Solving Multiobjective Unit Commitment Problem to Minimize Operation Cost and Emissions Using HBMO Algorithm

Ali Ahmadian, Mahdi Sedghi, and Masoud Aliakbar Golkar

***Abstract*—** Optimal operation of power plants is an important issue in electrical power engineering. On the other hand, emissions of greenhouse gases and environmental concerns have been noticed recently more than in the past. In this paper, the cost of operation and also power plants emissions are considered as a multiobjective optimization problem solved using HBMO which is a powerful optimization algorithm. In numerical studies, a power system containing 10 generation units is optimized for a 24-hour period. The results show that the operation and emission costs are decreased dominantly using the HBMO algorithm.

***Keywords*—**Unit commitment, Operation cost, Emission, HBMO algorithm.

I. Introduction

UNIT commitment (UC) is a common issue which decides to make the power plants on or off, and also determines the generating power of every power plant to optimize an objective function in a short-term period e.g. 24 hours. The cost objective should be minimized subject to technical constraints i.e. increasing/decreasing rate of generating power, minimum allowed on/off duration of units and reserve power restrictions [1]. The main objective in UC problem is minimizing of operation costs. On the other hand, one of the main contributions to the environmental pollutions is through the use of fossil-fuelled power plants. A major step in this direction is the Kyoto Protocol, which is with the objective of "stabilization and reconstruction of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". However, the recent advent of emission allowance trading has renewed interest in the environmentally constrained UC problem [2]. To solve the UC problem, several classic methods such as priority strategy [3], dynamic programming [4] and Lagrange method [5] are used. However, the classic methods are not efficient because of low accuracy, excessive computation time and complexity in practice. Therefore, smart methods based on metaheuristic algorithms instead of classic methods are used to improve the solution. The metaheuristcs which are based on iterations can find the local and global optimal solutions in limited computation time. Although some metaheuristics such as genetic algorithm [6], tabu search [7] and simulated annealing [8] have been successfully applied to the unit commitment problem, these methods have some flaws according the recent researches. For instance, they are not efficient enough for more complex objective functions that include correlated decision variables and a large number of parameters. Moreover, the precocious convergence is probable in these methods, which leads them to local optimums [9].

Honey Bee Mating Optimization (HBMO) algorithm which is more robust than the other methods, has been developed recently. Several papers have shown the advantages of HBMO in comparison with the other methods such as genetic algorithm to find the global optimal solution [10]. The BHMO algorithm is based on the honey bee mating process. This algorithm usually converges fast and it obtains more accurate solutions.

In recent years, emissions of greenhouse gases and environmental concerns have been noticed more seriously. Whereas conventional power plants have a great amount of pollution, they should be operated subject to the environmental concerns. However, the green house emission is not considered in traditional unit commitment problem at all, however, it has been considered in economic power flow problem [11].

In this paper, the unit commitment problem is solved to minimize two objectives i.e. operation cost and emission cost, using HBMO algorithm. In numerical studies, a power system containing 10 generation units is optimized for a 24-hour period. The results show that the operation and emission costs are decreased dominantly using the HBMO algorithm.

II. UC Problem Statement

Large power plants usually are preferred for operating because of their lower operating costs comparing with small plants. However, large power plants have lower power increasing/decreasing rate. In the other word, smaller power

Ali Ahmadian is a Ph.D. Student in the faculty of electrical engineering, K.N.Toosi university of technology, Tehran, Iran (corresponding author's phone: +989144107156 ; e-mail: Ali.ahmadian1367@gmail.com).

Mahdi Sedghi, is a Ph.D. Student in the faculty of electrical engineering, K.N.Toosi university of technology, Tehran, Iran (email:Meh.sedghi @gmail.com).

Masoud Aliakbar Golkar is a full professor in faculty of electrical engineering, K.N.Toosi university of technology, Tehran, Iran (e-mail: Golkar@eetd.kntu.ac).

plants are faster than the larger power plants. Moreover, the operation and emission cost of every unit is different from the others, depending on generating power, fuel type, size of the unit, installed technology and so on. The main challenge of the UC is the expensive small units scheduling to minimize operation and emission cost and to improve reliability of the system. As a result, the profit, emission, spinning reserve and reliability of the power system are dependent on the optimal scheduling. UC is a large and complex optimization problem where the main cost is due to the fuel and starting costs.

A. Fuel cost

The fuel cost of a thermal power plant is a function of generating power as follows.

$$FC_i(P_i(t)) = a_i + b_i * P_i(t) + c_i * P_i^2(t) \qquad (1)$$

B. Pollutant emission cost

The cost of pollutant emission can be stated similar to fuel cost as follows [10]:

$$\varepsilon C_i(P_i(t)) = \alpha_i + \beta_i * P_i(t) + \gamma_i * P_i^2(t) \qquad (2)$$

where α_i, β_i and γ_i are the constant coefficients related to the emission of i-th unit.

C. Start up cost

The start up cost of a unit is dependent on shut down duration time before starting up as follows.

$$S_i = S_{0i} + S_{1i}(1 - e^{-\frac{\tau}{t_i}}) \qquad (3)$$

The cost of shutting down a unit is usually given as a constant value for every unit.

D. Constraints

The objective function should be minimized under technical constraints as follows.

Power balancing constraint:

$$\sum_{i=1}^{N} U_{it}.P_{it} = P_{Dt} + P_{Losses} \quad t = 1, 2, ..., 24 \qquad (4)$$

where P_{it} is the generating power of the i-th unit and P_{Dt} is the total demand at time *t*.

Spinning reserve constraint:

To enhance the reliability of the system, enough spinning reserve is needed as follows.

$$\sum_{i=1}^{N} I_i(t).P_i^{\max}(t) \geq P_D(t) + R(t) \qquad (5)$$

Minimum and maximum generating power constraint:

The generating power of each unit is limited as follows.

$$P_i^{\min}(t) \leq P_i(t) \leq P_i^{\max}(t) \qquad (6)$$

Minimum allowed on/off time constraint:

When a generation unit starts up or shuts down, its state cannot be changed immediately, however it can be changed after a specific time as follows.

$$TO_i \geq \overline{TO}_i \qquad (7)$$
$$TS_i \geq \overline{TS}_i$$

Increasing/decreasing power rate constraint:

Change generating power of every unit in each hour is limited as follows:

$$P_i^{\min}(t) \leq P_i(t) \leq P_i^{\max}(t) \qquad (8)$$

Where

$$P_i^{\min}(t) = \max(P_i(t-1) - RDR_i, P_i^{\min}) \qquad (9)$$

$$P_i^{\max}(t) = \min(P_i(t-1) - RUR_i, P_i^{\max}) \qquad (10)$$

E. Objective function

The cost objective function consists of operation and emission costs as follows.

$$Min \ \mathrm{TC} = \mathrm{W}_c * (Fuel + Start - up) + W_e * emission \qquad (11)$$

Where, W_c and W_e are weighting coefficients for operation cost and emission cost, respectively. These coefficients increase the flexibility of the system. Changing the weights obtains different optimal solutions. In this paper, both of them are set to 0.5.

III. Proposed Approach Based HBMO Algorithm

The honey bee is one of the social insects that can just survive as a member of colony. The activity of honey bee suggests many characteristics like together working and communication. A honey bee colony normally includes of a single egg-laying queen with its life-span is more than other bees; and depend upon those seasons usually has more than 60,000 workers or more. A colony may contain a queen during its life-cycle. That is named mono-gynous one. Only the queen is fed by royal jelly. Nurse bees takes care of this gland and feed it to queen. The royal jelly makes the queen bee to be the biggest bee in the hive. Several hundred drones live with queen and its workers. Queen bee life-span is about 5 or 6 years, whereas rest of the bees, especially worker bees, life times do not reach to 1 year. The drones die after mating process.

The drones play the father role in the colony that are haploid and amplify or multiply their mother's genome without changing their genetic combinations, except mutation. So, drones are agents that anticipate one of the mother's gametes and by the sake of that female can do genetically like males. Broods, cared by workers, improve from fertilized or unfertilized eggs. They represent potential queens and prospective drones, respectively. In marriage process, the queens in mating period, their mates fly from the nest to the far places [10].

Insemination ends with the gradual death of drones, and by the sake of those queens receive the mating sign. Any drone can take part in mating process just one time, but the queens mate several times. These features make bee mating process very interesting among other insects.

A. Operation principle of HBMO

The queen plays the most important role in mating process in nature and also HBMO algorithm. The spermatheca is a place for sperm of drones and queen's, all drones, however are originally haploid; after successful, the drone's sperm is stored in the queen's spermatheca. A brood is reproduced by coming of some genes of drone's into the brood genotype. A brood has no thing only one genotype. Therefore, an HBMO algorithm would be constructed by the following five important stages [12]:

1. The algorithm starts with mating flight, where a queen selects drones probabilistically from the spermatheca. A drone is selected from list randomly for the generating broods.
2. generating new broods by combining of drone's genotypes and the queens.
3. Using of workers to lead local searching on broods.
4. Adaptation of worker's ability, based on the improvement of broods.
5. Substitution of queen's workers by stronger and aptitude broods.

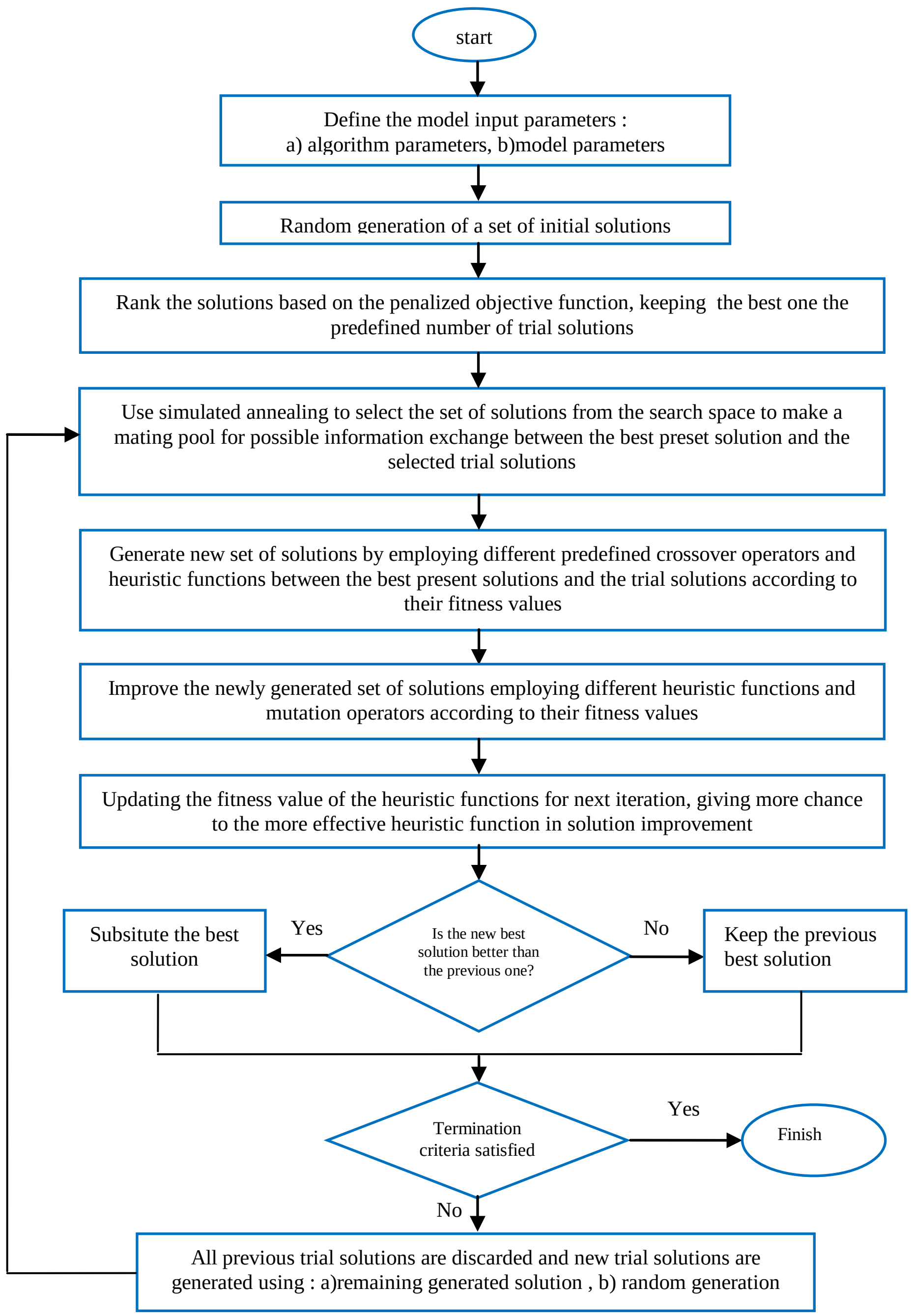

Fig. 1 Flowchart of the HBMO algorithm

When all queens completed their mating flights, start breeding. All of broods after generation, are sorted according to fitness, i.e. their weakness or health. The best brood is replaced by the worst queens until all queens will the best and there is no need to broods. After completing of mating, remaining broods finally are killed so that new mating process begin.

B. Original HBMO algorithm

A drone mates with a queen probabilistically using an annealing function like this:

$$\Pr ob(D,Q) = \exp(-\Delta f \ / S(t)) \tag{12}$$

Where *Prob(D,Q)* is probability of adding drone's sperm *D* to queen's spermatheca *Q*, *Δ(f)* is the perfect difference of fitness *D* of queen, and *S(t)* is the speed of the queen at time t. The mating is high whether queen's speed level is high, drone's fitness is equal with queen's. After every transition, the speed of queen will decrease according to the following equations:

$$s(t+1) = \alpha \times s(t) \tag{13}$$

$$E(t+1) = E(t) - \gamma \tag{14}$$

Where, α is a factor ε (0,1) and γ is the amount of energy, E(t) reduction after each transition

The algorithm starts with three user-defined parameters and one predefined parameter. The predefined parameter is the number of workers (W), representing the number of heuristics encoded in the program. The three user-defined parameters are the number of queens, the queen's spermatheca size representing the maximum number of mating per queen in a single mating flight, and the number of broods that will be born by all queens. The energy and speed of each queen at the start of each mating flight is initialized at random. A number of mating flights are realized. At the commence of a mating flight, drones are generated randomly and the queen selects a drone using the probabilistic rule in Eq. (12). If mating is done successfully, storage of drone's sperm in queen's spermatheca occur. Combination of drone's and queen's genotaypes, generate a new brood , which can be improved later by employing workers to conduct local search. One of the main difference between HBMO algorithm and classic evolutionary algorithms is storing of many different drone's sperm in spermatheca by queen which the uses some of them to create a new solution for fittest of broods, and gives the possibility to have more fittest broods. The role of workers is brood caring and for the sake of that they are not separated of population and are used to grow the broods generated by the queen. Every worker has different capability for producing in solutions. The computational flow chart of HBMO algorithm is shown in Figure 1.

IV. Simulation Results and Discussion

In this paper we use a system that has 10 units and simulated for the next 24 hours. The case study data obtained from [10]. The simulation results are shown in table 1 and figures 2 and 3. Results analysis show that the large cheaper units committed in system at the entire period of operation and the more expensive units committed at low operation periods according the minimizing of the operation costs and pollution.

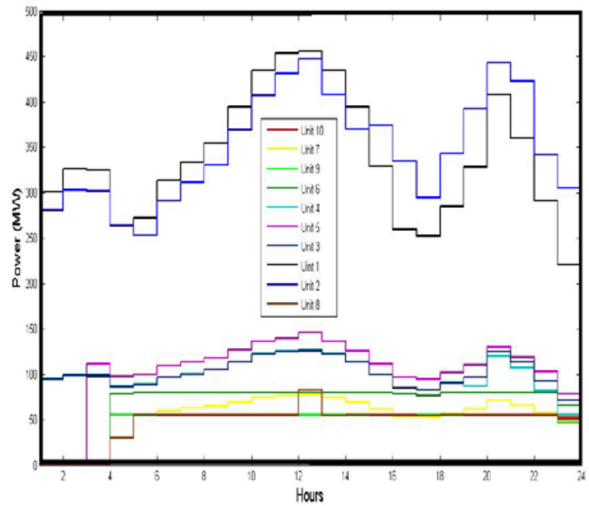

Fig. 2 output of the units

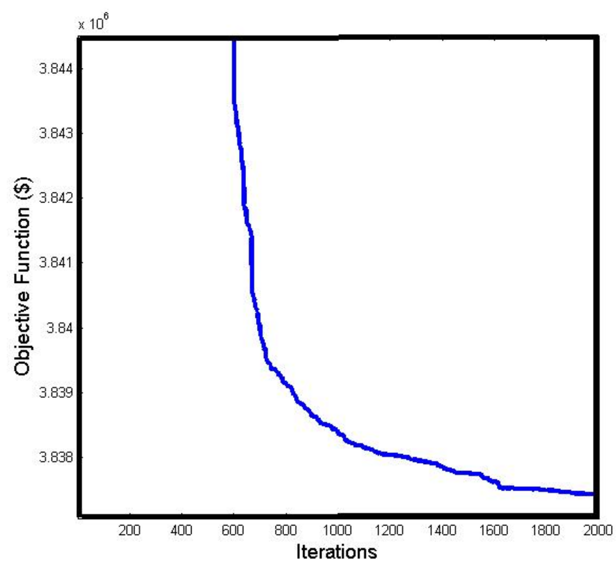

Fig. 3 objective function of UC problem

The UC problem was simulated based on HBMO algorithm in 2000 iterations in MATLAB. According to figure 3 it is clear that the proposed approach has reduced the objective function considerably. The result shows that the HBMO algorithm is able to solve the multiobjective problem appropriately.

http://dx.doi.org/10.15242/IIE.E0114082

V. CONCLUSION

In this paper minimizing of operation costs and pollution emission in the UC problem are considered as multiobjective optimization solved using HBMO algorithm. The proposed approach is applied to a case study including 10 units and it is simulated for the next 24 hours. The simulation results show that the proposed methodology can reduce the operation costs and pollution emission considerably.

TABLE I
OUTPUT OF HBMO ALGORITHM

Time (h)	Uint 1	Uint 2	Uint 3	Uint 4	Uint 5	Uint 6	Uint 7	Uint 8	Uint 9	Uint 10	Demand (MW)	Reserve (MW)
1	300.90	280.32	93.99	94.79	0	0	0	0	0	0	700	70
2	325.39	302.15	98.16	99.30	0	0	0	0	0	0	750	75
3	324.78	310.98	98.27	99.05	110.9	0	0	0	0	0	850	85
4	264.02	263.37	85.73	86.34	97.23	78.47	29.96	29.96	54.92	55	950	95
5	272.44	253	87.49	88.54	99.11	79.86	54.67	54.88	54.78	54.94	1000	100
6	313.55	290.78	95.82	96.73	108.5	79.97	59.65	55	54.95	55	1100	110
7	333.06	311.32	99.74	100.7	113.1	79.93	62.22	54.92	54.99	54.94	1150	115
8	254.26	329.85	104.5	105	117.3	79.8	64.34	55	54.99	54.95	1200	120
9	394.68	368.44	113.1	113.1	126.5	79.95	69.32	54.95	54.97	54.96	1300	130
10	434.14	406.72	121.3	112.7	135.8	79.98	74.48	54.99	54.99	54.90	1400	140
11	453	430.64	124.5	126	139.9	79.65	76.66	54.85	54.99	54.85	1450	145
12	454.87	447.05	126.7	126.7	145.8	80	77.50	82.42	54.99	54.89	1500	150
13	434.48	407.43	121.4	122.2	135.9	79.98	73.98	54.67	54.99	54.88	1400	140
14	393.95	396.79	112.7	113.1	126.3	79.96	69.40	55	54.87	54.90	1300	130
15	328.99	373.73	99.21	99.92	111.5	79.95	61.74	55.95	54.98	54.98	1200	120
16	259.48	334.02	84.29	85.22	95.88	78.02	53.24	55	54.86	54.98	1050	105
17	251.68	294.71	83.10	82.87	94.18	76.76	52.66	54.73	54.82	54.48	1000	100
18	284.31	342.66	89.94	90.70	101.6	79.80	56.20	55	54.82	55	1100	110
19	328.41	392.39	96.46	87.26	109.7	80	61.50	54.76	54.61	54.89	1200	120
20	408.40	442.13	125	119	129.6	79.85	71.12	54.98	54.88	54.99	1400	140
21	359.35	422.52	112.7	106.3	118.4	79.98	65.57	54.98	54.99	54.99	1300	130
22	290.73	341.80	91.78	81.73	103.1	79.82	56.95	54.88	54.20	54.97	1100	110
23	220.91	304.32	70.90	55.21	77.95	65.60	45.48	52.33	74.82	54.47	900	90
24	300.59	279.53	98.11	94.40	107.4	0	0	0	0	0	800	80

REFERENCES

[1] A.F. Wood and B.F. Wollenberg, "Power generation operation and control", 2nd Edition, New York: Wiley, 1966.

[2] D.S. Harison, T. Sreeengaraja, "Swarm intelligence to the solution of profit-Based unit commitment problem with emission limitations", Arabian Journal of Science and Engineering, 38, pp. 1415-1425, 2013. http://dx.doi.org/10.1007/s13369-013-0560-y

[3] G.B. Sheble, "Solution of the unit commitment problem by the method of unit periods", IEEE Trans. on Power Syst., Vol. 5, No. 1, pp. 257-260, Feb. 1990. http://dx.doi.org/10.1109/59.49114

[4] Z. Ouyang and S.M. Shahidehpour, "An intelligent dynamic programming for unit commitment application", IEEE Trans. on Power Syst., Vol. 6, No. 3, pp. 1203-1209, Aug. 1991. http://dx.doi.org/10.1109/59.119267

[5] F. Zhuang and F.D. Galiana, "Toward a more rigorous and practical unit commitment by lagrangian relaxation", IEEE Trans. on Power Syst., Vol. 3, No. 2, pp. 763-770, May 1988. http://dx.doi.org/10.1109/59.192933

[6] A. Safari, H.A. Shayanfar and R. Jahani, "Optimal unit commitment of power system using fast messy genetic algorithm", International Journal on Technical and Physical Problems of Engineering, Vol.1, No.2, pp. 22-27, June 2010.

[7] A.H. Mantawy, Y.L. Abdel-Magid, and S. Z. Selim, "Unit commitment by Tabu search," Proc. Inst. Elect. Eng., Gen. Transm. Dist., Vol. 145, No. 1, pp. 56–64, Jan. 1998. http://dx.doi.org/10.1049/ip-gtd:19981681

[8] F. Zhuang and F.D. Galiana, "Unit commitment by simulated annealing", IEEE Trans. on Power Syst., Vol. 5, No. 1, pp. 311-317, Feb. 1990. http://dx.doi.org/10.1109/59.49122

[9] C. Kue, "A novel coding scheme for practical economic dispatch by modified particle swarm approach", IEEE Tran. on power system, Vol. 23, No. 4, 2008.

[10] A. Afshar, B. Haddad, M.A. Marino, Bj. Adams, "Honey bee mating optimization (HBMO) algorithm for optimal reservoir operation", Journal of Franklin Institute, 344, pp. 452-462, 2007. http://dx.doi.org/10.1016/j.jfranklin.2006.06.001

[11] A. Yousuf Saber, G.K. Venayagamoorthy, “Intelligent unit commitment with vehicle-to-grid —A cost-emission optimization”, Journal of Power Sources, 195, pp. 898-891, 2010. http://dx.doi.org/10.1016/j.jpowsour.2009.08.035

[12] T. Niknam, H. D. Mojarrad, H. Z. Meymand, B. B. Firouzi, “A new honey bee mating optimization algorithm for non-smooth economic dispatch”, Energy, Vol. 36, 896-908, 2011. http://dx.doi.org/10.1016/j.energy.2010.12.021