Gbest based Artificial Bee Colony Optimization for Unit Commitment Problem

Manisha Govardhan, Research Scholar
Department of Electrical Engineering
S.V. National Institute of Technology,
Surat, India
manishagovardhan @yahoo.com

Ranjit Roy, Asso. Professor
Department of ElectricalEngineering
S.V. National Institute of Technology,
Surat, India
rr@eed.svnit.ac.in

Abstract— **Unit commitment (UC) is one of the most difficult optimal tasks of the power system. The main objective of this study is to solve UC problem to attain minimum operating cost while satisfying all the constraints over a period of time after proper scheduling of the generating units using three evolutionary techniques, namely Particle Swarm Optimization (PSO), Differential Evaluation (DE) and Gbest Artificial Bee Colony (GABC) algorithms. These algorithms are applied to 10 and 20 unit test system over a 24 hour scheduling period and the results are compared with the existing optimization method Intelligent Binary Particle Swarm Optimization (IBPSO) reported in literature. It is found that the results achieved by applying Gbest Artificial Bee Colony algorithm are better than other two proposed methods.**

Keywords- Gbest Articial bee colony algorithm (ABC), Differential Evaluation (DE), Particle Swarm Optimization (PSO), Unit Commitment (UC) .

I. INTRODUCTION

Unit commitment is an important optimization problem with a large number of 0-1 variables that represents the on/off state of generating unit in power system. It is a complex decision making process of allocating generation among the committed generating units over a period of time with minimum operating cost while satisfying the load demand and multiple constraints. UC problem grows exponentially as the number of unit increases and require excessive computation time to solve the problem which is impractical.

The scheduling of thermal units involves two sub-problems unit commitment and economic load dispatch. UC problem decides on/off status of the units over a scheduled period and economic dispatch problem distributes the generated power among the committed units to achieve optimal solution. The optimal solution with these two combined process is very difficult with real system model and require great effort to solve.

Many researchers have developed several optimization techniques to solve UC problem. The traditional methods include priority list method (PL) [1,2], branch and bound method (BB) [3], dynamic programming (DP) [4], mixed-integer programming (MIP) [5] and Lagrangian Relaxation (LR) [6,7]. Recently some methods based on meta-heuristics are also available such as genetic algorithm (GA) [8,9], evolutionary programming (EP) [10], simulated annealing (SA) [11] , fuzzy logic (FL) and particle swarm optimization (PSO) [12-15], tabu search [16] and ant colony optimization (ACO) [17]. But no method proves reliable and efficient to solve UC problem and research has been continued to find the best method.

The main goal of this paper is to solve UC problem of power system to achieve minimum operation cost without violating the constraints employing three optimization algorithms namely particle swarm optimization (PSO), differential evolution (DE) and gbest artificial bee colony algorithm (GABC). This paper is organized as follows: Section II describes the proposed objective function and constraints of UC problem. The brief idea about the employed optimization schemes is summarized in Section III. The simulation results are discussed in Section IV. Conclusion is drawn in Section V.

II. UNIT COMMITMENT PROBLEM FORMULATION

A. System objectives

The objective of the UC problem is to minimize the total operating cost of the generating unit test system while satisfying the load demand and various constraints. The operating cost is the sum of fuel, start up cost and shut down cost of each thermal unit over a scheduled period. Assuming zero shut down cost, the expression for objective function is mathematically defined as follows [18]:

$$\min F = \sum_{i=1}^{N} \sum_{t=1}^{T} [F_i(P_{i(t)}) + STC_i(1 - I_{i(t-1)})] I_{i(t)} \quad (1)$$

where N is number of thermal units, T is total scheduled duration. $P_{i\,(t)}$ is generated power, $STC_{(t)}$ is start-up cost, $I_{i(t)}$ is ON/OFF status (ON=1 and OFF=1) and $F_i(P_{i(t)})$ is fuel cost of unit i at hour t. Fuel cost of generating unit in quadratic polynomial form is given as :

$$F_i(P_{i(t)}) = a_i + b_i(p_{i(t)}) + c_i(p_{i(t)})^2 \quad (2)$$

where □$_i$, b_i and c_i are cost coefficients of fuel cost of unit i. The start-up cost of unit i is defined as:

$$STC_i = \begin{cases} h_{cost}, & \text{if } MDT_i \leq X_{i\,off} \leq H_{i\,off} \\ c_{cost}, & \text{if } X_{i\,off} > H_{i\,off} \end{cases} \quad (3)$$

$$H_{ioff} = MDT_i + CSH_i \quad (4)$$

where h_{cost} and c_{cost} are the hot and cold start-up cost respectively, MDT_i is minimum down time of unit *i*, $X_{i\ off}$ is duration of unit *i* being continuously off and CSH_i is cold start hour of unit *i*.

B. Constraints

1) Power balance consrtaints:

The total generation of each unit at hour *t* must be equal to load demand for that particular hour *t*.

$$\sum_{i=1}^{N} P_{i(t)} * I_{i(t)} = D_{(t)} \quad (5)$$

where $D_{(t)}$ is load demand at hour *t*.

2) Spining reserve (SR) constraint:

For system reliability some reserve capacity (assuming 10% of load demand) has to maintain.

$$\sum_{i=1}^{N} P_{i\max} * I_{i(t)} \geq D_{(t)} + SR_{(t)} \quad (6)$$

3) Generation limit constraint:

The power generation of each thermal unit must be within the specified limit.

$$P_{i\min} \leq P_i \leq P_{i\max} \quad (7)$$

Where $P_{i\ min}$ and $P_{i\ max}$ are minimum and maximum power generation limit of unit *i*.

4) Minimum up/down time constraint:

Each thermal unit has to keep on/off for particular time period before transition.

$$X_{i\ on} \geq MUTi \quad (8)$$
$$X_{i\ off} \geq MDTi$$

where $X_{i\ on}$ is continuously on duration of unit *i* and MUT_i is minimum up time of unit *i*.

5) Initial status

At the start of scheduling period initial status of each thermal unit must be considered.

III. OPTIMIZATION ALGORITHMS EMPLOYED

The optimization techniques such as Particle Swarm Optimization, Differential Evaluation and Gbest Artificial Bee Colony algorithms are implemented to compare the results of unit commitment in this paper. The brief information of the used techniques is mentioned in this section.

A. Overview of Particle Swarm Optimization Algorithm

Particle swarm optimization (PSO) is a stochastic, population based optimization technique motivated by social behavior of fish schooling or bird flocking. In PSO, multiple probable solutions coexist and collaborate simultaneously. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. These particles have their own velocities (*V*) and positions (*X*). The position of the particle is influenced by the best position (pbest) that it has achieved so far. Each particle knows the best value so far in the group (gbest) among the (pbest). In the basic PSO, each particle starts from a random location and searches the place with its own best knowledge and the swarm's best experience. A particle status on the search space is characterized by two factors: its position and velocity, which are updated by following equations [19]:

$$v_i^{k+1} = w * v_i^k + c_1 * r_1 * (pbest_i - x_i^k) + c_2 * r_2 * (gbest_i - x_i^k) \quad (9)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (10)$$

where v_i^k and x_i^k are the velocity and position vectors of particle *i* at iteration *k*, respectively. *w* is the inertia weight, c_1 and c_2 are two positive constants which are set to 2.05. r_1 and r_2 are random numbers between 0 to 1.

B. Overview of Differential Evaluation Algorithm

Differential Evaluation (DE) is an evolutionary algorithm based on the populations of possible candidate solutions with three operators: mutation, crossover and selection. In DE, candidate solutions are indicated by vectors and set of vectors generate the population. The basic concept is to formed new vector by means of the weighted difference between the two population vectors. These three vectors are chosen randomly. Then the fitness of new vector is checked. If the fitness of the last vector is better than the previous two, then the exchange takes place [20].

Initially population vector of size *NP* are generated randomly in the *D*-dimensional search space over a generation G as follows:

$$x_{ij} = rand * (x_j^{\max} - x_j^{\min}) + x_j^{\min} \quad (11)$$

where *i* = 1, 2,…., *NP* represents the individual's population index and *j* = 1, 2, ….., *D* represents the position in *D*-dimensional search space. rand is an uniformly distributed random number between 0 to 1, x_j^{max} and x_j^{min} are the upper bound and lower bound of the decision parameter respectively.

Mutation

For each target vector x_i^G, a mutant vector is generated as follows:

$$v_i^{(G-1)} = x_{r_1}^{(G)} + F * (x_{r_2}^{(G)} - x_{r_3}^{(G)}) \quad (12)$$

where r_1, r_2, r_3 are randomly chosen vectors ∈ {1, 2…..*NP*}. Further r_1, r_2 and r_3 should be different so that *NP* > 4 is required. The mutation factor *F* is a user chosen parameter used to control the amplification of the difference between two individuals to avoid search stagnation.

Crossover

After the mutation operation, crossover is applied to the population. For each mutant vector, a trial vector is generated as follows:

$$u_{ij}^G = \begin{cases} v_{ij}^G, & \text{if } rand_j(0,1) < Cr \text{ or } j = j_{rand} \\ x_{ij}^G, & \text{otherwise} \end{cases} \quad (13)$$

where crossover probability *Cr* is a fixed parameter used to generate trial vectors at all generations, j_{rand} a newly generated random value for each *i*.

Selection

The selection procedure compares the trial vector u_{ij}^G and target vector x_{ij}^G of current position and the vector with the better fitness is allowed to enter the next generation.

$$x_{ij}^{G+1} = \begin{cases} u_{ij}^G, & \text{if } f(u_{ij}^G) \le f(x_{ij}^G) \\ x_{ij}^G, & \text{otherwise} \end{cases} \quad (14)$$

C. Overview of gbest Artificial Bee Colony Algorithm

The ABC algorithm is a swarm based meta-heuristic algorithm developed by simulating the intelligent behavior of honeybees. The bees are mainly classified into three groups namely employed bees, onlookers and scouts [21]. In ABC, bees fly to hunt food in multidimensional search space. Some bees search food source depending on their earlier experience and some find randomly without using any experience. Employed bees pass their food information to the onlooker bees. The onlookers tend to select good food sources from those founded by employed bees and they further search food source near the selected food source. If there is no improvement in the food source then scout bees fly and explore the new food source randomly without using experience.

The position of a food source signifies a possible solution of the optimization problem. ABC generates randomly distributed initial population *P* of N_p solutions (food source site). Each x_i $(i= 1,2,\ldots\ldots N_p)$ is a D dimensional vector where *D* is the number of optimized parameters. To generate a new random food source the equation used is:

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) \quad (15)$$

where ϕ_{ij} is a random number between 0 to 1, $j \in \{1,2\ldots D\}$ and x_k denotes another solution selected randomly from the population. Next to take the advantage of global best (gbest) solution information to guide the search mechanism, the equation (15) is modified as [22]:

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) + \psi_{ij}(y_j - x_{ij}) \quad (16)$$

The last term on right-hand side of equation (16) is gbest term, y_j is the j^{th} element of the global best solution and Ψ_{ij} is a random number in [0, *C*] where *C* is a nonnegative constant.

IV. RESULTS AND DISCUSSION

The feasibility of the PSO, DE and GABC for UC are verified on test system containing 10 and 20 thermal unit systems. The 10 unit system parameters are given in Table I and 24 hour load demand is given in Table II. The simulation is carried out in MATLAB. For 20 unit system the initial 10 unit system is duplicated and load demand data are doubled. The all three algorithms are run for 20 trials and the best minimum cost solution is achieved.

In Table I, initial status (I_S) specifies how long the unit has been on/off. The positive/negative value indicates the number of hour unit has been on/off respectively.

In this paper Priority List (PL) method based on Full Load Average Production Cost (FLAC) is used to solve the unit commitment problem. FLAC (α) is defined as the cost per unit of power when the unit is at its maximum capacity. α can be calculated as:

$$\alpha_i = \frac{f_i(P_{i\max})}{P_{i\max}} = \frac{a_i}{P_{i\max}} + b_i + c_i * P_{i\max} \quad (17)$$

TABLE I 10-UNIT SYSTEM DATA

Unit	Pmax (MW)	Pmin (MW)	a ($)	b ($/MWh)	c ($/MWh^2)	MUT (h)	MDT (h)	HSC ($)	CSC ($)	CSH (h)	IS (h)
1	455	150	1000	16.19	0.00048	8	8	4500	9000	5	8
2	455	150	970	17.26	0.00031	8	8	5000	10000	5	8
3	130	20	700	16.60	0.00200	5	5	550	1100	4	-5
4	130	20	680	16.50	0.00211	5	5	560	1120	4	-5
5	162	25	450	19.70	0.00398	6	6	900	1800	4	-6
6	80	20	370	22.26	0.00712	3	3	170	340	2	-3
7	85	25	480	27.74	0.00079	3	3	260	520	0	-3
8	55	10	660	25.92	0.00413	1	1	30	60	0	-1
9	55	10	665	27.27	0.00222	1	1	30	60	0	-1
10	55	10	670	27.79	0.00173	1	1	30	60	0	-1

TABLE II HOURLY LOAD DEMAND

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Demand (MW)	700	750	850	950	1000	1100	1150	1200	1300	1400	1450	1500
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Demand (MW)	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100	900	800

The units are committed in ascending order of their α_i. Unit with lowest α_i will have highest priority to commit as given in Table III. PL methods are very fast and reduce computation time but give schedules with relatively high production cost.

TABLE III 10-UNIT PRIORITY LIST

Priority order	1	2	3	4	5
Unit	1	2	4	3	5
Priority order	6	7	8	9	10
Unit	6	7	8	9	10

The optimal schedule for 10 unit system and for 20 unit system is given in Table IV and Table V respectively. The schedule is following the FLAC-PL method. In Table IV, at 18th hour unit 5 is OFF and will remain OFF for next 3 hours to satisfy the minimum up/down constraint and the successive units are ON to satisfy the load demand which will increase the start-up cost.

TABLE IV OPTIMAL GENERATION SCHEDULING FOR 10- UNIT SYSTEM USING GABC ALGORITHM

Hour	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Cost	STC
1	455	245.0	0	0	0	0	0	0	0	0	13683.1	0
2	455	295.0	0	0	0	0	0	0	0	0	14554.5	0
3	455	265.0	0	130.0	0	0	0	0	0	0	16892.1	560
4	455	455.0	20.0	20.0	0	0	0	0	0	0	19396.9	550
5	455	348.2	130.0	66.7	0	0	0	0	0	0	20166.7	0
6	455	302.5	109.5	107.5	125.3	0	0	0	0	0	22689.3	1800
7	455	432.9	118.1	118.9	25.0	0	0	0	0	0	23272.5	0
8	455	455.0	129.2	130.0	30.7	0	0	0	0	0	24152.5	0
9	455	455.0	127.2	121.3	76.4	39.6	25.2	0	0	0	27336.7	860
10	455	455.0	128.2	93.6	162.0	32.0	25.0	49.0	0	0	30410.4	60
11	455	455.0	130.0	129.2	158.8	49.1	26.6	14.2	31.7	0	32039.0	60
12	455	454.1	126.7	106.6	162.0	40.9	25.0	46.8	52.0	30.6	34348.2	60
13	455	454.6	128.5	127.4	145.8	20.0	25.0	43.5	0	0	30226.8	0
14	455	455.0	103.5	112.5	70.0	71.6	32.2	0	0	0	27582.5	0
15	455	455.0	130.0	92.0	67.9	0	0	0	0	0	24268.9	0
16	455	335.0	129.9	130.0	0	0	0	0	0	0	21005.1	0
17	455	395.0	130.0	20.0	0	0	0	0	0	0	20204.4	0
18	455	422.0	112.9	89.6	0	20.3	0	0	0	0	22378.2	170
19	455	453.3	130.0	90.4	0	26.7	44.4	0	0	0	25090.7	260
20	455	444.4	130.0	130.0	0	77.0	84.3	14.6	24.2	40.2	32032.8	180
21	455	432.7	128.8	129.3	0	57.8	35.8	10.0	50.4	0	28805.6	0
22	455	378.7	54.4	118.1	93.6	0	0	0	0	0	22615.9	900
23	455	414.1	0	0	30.8	0	0	0	0	0	17698.6	0
24	455	256.5	0	0	88.4	0	0	0	0	0	16108.0	0
Total cost											566960.50	5460

TABLE V OPTIMAL GENERATION SCHEDULING FOR 20- UNIT SYSTEM USING G ABC ALGORITHM

Hour	Unit 1	unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11
1	455	455	243.1	244.9	0	0	0	0	0	0	0
2	455	455	455.0	150.0	0	0	0	0	0	0	0
3	455	455	285.8	368.1	0	0	130.0	0	0	0	0
4	455	455	455.0	157.0	130.0	0	128.2	124.7	0	0	0
5	455	455	416.0	306.8	114.3	0	128.0	127.2	0	0	0
6	455	455	421.5	353.5	87.6	129.4	130.0	130.0	38.1	0	0
7	455	455	437.2	422.1	69.4	117.7	40.8	58.9	82.0	162.0	0
8	455	455	454.7	419.2	130.0	130.0	130.0	130.0	25.9	71.1	0
9	455	455	455.0	415.5	121.1	99.6	130.0	130.0	160.3	71.9	54.8
10	455	455	452.6	445.5	129.6	111.0	112.4	128.0	158.2	161.5	72.2
11	455	455	454.7	446.0	130.0	130.0	130.0	124.3	158.1	132.1	57.7

12	455	455	455.0	455.0	98.0	128.0	130.0	130.0	162.0	130.6	80.0
13	455	455	455.0	455.0	130.0	130.0	81.9	130.0	162.0	79.1	58.9
14	455	455	455.0	453.2	130.0	130.0	130.0	130.0	162.0	41.2	64.9
15	455	455	455.0	455.0	130.0	121.9	130.0	130.0	26.9	38.5	0
16	455	455	399.0	272.7	130.0	129.6	130.0	130.0	0	0	0
17	455	455	449.5	301.6	116.6	0	91.0	130.0	0	0	0
18	455	455	455.0	448.8	85.6	0	130.0	107.5	0	0	20
19	455	455	384.4	443.9	130.0	0	87.3	130.0	0	0	29.9
20	455	455	455.0	455.0	130.0	0	130.0	130.0	0	0	79.8
21	455	455	455.0	455.0	130.0	0	128.2	130.0	0	0	79.8
22	455	455	455.0	338.0	130.0	99.1	112.1	130.0	25.6	0	0
23	455	455	429.5	306.4	0	128.9	0	0	25.0	0	0
24	455	455	150.0	391.3	0	98.3	0	0	48.3	0	0

Hour	Unit 12	Unit 13	Unit 14	Unit 15	Unit 16	Unit 17	Unit 18	Unit 19	Unit 20	Cost	STC
1	0	0	0	0	0	0	0	0	0	27366.2	0
2	0	0	0	0	0	0	0	0	0	29109.5	0
3	0	0	0	0	0	0	0	0	0	33193.1	560
4	0	0	0	0	0	0	0	0	0	37905.3	1110
5	0	0	0	0	0	0	0	0	0	39649.5	0
6	0	0	0	0	0	0	0	0	0	44283.9	2900
7	0	0	0	0	0	0	0	0	0	46601.0	1800
8	0	0	0	0	0	0	0	0	0	48306.1	0
9	26.5	25.0	0	0	0	0	0	0	0	54074.0	1200
10	49.4	25.0	25.0	10.0	10.0	0	0	0	0	60357.4	640
11	69.7	25.0	25.0	10.0	55.0	23.3	18.9	0	0	64190.2	120
12	80	48.8	37.9	15.7	55.0	10.0	28.5	35.3	10.0	68011.9	120
13	79.7	31.8	37.4	20.8	38.0	0	0	0	0	60368.5	0
14	51.7	50.8	0	0	0	0	0	0	0	53930.7	0
15	0	0	0	0	0	0	0	0	0	48367.0	0
16	0	0	0	0	0	0	0	0	0	42017.4	0
17	0	0	0	0	0	0	0	0	0	39662.3	0
18	20.0	25.0	0	0	0	0	0	0	0	44920.0	600
19	73.7	61.2	85.0	19.4	44.7	0	0	0	0	51208.4	380
20	80.0	85.0	28.2	55.0	50.4	54.9	55.0	55.0	46.5	64402.8	240
21	75.9	25.0	25.0	33.6	29.4	29.9	32.4	11.9	48.9	58921.4	0
22	0	0	0	0	0	0	0	0	0	44311.2	1450
23	0	0	0	0	0	0	0	0	0	35481.4	0
24	0	0	0	0	0	0	0	0	0	31997.5	0
Total cost										1128636.6	11120

The results of 10 and 20 unit system with three different algorithms namely Particle Swarm Optimization (PSO), Differential Evaluation (DE) and Gbest Artificial Bee Colony (GABC) are obtained and are compared with Intelligent Binary Particle Swarm Optimization (IBPSO) [23] in Table VI.

From the comparison Table, it is observed that the total cost of 10 units and 20 units test system is less using Gbest Artificial Bee Colony based algorithm compared to Particle Swarm Optimization and Differential Evaluation algorithm. The convergence characteristic of GABC is shown in Figure.1.

TABLE VI COMPARISION OF BEST SOLUTIONS OF EACH METHOD

Method	Cost of 10 unit	Cost of 20 unit
IBPSO[23]	573913.00	-
PSO	580266.90	1159082.00
DE	575364.79	1149843.00
Gbest ABC	572420.50	1139756.60

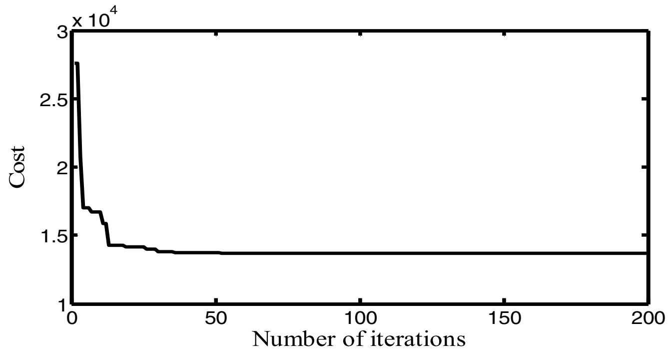

Figure.1 Convergence of 10 unit system with Gbest ABC

V CONCLUSION

In this paper three novel optimization techniques namely Particle Swarm Optimization, Differential Evaluation and Gbest Artificial Bee Colony optimization techniques are employed to solve the Unit Commitment problem using Priority List method based on Full Load Average Cost. The results are compared with the existing Intelligent Binary Particle Swarm Optimization in the literature. The Gbest ABC proves to be the best among all three algorithms for this problem.

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