. Nekooei, M. M. Farsangi, H. Nezamabadi-pour, “An improved harmony search approach to economic dispatch”. International Journal on “Technical and Physical Problems of Engineering”, Issue8, Vol. 3, No. 3, pp: 25-31, 2011.

[5] Y. H. Song, C. S. Chou, & T. J. Stonham "Combined heat and power dispatch by improved ant colony search algorithm. Electric Power Systems Research, vol. 52, pp: 115–121.

[6] C. T. Su, & C. L. Chiang "An incorporated algorithm for combined heat and power economic dispatch. Electric Power Systems Research, 69, 187–195. 346, 2004.

[7] A. Vasebi, M. Fesanghary, & S. M. T. Bathaee, "Combined heat and power economic dispatch by harmony search algorithm. International Journal of 348 Electrical Power Energy Systems, vol. 29, pp: 713–719. 349, 2007

[8] L. Wang, & C. Singh, "Stochastic combined heat and power dispatch based on multi-objective particle swarm optimization". International Journal of Electrical 351 Power Energy Systems, vol. 30, pp: 226–234. 2008

[9] K. P. Wong, & C. Algie, "Evolutionary programming approach for combined heat and power dispatch". Electric Power System Research, vol. 61, pp: 227–232, 2002

[10] Geem, ZW., Tseng, C., Park, Y., (2005), “Harmony search for generalized orienteering problem”, best touring in China. Springer Lect Notes Comput Sci, pp. 741–7150.

[11] Abedinia, O., Barazande, Ebrahim S., Amjady, N., (2012), “Solving Optimal Unit Commitment Problem Based on Wind Power Effects Using Harmony Search Algorithm”, International Journal of Basic and Applied Science (IJBAS), Vol. 2, No. 11, pp: 11764-11773.

[12] K. Deb, "Evolutionary Algorithms for Multi-Criterion Optimization in Engineering Design" Kanpur Genetic Algorithms Laboratory (KanGAL), Depatment of Mechanical Engineering, Indian Institute of Technology, Kanpur, India, 1999.

[13] E. Zitzler, “Evolutionary Algorithms for Multiobjective Optimization: Methods and Application” Computer Engineering and Networks Laboratory (TIK), Swiss Federal Institute of Technology (ETH) Zurich, November 1999. T. Guo, M. I. Henwood, & M. van Ooijen. "An algorithm for heat and power dispatch". IEEE Transactions on Power Systems, vol. 11, no. 4, pp: 1778–1784, 1996.

[14] M. Basu." Bee colony optimization for combined heat and power economic dispatch". Expert Systems with Applications, 2011