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Solution to Unit Commitment with Priority List Approach

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ABSTRACT: Unit commitment problem (UCP) plays a key role in the power system operation and control. This paper deals with the mathematical formulation of conventional UCP and its solution with priority list (PL) approach using GABC algorithm. In this study, three different PL approaches are deliberated, namely, cost priority, power priority and hybrid priority to attain optimum solution. The optimal results ofUCP with different PL approaches are compared over a scheduling period which yields that the power priority and hybrid priority methods provide better result compared to the conventional cost priority approach for standard IEEE 10-unit system.

KEYWORDS: Cost priority (CP), Global best Artificial Bee Colony (GABC) algorithm, hybrid priority (HP), power priority (PP), unit commitment problem (UCP).

I. INTRODUCTION

Due to growing energy demand and limited generation resources, generation scheduling has become a challenging task for the utility and power system operators. In modern power system, unit commitment problem (UCP) is the most important and stimulating power system problem of daily generation planning. Due to the inconsistent nature of load demand, it becomes indispensable for the generation authorities to predict the generation scheduling in advance to obtain the economic and reliable system while satisfying the load demand. UCP combines two sub problems of power system such as unit commitment (UC) and economic load dispatch (ELD). UC decides when to start-up and shut down the generating units while ELD performs distribution of generated power among the committed units. Hence, the combine solution to UC and ELD as UCP is considered as the most challenging task due to its nonlinear and random nature that involves definite constraints, nonlinear objective function and enormous dimensions. Although, researchers extensively studied this complex problem from decades, the research is still ongoing on UCP and many methods and optimization techniques have been developed to solve the classic UCP. Exhaustive enumeration (EE) [1] selects the best solution by enumerating the all possible combinations of the generating units and hence, it is not suitable for large scale system and even for medium size UCP.

The traditional methods include priority list (PL) method [2-3], branch and bound (BB) method [4], dynamic programming (DP) [5], mixed-integer linear programming (MIP) [6] and Lagrangian Relaxation (LR) [7-8]. Among these traditional methods, the PL method is the simplest and fastest as it commits the generating units in ascending order of their average production cost. Hence, units with low generation cost are committed first. The BB method has a limitation of lack of storage capacity and computation time grows exponentially as the number of generating unit increases. The DP method is flexible and provides optimal solutions in small power systems. However, considering all constraints and possible combinations of generating units require enormous computation in large-scale power systems. The MIP method adopts linear programming techniques to obtain an integer solution which is imprecise to solve the non-linear UCP. The LR method attempts to obtain the appropriate co-ordination technique that generates feasible solution with reduced duality gap. Hence, the LR method suffers from convergence problem and poor quality solution due to the dual nature of the algorithm.

The main objective of this study is toimplement different priority list approaches and analyse their impact on the optimal scheduling of thermal units and total cost of the system. The simulation study is carried out by employing an efficient Global best artificial bee colony (GABC) optimization algorithm. The deployment of the rest of this paper is as follows: Section 2 describes the mathematical formulation of UCP with several constraints. A brief introduction

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tothe GABC optimization algorithm is presented in section 3. Section 4 deliberates the simulation results and comparisons of different cases considered. Finally, the conclusion is drawn in section 5.

II. PROBLEM FORMULATION

The main objective of the classic UCP is to minimize the total cost of the system while satisfying the load demand, spinning reserve and other constraints over the scheduled time horizon as follows:

$$\min C_{total} = \sum_{h=1}^{T}\left\{\sum_{i=1}^{N_G} C_i(P_{G(i,h)})U_{(i,h)} + SC_{(i)}x_{(i,h)} + SD_{(i)}y_{(i,h)}\right\} \tag{1}$$

where C_{total} describes the total cost of the system. N_G is specified as number of generating units and T is the schedule time horizon. $U_{(i,h)}$ indicates the on/off status of i^{th} unit at hour h and h signifies the hour index. $x_{(i,h)}$ and $y_{(i,h)}$ are the start-up and shut down indicators of unit i at hour h respectively.

The operation cost of the system is an accumulation of the fuel cost, start-up cost and shut down cost of all committed units over the scheduled time period. The first term in equation (1) is the fuel cost of a generating unit which can be characterized in quadratic polynomial form as:

$$C_i(P_{G(i,h)}) = a_i + b_i P_{G(i,h)} + c_i P_{G(i,h)}{}^2 \tag{2}$$

where a_i, b_i and c_i are the fuel cost coefficients and $P_{G(i,h)}$ is the power output at hour h of i^{th} generating unit. The second and third terms describe the start-up and shut down costs of each generating unit respectively. Generally, shut down cost is constant for each unit and the start-up cost depends on boiler temperature of a thermal unit and can be specified as:

$$SC_{(i)} = \begin{cases} HSC_{(i)} & if \quad MD_{(i,h)} \le U_{(i,h)}{}^{off} \le MD_{(i,h)} + CSH_{(i,h)} \\ CSC_{(i)} & if \quad U_{(i,h)}{}^{off} > MD_{(i,h)} + CSH_{(i,h)} \end{cases} \tag{3}$$

where $U_{(i,h)}{}^{off}$ is the duration during which i^{th} generating unit continuously remains off till hour h. HSC and CSC are referred to as hot and cold start-up cost respectively. CSH_i is cold start hour and $MU_{(i,,h)}$ and $MD_{(i,,h)}$ are minimum up and down time of unit i at hour h respectively.The execution of the above UCP model must satisfy several constraints listed below:

A) Power balance constraint: The accumulation of power generated from all the committed units must satisfy the load demand at that particular interval and is characterized as:

$$\sum_{i=1}^{N_G} P_{G(i,h)} U_{(i,h)} = P_{L(h)} \tag{4}$$

where $P_{L(h)}$ is denoted as hourly load demand.

B) Generation limit constraint: For system stability and safe operation of each generating unit, the generated power must be within the specified lower and upper limits as follows:

$$P_{G(i)}{}^{\min} \le P_{G(i)} \le P_{G(i)}{}^{\max} \tag{5}$$

where $P_G{}^{min}$ and $P_G{}^{max}$ are minimum and maximum generation capacities of each thermal unit respectively.

***C) Minimum up/down constraint*:** In thermal power plants, each generating unit necessitates some time before any commitment or decommitment depending on the temperature and pressure of the steam and has to remain in on or off state for a predefined time period before any change over takes place.

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$$U_i^{on} \geq MU_i$$
$$U_i^{off} \geq MD_i \tag{6}$$

where U_i^{on} and MU are the minimum on time and minimum up time respectively.

D) Spinning reserve constraint: Adequate spinning reserve (SR) should be required for stable and reliable operation. The SR constraint can be designed as:

$$\sum_{i=1}^{N_G} P_{G(i,h)}{}^{\max} U_{(i,h)} = P_{L(h)} + SR_{(h)} \tag{7}$$

III. OVERVIEW OF GABC ALGORITHM

Karaboga has developed the basic concept of artificial bee colony algorithm which emphases the food finding habits of honeybees. The artificial bees are mainly distributed into three groups, namely, employed bees, onlookers and scouts [9]. These bees fly in multidimensional search space to pursue their food source. Employed bees use their own experience to find the food source while scout bees hunt their food source arbitrarily. The onlooker bees pick good food source from those founded by the employed bees and they further search food source nearby the selected food source. Each food source signifies the possible solution of the optimization problem and quality of the food source is judged by the nectar amount of the food source. In ABC,the initial population P of N_p possible solution is generated randomly. Each P_i $(i= 1, 2,……N_p)$ is a D dimensional vector where D is the number of optimized parameters. In employed bee phase, the new random food source is generated as follows [10]:

$$v_{ij} = P_{ij} + \varphi_{ij}(P_{ij} - P_{kj}) \tag{8}$$

where P_{ij} and v_{ij} indicate the previous and new food source respectively and φ_{ij} denotes a random number between 0 to 1, j € $\{1,2…D\}$ and P_k indicates an alternative solution chosen randomly from the population. In GABC, global best (gbest) solution is used to improve the search mechanism and the equation (22) is modified as [10]:

$$v_{ij} = P_{ij} + \varphi_{ij}(P_{ij} - P_{kj}) + \Psi_{ij}(y_j - P_{ij}) \tag{9}$$

The added term in (23) 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. In onlooker phase, each onlooker bee chooses a food source according to the probability value $p_i = fit_i / \Sigma_n fit_n$ where *fit* describes the fitness of a solution. Thereafter, onlooker bees further searches for better solution (food source) in the neighborhood of the selected one according to (23). If the solution has not improved after certain trials, then scout bees generate new food source and repeat the hunting process.

IV. RESULT AND DISCUSSION

The conventional priority list (PL) method is considered to solve the UCP in this section. In this study, three different strategies of the priority selection of generating units are considered. The priority order of each generating unit is decided according to the cost priority (CP), power priority (PP) and hybrid priority (HP) [11].

Cost priority (CP): CP is the conventional priority list method based on Full load average production cost (FLAC) 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 [1]:

$$\alpha_i = \frac{f_i(P_{Gi}{}^{\max})}{P_{Gi}{}^{\max}} = \frac{a_i}{P_{Gi}{}^{\max}} + b_i + c_i P_{Gi}{}^{\max} \tag{10}$$

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The units are committed in ascending order of their αi. The thermal unit with lowest αi will have the highest priority to commit. While decommitment of thermal units, reverse order is followed, i.e. the unit with the highest αi is withdrawn first.

Power priority (PP): PP is based on the maximum power rating of the generating unit. The units are arranged according to their maximum generation capacities and unit with the highest power rating will have the first priority to commit and so on.

Hybrid priority (HP): In HP, hybrid strategy of CP and PP is applied. Initially, the priority of generating unit is decided according to the maximum power rating of the unit. Thermal unit with the highest power rating will have first priority. Then, this priority order is rearranged according to the traditional priority list method based on full load average cost (FLAC). Hence, the thermal units with higher generation limit and lowest FLAC will have the first priority.

In this study, GABC is employed to solve the basic UCP using different priority approaches for standard IEEE 10 unit system. The generation characteristics of 10 unit system and 24 hours load demand data obtained from [12] are provided in Table 1 and Table 2 respectively. For system reliability, spinning reserve is assumed as 10% of the hourly load demand.

Table 1 10- unit system data

Unit	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
P^{max}(MW)	455	455	130	130	162	80	85	55	55	55
P^{min}(MW)	150	150	20	20	25	20	25	10	10	10
a ($)	1000	970	700	680	450	370	480	660	665	670
b ($/MWh)	16.19	17.26	16.6	16.5	19.7	22.26	27.74	25.92	27.27	27.79
c ($/MWh^2)	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
MU(h)	8	8	5	5	6	3	3	1	1	1
MD(h)	8	8	5	5	6	3	3	1	1	1
HSC($)	4500	5000	550	560	900	170	260	30	30	30
CSC($)	9000	10000	1100	1120	1800	340	520	60	60	60
CSH(h)	5	5	4	4	4	2	0	0	0	0
IS(h)	8	8	-5	-5	-6	-3	-3	-1	-1	-1

Table 2Hourly load demand

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Load 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
Load Demand (MW)	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100	900	800

The priority orders of generating units according to the CP, PP and HP for 10 unit system are given in Table 3. From the Table 3, it can be seen that the scheduling order for units U1, U2, U8, U9 and U10 remain same for CP, PP and HP. While units U3-U7 schedule according to their priority approach.The optimal scheduling of thermal units for CP, PP and HP are given in Table 4, Table 5 and Table 6 respectively.

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Table 3 Priority order for 10 unit system

Units	FLAC(α_i)	P_{Gmax}	CP	PP	HP
U1	18.6062	455	1	1	1
U2	19.5329	455	2	2	2
U3	22.2446	130	4	5	5
U4	22.0051	130	3	3	4
U5	23.1225	162	5	4	3
U6	27.4546	80	6	7	7
U7	33.4542	85	7	6	6
U8	38.1472	55	8	8	8
U9	39.4830	55	9	9	9
U10	40.0670	55	10	10	10

Table 4 Generation scheduling for CP

Hour	U1 (MW)	U2 (MW)	U3 (MW)	U4 (MW)	U5 (MW)	U6 (MW)	U7 (MW)	U8 (MW)	U9 (MW)	U10 (MW)	C_{total} ($)
1	455.0	245.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13683.1
2	455.0	295.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14554.5
3	455.0	265.0	0.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	17452.1
4	455.0	455.0	20.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	19946.9
5	455.0	348.2	130.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	20166.7
6	455.0	302.5	109.5	107.5	125.3	0.0	0.0	0.0	0.0	0.0	24489.3
7	455.0	432.9	118.1	118.9	25.0	0.0	0.0	0.0	0.0	0.0	23272.5
8	455.0	455.0	129.2	130.0	30.7	0.0	0.0	0.0	0.0	0.0	24152.5
9	455.0	455.0	127.2	121.3	76.4	39.6	25.2	0.0	0.0	0.0	28196.7
10	455.0	455.0	128.2	93.6	162.0	32.0	25.0	49.0	0.0	0.0	30470.4
11	455.0	455.0	130.0	129.2	158.8	49.1	26.6	14.2	31.7	0.0	32099.0
12	455.0	454.1	126.7	106.6	162.0	40.9	25.0	46.8	52.0	30.6	34408.2
13	455.0	454.6	128.5	127.4	145.8	20.0	25.0	43.5	0.0	0.0	30226.8
14	455.0	455.0	103.5	112.5	70.0	71.6	32.2	0.0	0.0	0.0	27582.5
15	455.0	455.0	130.0	92.0	67.9	0.0	0.0	0.0	0.0	0.0	24268.9
16	455.0	335.0	129.9	130.0	0.0	0.0	0.0	0.0	0.0	0.0	21005.1
17	455.0	395.0	130.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	20204.4
18	455.0	422.0	112.9	89.6	0.0	20.3	0.0	0.0	0.0	0.0	22548.2
19	455.0	453.3	130.0	90.4	0.0	26.7	44.4	0.0	0.0	0.0	25350.7
20	455.0	444.4	130.0	130.0	0.0	77.0	84.3	14.6	24.2	40.2	32212.8
21	455.0	432.7	128.8	129.3	0.0	57.8	35.8	10.0	50.4	0.0	28805.6
22	455.0	378.7	54.4	118.1	93.6	0.0	0.0	0.0	0.0	0.0	23515.9
23	455.0	414.1	0.0	0.0	30.8	0.0	0.0	0.0	0.0	0.0	17698.6
24	455.0	256.5	0.0	0.0	88.4	0.0	0.0	0.0	0.0	0.0	16108.0
Total cost ($)											572420.5

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Table 5 Generation scheduling for PP

Hour	U1 (MW)	U2 (MW)	U3 (MW)	U4 (MW)	U5 (MW)	U6 (MW)	U7 (MW)	U8 (MW)	U9 (MW)	U10 (MW)	C_{total} ($)
1	455.0	245.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13683.1
2	455.0	295.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14554.5
3	455.0	370.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	17709.6
4	455.0	454.6	0.0	0.0	40.4	0.0	0.0	0.0	0.0	0.0	18598.6
5	455.0	388.2	130.0	0.0	26.7	0.0	0.0	0.0	0.0	0.0	20605.4
6	455.0	384.9	106.0	129.0	25.0	0.0	0.0	0.0	0.0	0.0	22397.6
7	455.0	409.8	130.0	130.0	25.2	0.0	0.0	0.0	0.0	0.0	24382.5
8	455.0	455.0	129.9	129.8	30.2	0.0	0.0	0.0	0.0	0.0	24150.9
9	455.0	445.3	130.0	129.0	95.6	20.0	25.0	0.0	0.0	0.0	28142.0
10	455.0	454.3	129.7	130.0	152.4	43.5	25.0	10.0	0.0	0.0	30140.6
11	455.0	454.7	126.6	129.4	162.0	77.3	25.0	10.0	10.0	0.0	32002.5
12	455.0	454.7	130.0	130.0	161.9	80.0	27.9	29.0	10.0	21.3	33975.7
13	455.0	455.0	129.8	128.5	162.0	27.5	25.0	17.1	0.0	0.0	30090.4
14	455.0	452.5	130.0	129.9	86.2	21.1	25.3	0.0	0.0	0.0	27263.5
15	455.0	455.0	130.0	130.0	30.0	0.0	0.0	0.0	0.0	0.0	24150.4
16	455.0	447.8	122.2	0.0	25.0	0.0	0.0	0.0	0.0	0.0	20930.4
17	455.0	407.8	112.2	0.0	25.0	0.0	0.0	0.0	0.0	0.0	20058.7
18	455.0	453.6	129.4	0.0	37.0	0.0	25.0	0.0	0.0	0.0	22828.6
19	455.0	451.4	128.5	0.0	118.6	20.0	26.5	0.0	0.0	0.0	25202.4
20	455.0	455.0	129.8	0.0	161.9	80.0	29.4	55.0	23.4	10.3	32021.3
21	455.0	454.9	128.1	130.0	86.9	20.0	25.0	0.0	0.0	0.0	27817.3
22	455.0	369.5	125.6	124.9	25.0	0.0	0.0	0.0	0.0	0.0	22390.9
23	455.0	315.0	0.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	17764.1
24	455.0	218.5	0.0	126.4	0.0	0.0	0.0	0.0	0.0	0.0	16022.9
Total cost ($)											566884.3

Table 6 Generation scheduling for HP

Hour	U1 (MW)	U2 (MW)	U3 (MW)	U4 (MW)	U5 (MW)	U6 (MW)	U7 (MW)	U8 (MW)	U9 (MW)	U10 (MW)	C_{total} ($)
1	455.0	245.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13683.1
2	455.0	295.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14554.5
3	455.0	370.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	17709.5
4	455.0	455.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	18597.7
5	455.0	390.0	0.0	130.0	25.0	0.0	0.0	0.0	0.0	0.0	20579.9
6	455.0	356.6	130.0	129.4	29.0	0.0	0.0	0.0	0.0	0.0	23497.1
7	455.0	417.8	130.0	122.2	25.0	0.0	0.0	0.0	0.0	0.0	23265.8
8	455.0	455.0	130.0	130.0	30.0	0.0	0.0	0.0	0.0	0.0	24150.3
9	455.0	455.0	127.7	130.0	82.6	24.8	25.0	0.0	0.0	0.0	28129.2
10	455.0	455.0	129.1	129.8	162.0	29.3	25.0	14.8	0.0	0.0	30139.9
11	455.0	454.9	130.0	130.0	162.0	65.0	25.0	17.4	10.6	0.0	31999.8

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12	455.0	455.0	130.0	130.0	162.0	79.9	26.9	37.1	10.0	14.1	33959.7
13	455.0	455.0	130.0	129.8	162.0	30.3	25.0	12.8	0.0	0.0	30067.8
14	455.0	451.5	124.6	127.8	96.0	20.0	25.0	0.0	0.0	0.0	27286.3
15	455.0	454.9	130.0	130.0	30.0	0.0	0.0	0.0	0.0	0.0	24150.4
16	455.0	437.1	0.0	130.0	27.9	0.0	0.0	0.0	0.0	0.0	20902.7
17	455.0	390.0	0.0	130.0	25.0	0.0	0.0	0.0	0.0	0.0	20020.0
18	455.0	453.6	0.0	130.0	36.1	0.0	25.2	0.0	0.0	0.0	22797.6
19	455.0	455.0	0.0	130.0	115.0	20.0	25.0	0.0	0.0	0.0	25144.2
20	455.0	455.0	0.0	130.0	162.0	80.0	26.6	54.9	25.9	10.5	31987.6
21	455.0	452.9	130.0	129.4	87.5	20.0	25.1	0.0	0.0	0.0	27809.5
22	455.0	383.9	109.2	126.9	25.0	0.0	0.0	0.0	0.0	0.0	22397.0
23	455.0	315.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17795.3
24	455.0	215.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16052.8
Total cost ($)											566678.0

The comparison of total cost for different priority approaches employing GABC is given in Table 7 which shows that CP yields maximum cost whereas both PP and HP perform almost similar and result in lower cost compared to the CP.

Table 7 Comparison of total cost

Priority	Total cost ($)
CP	572420.5
PP	566884.3
HP	566678.0

V.CONCLUSION

In this paper, three different priority list approaches, namely, cost priority (CP), power priority (PP) and hybrid priority (HP), are employed to solve the basic UCP with an effective GABC algorithm. In PL approach, it can be observed that the results obtained with PP and HP are almost similar and better than CP. The results confirm that PL method is simple, but may results in sub-optimal solution since it provides the schedule according to the predefined priority order as priority order of generating unitshas the great influence on the total cost. Also, PL method may leads to a solution with relatively higher generation cost because start-up cost and ramp rate limits are not considered in determining the priority order of the committed units. But, PL method proves simple and fast for large scale unit system.

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