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A Simple Approach for Optimal Generation Scheduling to Maximize GENCOs Profit Using PPD Table and ABC Algorithm under Deregulated Environment

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ABSTRACT

In this paper an attempt has been made to solve the profit based unit commitment problem (PBUC) using pre-prepared power demand (PPD) table with an artificial bee colony (ABC) algorithm. The PPD-ABC algorithm appears to be a robust and reliable optimization algorithm for the solution of PBUC problem. In a deregulated environment, generation companies (GENCOs) has the choice to buy or sell from Independent System Operator (ISO), in addition to generating power on its own. The profit based unit commitment problem is considered as a stochastic optimization problem in which the objective is to maximize their own profit and the decisions are needed to satisfy the standard operating constraints. The PBUC problem is solved by the proposed methodology in two stages. In the first step, the unit commitment scheduling is performed by considering the pre-prepared power demand (PPD) table and then the problem of fuel cost and revenue function is solved using ABC Algorithm. The PPD table suggests the operator to decide the units to be put into generation there by reducing the complexity of the problem. The proposed approach is demonstrated on 10 units 24 hour and 50 units 24 hour test systems and numerical results are tabulated. Simulation result shows that this approach effectively maximizes the GENCO's profit than those obtained by other optimizing methods.

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NOMENCLATURE

PF	total profit of GENCOs
RV	total revenue of GENCOs
TC	total generation cost of GENCOs
P_{it}	real power output of i^{th} Generator
P_{Dt}	forecasted system demand during hour t
P_{it}^{max}	maximum limit of i^{th} unit during hour of t
P_{it}^{min}	minimum limit of i^{th} unit during hour of t
SP_t	forecasted market price at hour of t
ST	start up cost
T	number of time Periods considered
PPD	pre-prepared power demand table
$RPPD$	reduced pre-prepared power demand table
ABC	artificial bee colony
λ	Incremental cost

N	number of generating units
a_i, b_i, c_i	cost co-efficient of i^{th} generator
GENCO	generation Company
TRANSCO	transmission Company
DISCO	distribution Company
R_i *(t)*	Reserve of i^{th} generating unit during hour of t
SR *(t)*	spinning reserve during hour of t
X_{it}	unit status

1. INTRODUCTION

In a vertically integrated utility environment, the objective of Unit Commitment (UC) involves scheduling the generators apart from satisfying the system constraints. The Unit commitment performs the scheduling process in a utility for minimizing the total generation cost over the time period [1]-[2]. The introduction of deregulation and restructuring in Electric power system creates a competitive open market scenario. The generation company adopts Unit Commitment for maximizing their own profit instead of minimizing the total generation cost of the centralized power system. This problem is referred as Profit Based Unit Commitment (PBUC) problem. Profit Based Unit Commitment is defined as a method which schedules their generators economically based on forecasted information such as spot price, reserve price, demand and unit data with an objective to maximize the GENCOs profit. So, the solution methodology of PBUC problem seems to be complex than traditional UC problem. The PBUC problem is divided into two sub problems [3]-[4]. The first sub-problem is the determination of status of the generating units and second sub-problem is the determination of output powers of committed units.

Earlier, classical methods such as [5]-[11] Priority List (PL), Dynamic Programming (DP), Branch-Bound, Mixed Integer Programming (MIP) and Lagrangian relaxation (LR) were used to solve the UC problem. Among these methods, the Priority List method [6] is a simple method but the quality of solution is rough. The Dynamic Programming [7] is a flexible method to solve the UC problem. This approach features the classification of generating units into related groups so as to minimize the number of unit combinations which must be tested without precluding the optimal path. The dynamic programming technique involves huge computational time to obtain the solution because of its complex dimensionality with large number of generating units. Another approach has been presented for solving the unit commitment problem based on branch and bound techniques [8]. The method incorporates time-dependent start-up costs, demand and reserve constraints and minimum up and down time constraints. The priority ordering of the units is not necessary in this technique.

Lagrange Relaxation method [11] provides fast solution but sometimes it suffers from numerical convergence problem especially when the problem is nonconvex. Besides, this method strongly depends on the technique used to update Lagrange multipliers. Many researchers dealing with LR are using sub gradient technique for solving this problem. Even though, the solution obtained from gradient-based method suffers from convergence problem and always gets stuck into a local optimum. In order to overcome these problems, many stochastic optimizations such as [12]-[19] genetic algorithm [12]-[13], Memetic algorithm [14], Ant colony optimization [15], Particle swarm optimization [16]-[17] and Muller method [18]-[19] were introduced into power system optimization. These methods begin with a population of starting points, use only the objective function information, and search a solution in parallel using operators borrowed from natural biology. These methods are seems to be fast and reliable, but it has a problem of convergence on large scale power system problem. Hybrid methods such as LR-MIP [20], LR-GA [21] and LR-EP [22]-[23] have been used for solving the PBUC problems

In this article, a simple method for maximizing the profit of GENCOs is developed based on Pre-prepared Power Demand (PPD) table with an Artificial Bee Colony (ABC) algorithm. The preparation of PPD table simplifies the solution methodology of Profit Based Unit Commitment problem irrespective of dimensionality of the system size. Also the execution time of the proposed approach is reduced when compared with the existing methods. The proposed PPD-ABC approach has been tested on two test systems and numerical results are presented to prove the effectiveness of the proposed method.

2. PROBLEM FORMULATION

2.1 Traditional unit commitment problem

In the past, UC is defined as a method to schedule generators economically in a power system in order to meet the requirements of load and spinning reserve. Traditional UC can be defined mathematically as an optimization problem as follows:

The objective function

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N} F(P_{it})X_{it} + ST.X_{it} \tag{1}$$

Constraints

The following constraints must be satisfied during the optimization process:

1. Power balance constraint

$$\sum_{i=1}^{N} P_{it}X_{it} = P_{Dt} \qquad t = 1,2..........T \tag{2}$$

2. Spinning reserve constraint

$$\sum_{i=1}^{N} P_i^{\max} X_{it} \geq P_{Dt} + SR_t \qquad t = 1,2........T \tag{3}$$

3. Generation limit constraint

$$P_i^{\min} \leq P_i \leq P_i^{\max} \qquad i = 1,2.......N \tag{4}$$

4. Minimum up and down-time constraints

$$Ton_i \geq Tup_i, \qquad i = 1..........N$$
$$Toff_i \geq Tdown_i, \quad i = 1.........N \tag{5}$$

2.2 Profit based unit commitment problem

The objective is to determine the generating unit schedules for maximizing the profit of Generation Companies subject to all prevailing constraints such as load demand, spinning reserve and market prices. The term profit is defined as the difference between revenue obtained from sale of energy with market price and total operating cost of the generating company.

The objective function

The PBUC can be mathematically formulated by the following equations.

$$Maximize\ PF = RV - TC \tag{6}$$

$$RV = \sum_{t=1}^{T}\sum_{i=1}^{N} P_{it} SP_t X_{it} \tag{7}$$

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N} F(P_{it})X_{it} + ST.X_{it} \tag{8}$$

The total operating cost, over the entire scheduling period is the sum of production cost and start-up/shutdown cost for all the units. Here, the shutdown cost is considered as equal to zero for all units. The production cost of the scheduled units is given in a quadratic form

$$Min.F_{it}(P_{it}) = a_i + b_i P_{it} + C_i P_{it}^2 \tag{9}$$

Constraints

1. Load demand constraint

$$\sum_{i=1}^{N} P_{it}X_{it} \leq P_{Dt} \qquad 1 \leq i \leq N \tag{10}$$

2. Generator limits constraint

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad 1 \le i \le N \tag{11}$$

3. Spinning reserve constraint

$$\sum_{i=1}^{N} R_{it} X_{it} \le SR \qquad 1 \le t \le T \tag{12}$$

4. Minimum up/down time constraints

$$\begin{aligned} Ton_i &\ge Tup_i, \quad i = 1..........N \\ Toff_i &\ge Tdown_i, \; i = 1.........N \end{aligned} \tag{13}$$

3. SOLUTION METHODOLOGY

It is experienced from the literatures, that most of the prevailing algorithms have limitations to provide optimal solution. Therefore, this paper is focused to derive a simple approach to improve GENCOs profit under deregulated environment. For this, a table namely pre-prepared power demand is prepared using the unit data, forecasted price and system demand. The PPD table identifies the commitment of units and then ABC algorithm is prescribed to solve the fuel cost and revenue function. Remaining part of the article is described as follows.

3.1. Mathematiacal model of Pre-prepared Power Demand (PPD) table

A complete algorithmic steps to prepare the PPD table is given below.

1. The minimum and maximum values of lambda are calculated for all generating units at their minimum and maximum output powers (P_{imin} , P_{imax}). Two lambda values are possible for each generating units.

The value of lambda (λ) are estimated by using the following equations

$$\lambda_{j\min} = \frac{p_{i\min} + \frac{b_i}{2c_i}}{\frac{1}{2c_i}} \tag{14}$$

$$\lambda_{j\max} = \frac{p_{i\max} + \frac{b_i}{2c_i}}{\frac{1}{2c_i}} \tag{15}$$

2. The lambda values are arranged in ascending order and label them as λ_j *(where j =1, 2…2N).*

3. The output powers for all generators at each λ_j value are calculated using the formulation

$$p_{ji} = \frac{\lambda - b_i}{2c_i} \tag{16}$$

4. The minimum and maximum output power of generators are fixed as follows.

(i) For minimum output power limit

If $\lambda_j < \lambda_{i\min}$ then set $p_{ji} = 0$ (17)

If $\lambda_j = \lambda_{i\min}$ then set $p_{ji} = p_{i\min}$ (18)

(ii) For maximum output power limit

If $\lambda_j > \lambda_{i\max}$ then set $p_{ji} = p_{i\max}$ (19)

5. Lambda (λ) value, output powers (P_{ji}) and sum of output powers (SOP) for each λ are listed in the table in ascending order. This table is referred as Pre-prepared Power Demand (PPD) table.

To illustrate the preparation of PPD Table, a typical 10 unit system is considered and unit data are shown in Table -1.

Table 1. Fuel cost and generator limits data for 10 unit system

Unit	*a* ($)	*b* ($/MW)	*c* ($/MW^2)	P_{imin} (MW)	P_{imax} (MW)
1	1000	16.19	0.00048	150	455
2	970	17.26	0.00031	150	455
3	700	16.60	0.00200	20	130
4	680	16.50	0.00211	20	130
5	450	19.70	0.00398	25	162
6	370	22.26	0.00712	20	80
7	480	27.74	0.00079	25	85
8	660	25.92	0.00413	10	55
9	665	27.27	0.00222	10	55
10	670	27.79	0.00173	10	55

Table 2. Ascending order values of lambda for ten generating units

S.No	λ	S.No	λ	S.No	λ	S.No	λ
1	16.33	6	17.12	11	22.54	16	27.51
2	16.58	7	17.35	12	23.48	17	27.78
3	16.63	8	17.54	13	26.00	18	27.82
4	16.68	9	19.90	14	26.37	19	27.87
5	17.05	10	20.99	15	27.31	20	27.98

The ascending order values of lambda are given in Table - 2. Finally the PPD Table is prepared by applying the above algorithmic steps and shown in Table – 3.

3.2. Mathematical model of Reduced Pre-prepared Power Demand (RPPD) table:

The Forecasted price plays an important role in preparing the RPPD Table. Because GENCOs yield profit only when the forecasted price at the given hour is more than the incremental fuel cost of the generators.

There are two ways to form the RPPD table from the PPD table**.**

1. From the PPD table, two rows are selected for the predicted power demand, such that the power demand lies within the Sum of Powers (SOP) limits. The corresponding rows are considered k and $k+1$.
2. Here, two rows corresponds to the forecasted price are selected from the PPD table .So that forecasted
   price falls within the incremental cost. The rows are considered as l and $l+1$.

Table 3. Pre-prepared power demand (PPD) table for 10 unit 24 hour systems
(Including generator limits, minimum up and down time constraints and initial status of generators)

S.NO	λ ($/MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_7 (MW)	P_8 (MW)	P_9 (MW)	P_{10} (MW)	SOP (MW)
1	16.33	150	455	0	0	0	0	0	0	0	0	605.00
2	16.58	455	455	0	0	0	0	0	0	0	0	910.00
3	16.63	455	455	0	30.80	0	0	0	0	0	0	940.80
4	16.68	455	455	0	42.65	0	0	0	0	0	0	952.65
5	17.05	455	455	112.50	130	0	0	0	0	0	0	1152.50
6	17.12	455	455	130	130	0	0	0	0	0	0	1170.00
7	17.35	455	455	130	130	0	0	0	0	0	0	1170.00
8	17.54	455	455	130	130	0	0	0	0	0	0	1170.00
9	19.90	455	455	130	130	25.12	0	0	0	0	0	1195.12
10	20.99	455	455	130	130	162	0	0	0	0	0	1332.00
11	22.54	455	455	130	130	162	20	0	0	0	0	1352.00
12	23.48	455	455	130	130	162	80	0	0	0	0	1412.00
13	26.00	455	455	130	130	162	80	0	10	0	0	1422.00
14	26.37	455	455	130	130	162	80	0	54.48	0	0	1466.48
15	27.31	455	455	130	130	162	80	0	55	10	0	1477.00
16	27.51	455	455	130	130	162	80	0	55	54.05	0	1521.05
17	27.78	455	455	130	130	162	80	0	55	55	0	1522.00
18	27.82	455	455	130	130	162	80	50.63	55	55	10	1582.63
19	27.87	455	455	130	130	162	80	82.28	55	55	23.12	1627.40
20	27.98	455	455	130	130	162	80	85	55	55	54.91	1661.91

Therefore, the Reduced Pre-prepared Power Demand (RPPD) table is formed by

a) If the row $k < l$, then the RPPD table is formed by considering the option 1.

b) If the row $l < k$, then the RPPD table is formed by choosing the option 2.

The RPPD Table for various power demands are developed and shown in the Table - 4 to Table - 8.

Table 4. RPPD Table for Forecasted Demand of 700 MW to 850 MW

λ ($/MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_7 (MW)	P_8 (MW)	P_9 (MW)	P_{10} (MW)	SOP (MW)
16.33	150	455	0	0	0	0	0	0	0	0	605.00
16.58	455	455	0	0	0	0	0	0	0	0	910.00

Table 5. RPPD Table for Forecasted Demand of 950 MW to 1150 MW

λ ($/MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_7 (MW)	P_8 (MW)	P_9 (MW)	P_{10} (MW)	SOP (MW)
16.68	455	455	0	42.65	0	0	0	0	0	0	952.65
17.05	455	455	112.50	130	0	0	0	0	0	0	1152.50

Table 6. RPPD Table for Forecasted Demand of 1200 MW to 1300 MW

λ ($/MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_7 (MW)	P_8 (MW)	P_9 (MW)	P_{10} (MW)	SOP (MW)
19.90	455	455	130	130	25.12	0	0	0	0	0	1195.12
20.99	455	455	130	130	162	0	0	0	0	0	1332.00

Table 7. RPPD Table for Forecasted Demand of 1400 MW

λ ($/MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_7 (MW)	P_8 (MW)	P_9 (MW)	P_{10} (MW)	SOP (MW)
22.54	455	455	130	130	162	20	0	0	0	0	1352.00
23.48	455	455	130	130	162	80	0	0	0	0	1412.00

Table 8. RPPD Table for Forecasted Demand of 1500 MW

λ ($/MW)	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_7 (MW)	P_8 (MW)	P_9 (MW)	P_{10} (MW)	SOP (MW)
27.31	455	455	130	130	162	80	0	55	10	0	1477.00
27.51	455	455	130	130	162	80	0	55	54.05	0	1521.05

Now, it is necessary to form the Reduced Scheduling Units (RSU) table which explains the status of committed units. The RSU table is obtained from RPPD table by substituting the binary values such a way that if any element in the table is non zero, then it is replaced by 1. Therefore, if binary value is zero, then the corresponding unit is in OFF state. Similarly if binary value is 1, then the unit is in ON state.

For example, the status of generating units for forecasted power demand of 700 MW is as follows

U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}
1	1	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0

The decommitment of units, Inclusion of minimum up time and minimum down time constraints are incorporated in the PBUC problem.

3.3. De-commitment of units

The profit of GENCOs depends on the proper scheduling of units. Sometimes, the spinning reserve of the system is increased, due to the large gap between the selected lambda values in the RPPD table. So, it is important to note that the decommitment of the unit is necessary to improve the financial benefits of GENCOs.

If there is any excessive spinning reserve, then the RPPD table is examined. Then the excessive units in the RPPD Table are decommitted after satisfying the spinning reserve constraints.

3.4. Minimum up time and minimum down time constraints

The OFF time of the unit is less than the minimum down- time, then status of that unit will be OFF. Similarly if ON time of the unit is greater than the up time of the unit, then that unit will be ON. All these useful information are applied in RPPD Table to perform the final unit commitment scheduling. Then Artificial Bee Colony (ABC) algorithm has been proposed to solve the Economic Dispatch (ED) problem.

3.5. Artificial Bee Colony (ABC) Algorithm

Artificial Bee Colony (ABC) is the recently defined algorithms by Dervis Karaboga in 2005, motivated by the intelligent behavior of honey bees [24]-[25]. ABC in an optimization tool provides a population-based search procedure in which individuals called foods positions are modified by the artificial bees with time and the bee’s aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar.

In the ABC algorithm, the colony of artificial bees contains of three groups of bees: employed bees, onlookers and scouts. The food source represents a possible solution of the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. Every food source has only one employed bee. Thus, the number of employed bees or the onlooker bees is equal to the number of food sources (solutions).

The onlooker bees evaluate the nectar information and choose a food source depending on the probability value associated with that food source (p_i), calculated by the following expression.

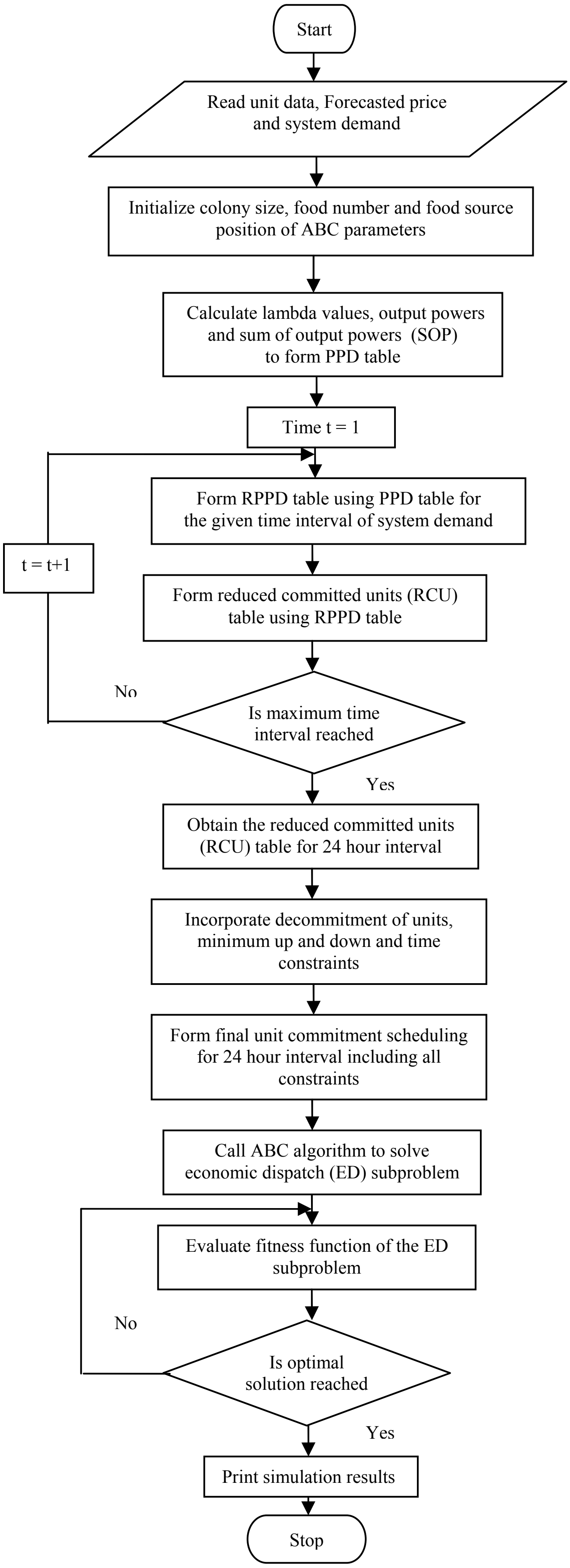

Figure 1. Flow chart for proposed method

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \tag{20}$$

Where fit_i is the fitness value of the solution i which is proportional to the nectar amount of the food source in the position i and *SN* is the number of food sources is equal to the number of employed bees.

The employed bees exchange their information with the onlookers. In order to produce a candidate food position from the old one, the ABC uses the following expression

$$V_{ij} = X_{ij} + \phi_{ij}(X_{ij} - X_{kj}) \tag{21}$$

Where, $k \in \{1,2..........,BN\}$ and $j \in \{1,2..........,D\}$ are randomly chosen indexes. Although k is determined randomly, it has to be different from i. ϕ_{ij} is a random number between [0, 1]. It controls the production of a neighbour food source position around X_{ij} and the modification represents the comparison of the neighbour food positions visually by the bee.

If a predetermined number of trials does not improve a solution representing a food source, then that food source is abandoned and the employed bee associated with that food source becomes a scout. The number of trials for releasing a food source is equal to the value of 'limit', which is an important control parameter of ABC algorithm.

The limit value usually varies from $0.001n_eD$ to n_eD. If the abandoned source is X_{ij}, $j \in (1,2,...D)$ then the scout discovers a new food source X_{ij}, calculated by using the equation.

$$X_{ij} = X_{j\min} + rand(0,1) \times (X_{j\max} - X_{j\min}) \tag{22}$$

Where $X_{j\min}$ and $X_{j\max}$ are the minimum and maximum limits of the parameter to be optimized. There are four control parameters used in ABC algorithm. They are the number of employed bees, number of unemployed or onlooker bees, the limit value and the colony size. Thus, ABC system combines local search carried out by employed and onlooker bees, and global search managed by onlookers and scouts, attempting to balance exploration and exploitation process.

4. SIMULATION AND RESULTS COMPARISON

The Pre-prepared power demand (PPD) table with an artificial bee colony algorithm (ABC) based PBUC is first tested on 10 unit system available in the literature [18] and [23] as Case 1. It is also validated on multiple test systems of 50 units in Case 2.

4.1 Test case: 1 (Ten unit Test System)

This test system adapted from [23] consisting of ten generating units with Twenty Four hour scheduling periods and the fuel cost of each generators is estimated into quadratic form. The generator data, forecasted market and demand price are also considered from the same reference.

Table 9. Unit Data for Ten Unit System

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
P_{max}	455	455	130	130	162	80	85	55	55	55
P_{min}	150	150	20	20	25	20	25	10	10	10
a	1000	970	700	680	450	370	480	660	665	670
b	16.19	17.26	16.60	16.50	19.70	22.26	27.74	25.92	27.27	27.79
c	0.00048	0.00031	0.00200	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
Min up	8	8	5	5	6	3	3	1	1	1
Min down	8	8	5	5	6	3	3	1	1	1
ST	4500	5000	550	560	900	170	260	30	30	30
Initial	8	8	-5	-5	-6	-3	-3	-1	-1	-1

These data are described in Table-9 and Table-10. The feasible parameters obtained by various processes for Artificial Bee Colony (ABC) algorithm are as follows. Colony size = 20; food number = 10; Food source limit =100; and maximum number of iterations = 1000.

The proposed PPD-ABC methodology is tested to demonstrate its superior performance on ten units twenty four hour system using MATLAB. Final unit commitment scheduling and output powers of committed generators are displayed in Table - 11 and Table - 12 in detail. From this table, it is observed that the GENCO decides to shut off Units 7 to 10 in all the commitment period and to sell power and reserve below the forecasted level in some periods. This is because the objective of PBUC is not to minimize the costs as before, but to maximize the profit with relaxation of the demand fulfillment and constraint. Comparative studies have also been made to analyze the total cost, revenue and profit of Traditional and PBUC system. The numerical results are presented in Table - 13. In order to verify the performance advantages of PPD-ABC further, the simulation results were compared with that of other optimizing techniques and comparison results are given in Table - 14 and 15. Fig-2 exhibits the graphical representation of total cost, revenue and profit. Also Fig-3 compares the profit of four different optimization algorithm viz., traditional unit commitment, Muller method, parallel PSO and nodal ACO. From the results, it is clear that the proposed methods provides maximum profits and are compared with those published in the recent literatures.

Table 10. Forecasted Demand and Spot Price for Ten Unit 24 Hour System

Hour (h)	Forecasted Demand (MW)	Forecasted Reserve (MW)	Forecasted Market price ($/MWh)
1	700	70	22.15
2	750	75	22.00
3	850	85	23.10
4	950	95	23.65
5	1000	100	22.25
6	1100	110	22.95
7	1150	115	22.50
8	1200	120	22.15
9	1300	130	22.80
10	1400	140	29.35
11	1450	145	30.15
12	1500	150	31.65
13	1400	140	24.60
14	1300	130	24.50
15	1200	120	22.50
16	1050	105	22.30
17	1000	100	22.25
18	1100	110	22.05
19	1200	120	22.20
20	1400	140	22.65
21	1300	130	23.10
22	1100	110	22.95
23	900	90	22.75
24	800	80	22.55

Table 11. Final Unit Commitment Scheduling for 10 Unit 24 Hour System

Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
U_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U_2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
U_3	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
U_4	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
U_5	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
U_6	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
U_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 12. Power dispatch of ten unit 24 hour system

Hour (hr)	P_D (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)
1	700	455	245	0	0	0	0	0	0	0	0
2	750	455	295	0	0	0	0	0	0	0	0
3	850	455	395	0	0	0	0	0	0	0	0
4	950	455	455	0	0	0	0	0	0	0	0
5	1000	455	455	0	0	0	0	0	0	0	0
6	1100	455	455	130	60	0	0	0	0	0	0
7	1150	455	455	130	110	0	0	0	0	0	0
8	1200	455	455	130	130	30	0	0	0	0	0
9	1300	455	455	130	130	130	0	0	0	0	0
10	1400	455	455	130	130	162	68	0	0	0	0
11	1450	455	455	130	130	162	80	0	0	0	0
12	1500	455	455	130	130	162	80	0	0	0	0
13	1400	455	455	130	130	162	68	0	0	0	0
14	1300	455	455	130	130	130	0	0	0	0	0
15	1200	455	455	130	130	0	0	0	0	0	0
16	1050	455	335	130	130	0	0	0	0	0	0
17	1000	455	285	130	130	0	0	0	0	0	0
18	1100	455	385	130	130	0	0	0	0	0	0
19	1200	455	455	130	130	0	0	0	0	0	0
20	1400	455	455	130	130	0	0	0	0	0	0
21	1300	455	455	130	130	0	0	0	0	0	0
22	1100	455	385	130	130	0	0	0	0	0	0
23	900	455	445	0	0	0	0	0	0	0	0
24	800	455	345	0	0	0	0	0	0	0	0

Table 13. Simulation results for 10 unit 24 hour system

Hour (hr)	P_D (MW)	Unit Commitment (Traditional method)			PPD-ABC (Proposed method)		
		Total cost ($)	Revenue ($)	Profit ($)	Total cost($)	Revenue ($)	Profit ($)
1	700	13683	15505	1822	13683	15505	1822
2	750	14554	16500	1946	14554	16500	1946
3	850	16302	19635	3333	16302	19635	3333
4	950	18965	20612	1647	17353	20612	3259
5	1000	20529	21158	629	17353	21158	3805
6	1100	24548	25245	697	22701	25245	2544
7	1150	22755	25875	3120	20214	23400	3186
8	1200	25950	25916	-34	20214	23036	2822
9	1300	26184	29640	3456	23106	26676	3570
10	1400	29108	41090	11982	28770	41090	12320
11	1450	30759	42572	11813	29048	42572	13524
12	1500	32773	46431	13658	29048	44690	15642
13	1400	28768	34440	5672	28768	34440	5672
14	1300	26184	31850	5666	26196	31850	5654
15	1200	24150	26325	2175	24191	27000	2809
16	1050	21005	23415	2410	21523	23415	1892
17	1000	20133	16799	-3334	20677	22250	1573
18	1100	21879	24255	2376	22404	24255	1851
19	1200	23106	25974	2868	24194	26640	2446
20	1400	31876	26501	-5375	26852	30170	3318
21	1300	27268	27027	-241	26213	30030	3817
22	1100	22348	25245	2897	21879	25245	3366
23	900	17178	20475	3297	17178	20475	3297
24	800	15427	18040	2613	15427	18040	2613
		Total profit ($)		**75093**	**Total profit ($)**		**106081**

Table 14. Comparison of total profits of existing methods with the proposed method

Method	Profit($)
TS-RP [6]	101086
TS-TRP [16]	103261
PSO [17]	104356
PPD - ABC (Proposed method)	106081

Table 15. Comparison of hourly profits of existing methods with the proposed method

Hour (h)	Demand (MW)	Traditional UC	Muller method	Parallel PSO	Nodal ACO	PPD-ABC (Proposed)
1	700	1822	1822	1821.87	1822	1822
2	750	1946	1946	1945.50	1946	1946
3	850	3333	3333	3333.11	3333	3333
4	950	1647	3259	3258.20	3259	3259
5	1000	629	3805	3804.20	3805	3805
6	1100	697	1146	1145.67	2534	2544
7	1150	3120	3120	3119.96	3186	3186
8	1200	-34	2810	2809.74	2822	2822
9	1300	3456	1656	1655.98	2470	3570
10	1400	11982	11982	11981.79	10182	12320
11	1450	11813	13524	13523.82	13524	13524
12	1500	13658	15225	15641.82	15642	15642
13	1400	5672	5672	5671.79	5672	5672
14	1300	5666	5666	5261.04	5666	5654
15	1200	2175	3219	3219.24	3066	2809
16	1050	2410	2410	2409.83	2410	1892
17	1000	-3334	865	2117.44	2117	1573
18	1100	2376	2376	2375.67	2376	1851
19	1200	2868	2868	2868.24	2868	2446
20	1400	-5375	3395	3394.74	3395	3318
21	1300	-241	3921	3921.24	3921	3817
22	1100	2897	3366	3365.67	3623	3366
23	900	3297	3297	3297.09	3297	3297
24	800	2613	2613	2612.58	2613	2613
	Total profit ($)	**75093**	**103296**	**104556.23**	**105549**	**106081**

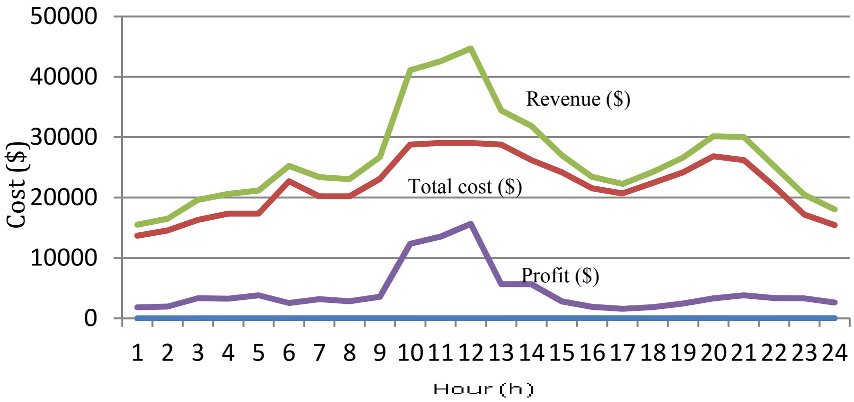

Figure 2. Revenue, Fuel cost and profit for the Ten unit 24 hour system

4.2 Test Case: 2 (Fifty Unit Test System)

In this example, the test system consists of multiple generating units such as 50 generating units. More number of generating units is considered in order to validate the feasibility of the application of PPD-ABC for large scale power system. The data for different groups of generating units are obtained by duplicating the 10 unit system data. The demand is multiplied with respect to the system size; however the generator limits, the minimum up/down time constraints remain same. Based on the forecasted market price of energy information, the proposed approach is used to generate dispatch schedule for 24 hours time period. The parameter setting of the 10 unit system is extended for the multiple test systems. The simulation results such as unit status, total cost, revenue and profit for 50 Unit 24 Hour System are given in Table – 16. From the results, it is evident that the proposed method improves the profit of the GENCOs than existing methods.

Table 16. Simulation results for 50 unit 24 hour system

Hour (hr)	Demand (MW)	Unit status	Fuel cost ($)	Revenue ($)	Profit ($)
1	3500	1111111111000000000000000 0000000000000000000000000	68420	77530	9110
2	3750	1111111111000000000000000 0000000000000000000000000	72780	82500	9720
3	4250	1111111111000000000000000 0000000000000000000000000	81510	98180	16670
4	4750	1111111111000000000000000 0000000000000000000000000	86770	103060	16290
5	5000	1111111111000000000000000 0000000000000000000000000	86770	105790	19020
6	5500	1111111111000001111100000 0000000000000000000000000	101070	119640	18570
7	5750	1111111111000001111100000 0000000000000000000000000	101070	117000	15930
8	6000	1111111111000001111100000 0000000000000000000000000	101070	115180	14110
9	6500	1111111111111111111100000 0000000000000000000000000	115530	133380	17850
10	7000	1111111111111111111111111 1111100000000000000000000	143940	205450	61510
11	7250	1111111111111111111111111 1111100000000000000000000	145240	212860	67620
12	7500	1111111111111111111111111 1111100000000000000000000	145240	223450	78210
13	7000	1111111111111111111111111 1111100000000000000000000	144010	172200	28190
14	6500	1111111111111111111111111 0000000000000000000000000	131160	159250	28090
15	6000	1111111111111111111111111 0000000000000000000000000	122060	135000	12940
16	5250	1111111111111111111111111 0000000000000000000000000	108500	117080	8580
17	5000	1111111111111111111111111 0000000000000000000000000	104040	111250	7210
18	5500	1111111111111111111111111 0000000000000000000000000	112710	121280	8570
19	6000	1111111111111111111111111 0000000000000000000000000	122020	133200	11180
20	7000	1111111111111111111111111 0000000000000000000000000	134260	150850	16590
21	6500	1111111111111111111111111 0000000000000000000000000	131220	150150	18930
22	5500	1111111111111111111100000 0000000000000000000000000	109440	126230	16790
23	4500	1111111111000000000000000 0000000000000000000000000	85890	102380	16490
24	4000	1111111111000000000000000 0000000000000000000000000	77140	90200	13060
				Total profit	**531330**

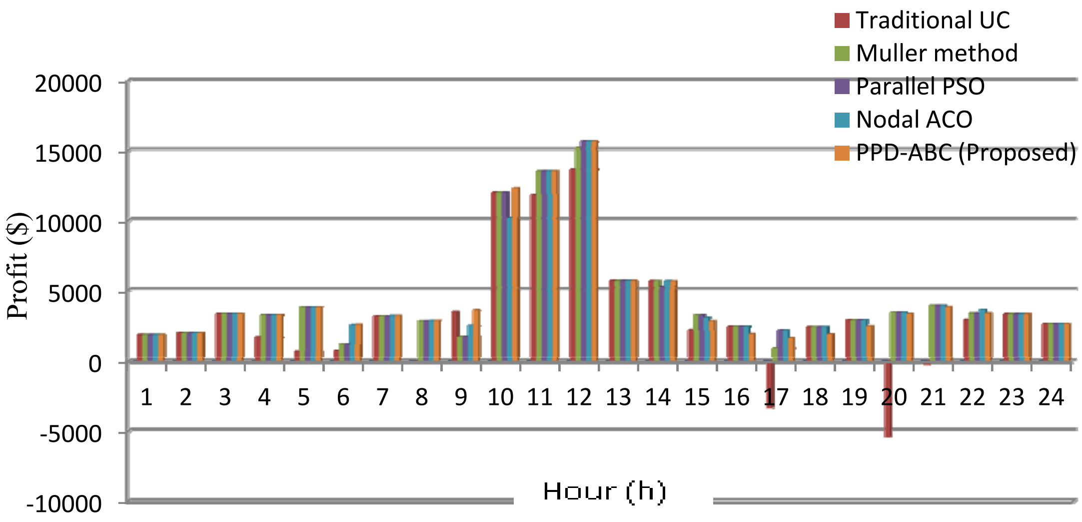

Fig-3. Comparison of profits with proposed and existing methods for ten unit 24 hour system

5. CONCLUSION

In this research work, the Profit Based Unit Commitment (PBUC) problem is described under deregulated environment. A simple and reliable approach of pre-prepared power demand (PPD) table with an Artificial Bee Colony (ABC) algorithm is proposed to solve the PBUC problem. The devised algorithm finds the most economical scheduling plan for GENCO by considering both power and reserve generation. To demonstrate the effectiveness and applicability of this method, it has been tested on ten units 24 hour and fifty units 24 hour test systems and numerical results are tabulated. Results are obtained for the optimal unit commitment schedule and MW values for real power, hourly profit and also the total profit of the GENCO. The simulation result has been compared with Traditional method, PSO, parallel PSO, nodal ACO, Muller method and hybrid methods such as TS-RP and TS-TRP. This results show that the proposed algorithm provides maximum profit with less computational time compared to existing methods. Therefore it can be concluded that the proposed PPD-ABC approach paves the best way for solving the power system optimization problems under deregulated environment.

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