Improved Pre-prepared Power Demand Table and Muller's Method to Solve the Profit Based Unit Commitment Problem

K. Chandram†, N. Subrahmanyam* and M. Sydulu**

Abstract – This paper presents the Improved Pre-prepared Power Demand (IPPD) table and Muller's method as a means of solving the Profit Based Unit Commitment (PBUC) problem. In a deregulated environment, generation companies (GENCOs) schedule their generators to maximize profits rather than to satisfy power demand. The PBUC problem is solved by the proposed approach in two stages. Initially, information concerning committed units is obtained by the IPPD table and then the subproblem of Economic Dispatch (ED) is solved using Muller's method. The proposed approach has been tested on a power system with 3 and 10 generating units. Simulation results of the proposed approach have been compared with existing methods and also with traditional unit commitment. It is observed from the simulation results that the proposed algorithm provides maximum profit with less computational time compared to existing methods.

Keywords: Profit Based Unit Commitment, Muller's method and deregulation

Nomenclature

PF	Profit of GENCOs
RV	Revenue of GENCOs
TC	Total cost of GENCOs
$F(P_{ij})$	Fuel cost function of j^{th} generating unit at i^{th} hour
X_{ij}	ON/OFF status of j^{th} generating unit at i^{th} hour
P_{ij}	Output power of j^{th} generating unit at i^{th} hour
SP_i	Spot price at i^{th} hour
ST	Start up cost
T	Number of hours
N	Number of generating units
PD_i	Power demand at i^{th} hour
R_{ij}	Reserve j^{th} generating unit at i^{th} hour
SR_i	Spinning reserve at i^{th} hour
$P_{ij}^{\min}$	Min output power of j^{th} generating unit at i^{th} hour
$P_{ij}^{\max}$	Max output power of j^{th} generating unit at i^{th} hour
T_j^{on}	Minimum time that the j^{th} unit has been continuously online
T_j^{off}	Minimum time that the j^{th} unit has been continuously offline
T_j^{up}	The minimum up time of j^{th} unit
T_j^{down}	The minimum down time of j^{th} unit

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1. Introduction

The Profit Based Unit Commitment (PBUC)[1,8] problem is one of the most important optimization problems relating to power system operation under a deregulated environment. Earlier, power generation was dominated by Vertically Integrated Electric Utilities (VIEUs) that owned most of the generation, transmission and distribution sub-systems. Recently, most Electric Power Utilities are un-bundling these sub-systems as part of the deregulation process. Deregulation requires the unbundling vertically integrated power systems into generation (GENCOs), transmission (TRANSCOs) and distribution companies (DISCOMs). The basic aim of deregulation is to create competition among generating companies and provide a choice of different generation options at a cheaper price to consumers. The main interest of GENCOs in the deregulation is the maximization of profit whereas the objective of VIEUs is to minimize the fuel cost function. This aspect leads to a change in strategies to solve existing Power System problems caused by deregulation. Since the objective of GENCOs is to maximize profits, the problem of UC needs to be rephrased as Profit Based Unit Commitment (PBUC). Generally, GENCOs place bids depending on price forecast, load forecast, unit characteristics and unit availability in different markets. Mathematically, the PBUC problem is a mixed integer and continuous nonlinear optimization problem, which is complex to solve because of its enormous dimensionality due to a nonlinear objective function and large number of constraints. The PBUC problem is divided into two subproblems: the first is the determination of status of the generating units, and the second is the determination of output powers of committed units.

Previous efforts to solve the PBUC problem were based on conventional methods such as dynamic programming and Lagrangian relaxation (LR) [3] methods. Due to the curse of dimensionality caused by increased numbers of generating units, dynamic programming takes a huge amount of computational time to obtain an optimal solution. The Lagrangian Relaxation method provides a fast solution but suffers from numerical divergence.

Recently, genetic algorithms [6] have been used to solve the PBUC problem. GA is a parallel search technique which imitates natural genetic operation. Due to its high potential for global optimization, GA has received great attention in solving UC problems. The disadvantage of the GA solution to the PBUC problem is that the final solution, being heuristic in nature, may not be satisfactory. Also, meta-heuristic techniques such as the Particle Swarm Optimization (PSO) [5] method have been used to solve the PBUC problem. It has gained much attention to solve various power system problems because it is computationally effective and easier to implement than other heuristic methods. With PSO, the solution quality depends on control parameters. Consequently, it requires more computational time to arrive at the final solution. Hybrid methods such as LR-EP [2] and TS-IRP-PSO-SQP [7] have been used to solve the PBUC problem due to their ability to solve PBUC problems more efficiently.

From the literature surveyed, it is observed that most of the existing algorithms have limitations when it comes to providing a qualitative solution. In this context, IPPD table has been introduced to solve the PBUC problem and Muller's method (root finding method) available in numerical methods is used to solve the Economic Dispatch subproblem.

The proposed approach has been implemented in MATLAB on a Pentium IV, 3 GHz personal computer with 512-MB RAM. The paper is organized in the following sections. The formulation of the PBUC problem is introduced in Section II. The description of the algorithm for solving the PBUC problem is given in Section III. Simulation results of the proposed approach for various generating units are presented in Section IV. Conclusions are given in the last section.

2. Formulation of Profit Based Unit Commitment Problem

The problem with PBUC deregulation is one of optimization, the main objective of which is the allocation of generating units so as to maximize profits for generating companies. This problem is solved based on forecasted price and power demand. It can be mathematically formulated by the following equations:

2.1 The objective function is maximization of profit for generating companies.

$$Max \quad PF = RV - TC \tag{1}$$

$$RV = \sum_{i=1}^{T}\sum_{j=1}^{N} P_{ij} SP_i X_{ij} \tag{2}$$

$$TC = \sum_{i=1}^{T}\sum_{j=1}^{N} F(P_{ij}) X_{ij} + ST.X_{ij} \tag{3}$$

2.2 Constraints The objective function is subjected to the following constraints:

2.2.1 Power demand constraint In the PBUC problem, it is not necessary to allocate generating units to meet power demand. Therefore, the power balance constraint is modified as a power demand constraint. Here, the sum of output powers of allocated generating units is always less than the forecasted power demand.

$$\sum_{j=1}^{N} P_{ij} X_{ij} \le PD_i; \; \mathrm{i} = 1,2,\ldots,\mathrm{T} \tag{4}$$

2.2.2 Reserve constraint

$$\sum_{j=1}^{N} R_{ij} X_{ij} \le SR_i; \; \mathrm{i} = 1,2,\ldots,\mathrm{T} \tag{5}$$

2.2.3 Real power operating limit

$$P_{ij}^{\min} \le P_{ij} \le P_{ij}^{\max}; \; \mathrm{i} = 1,2,\ldots,\mathrm{T} \tag{6}$$

2.2.4 Minimum up/down time constraint

$$T_j^{on} \ge T_j^{up} \tag{7}$$

$$T_j^{off} \ge T_j^{down} \tag{8}$$

3. Solution methodology

Solution of the PBUC problem is decomposed into the following steps:

3.1 Solution of the Profit Based Unit Commitment Problem

The PBUC problem involves an on and off decision for units depending on variations in power demand. In this paper, a simple approach has been proposed.

3.1.1 Formation of the IPPD table

The procedure to form the IPPD table is given below.

Step-1 Determine minimum and maximum values of λ for all generating units at their $P_{i,min}$ and $P_{i,max}$. for each units two λ values are possible. Then arrange these λ values in ascending order and index them as λ_j (where $j = 1,2,....2N$)

Step-2 Evaluate output powers ($p_{ji} = \frac{\lambda_j - b_i}{2c_i}$) for all generators at each λ_j value.
Incorporate $P_{i,min}$ and $P_{i,max}$ as below.

(i) Setting of the minimum output power limit

$$\text{if } \lambda_j < \lambda_{i,\min} \quad \text{then set} \quad p_{j,i} = 0 \tag{9}$$

$$\text{if } \lambda_j = \lambda_{i,\min} \text{ then set } p_{j,i} = p_{i,\min} \tag{10}$$

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$$\text{if } \lambda_j < \lambda_{i,\min} \text{ then set } p_{j,i} = p_{i,\min} \tag{11}$$

(ii) Setting of the maximum output power limit

$$\text{if } \lambda_j \geq \lambda_{i,\max} \text{ then set } p_{j,i} = p_{i,\max} \tag{12}$$

Step-3 λ values, output powers and sum of output powers (SOP) at each λ are arranged in the table in ascending order of λ values. This table is known as the Improved Pre-prepared Power Demand (IPPD) table.

Here, a typical 3 unit system is considered. The fuel cost data is given below.

U	a_i (\$)	b_i (\$/MW)	c_i (\$/MW^2)	$P_{i\min}$ (MW)	$P_{i\max}$ (MW)
1	500	10	0.0020	100	600
2	300	08	0.0025	100	400
3	100	06	0.0050	050	200

For this system, the lambda values at $P_{i,min}$ and $P_{i,max}$ are given below.

	Lambda values		
	Unit 1	Unit 2	Unit 3
At $P_{i,min}$	10.4	8.5	6.5
At $P_{i,max}$	12.4	10	8

The Improved Pre-prepared Power Demand table is given below.

S.no	Lambda (\$/MW)	P1 (MW)	P2 (MW)	P3 (MW)	SOP (MW)
1	6.5	0	0	50	50
2	8	0	0	200	200
3	8.5	0	100	200	300
4	10	0	400	200	600
5	10.4	100	400	200	700
6	12.4	600	400	200	1200

The structure of the IPPD table is as follows:

- Entries of Column-1 of the IPPD table are evaluated λ values arranged in ascending order.
- Entries of Column-2 to Column- N+1 are output powers of each generating unit '*I*' subject to constraints on λ given in eqn. (9)-(12).
- The last column of the IPPD table consists of the sum of the output powers (SOP) of the generating units at each of the evaluated λ values.

Here, λ values are evaluated at $P_{i,min}$ and $P_{i,max}$. Thus, for '*N*' units system, $2N$ lambda values are available. The IPPD table has $2N$ rows and $N+2$ columns for a system with N generating units.

Assume that a selected power demand plus spinning reserve lies between $SOP_{j-1,N+2}$ and $SOP_{j,N+2}$. Then j-1th and j^{th} rows from the IPPD table are selected and form a new table. This new table is called the Reduced IPPD (RIPPD) table.

Assume that the power demand is 170 MW. The power demand is in between the 1st and 2nd rows. The RIPPD table for a 3 unit system is given below.

S.no	Lambda (\$/MW)	P1 (MW)	P2 (MW)	P3 (MW)	SOP (MW)
1	6.5	0	0	50	50
2	8	0	0	200	200

It may be noted that the RIPPD table gives information about the status of the units at selected λ values and also the transition of commitment of units at one λ to other λ in the table. The Unit Commitment schedule for a time horizon having t intervals will be evaluated from the IPPD table (as explained in procedure below) for the given power demand in each time interval.

The IPPD table acts as an effective data structure for locating the RIPPD table, which is very important for solving the UC problem.

Salient features of the IPPD table are listed below.

1. The generating unit with the least lambda value is in the first row of the IPPD table. Minimum output power of the first generating unit is available and the output powers of the remaining units are zero in the first row. Therefore, the available output power is the minimum output power of that generating unit with the least lambda.

2. From the second row onwards, generating units are added in the IPPD table based on the ascending order of the lambda values of the generating units.
3. On or off states of the generating units are available in the IPPD table up to the addition of the last generating unit.

3.1.2 Formation of the RIPPD table

Profit is obtained only when the forecasted price at the given hour is greater than the incremental fuel cost of the given unit. Therefore, the forecasted price is taken as the main index to select the Reduced IPPD (RIPPD) table from the IPPD table.

There are two options to select the RIPPD table from the IPPD table.

Option 1: At the predicted forecasted price, two rows from the IPPD table are selected such that the predicted forecast price lies within the lambda limits. Assume here that the corresponding rows are m and $m+1$.

Option 2: At the predicted power demand, two rows from the IPPD table are selected such that the predicted power demand lies within the Sum of Powers (SOP) limits. Assume here that the corresponding rows are n and $n+1$.

Therefore, the Reduced IPPD table is as follows:

(i) If $m<n$, then the RIPPD table is selected based on option 1. Here, the power demand is modified as the SOP of $m+1$ row. In the PBUC problem, the power demand constraint is relaxed and it is not necessary to operate the generating units so as to meet power demand.

(ii) If $m>n$, then the RIPPD table is selected as option 2.

Once the RIPPD table is identified, the information about the Reduced Committed Units (RCU) table is generated by simply assigning +1 if the output power of the unit 'i' $p_i \neq 0$ and 0 if $p_i = 0$. The RCU table will have binary elements indicating the status of all units.

Now, "incorporation of no-load cost", "decommitment of units" and "Inclusion of minimum up time and minimum down time constraints" in the PBUC problem need to be addressed.

3.1.3 Incorporation of no load cost

Formulation of the IPPD table is based on incremental fuel costs (λ). Therefore, a no-load cost is not considered in the IPPD table. In the fuel cost data, some generating units may have huge no-load costs and less incremental fuel costs. Hence, incorporation of a no-load cost is needed to reduce the total fuel cost.

The Priority List may not exactly reflect the actual status of the operation cost of medium load units because these units may operate at a lower output power than their maximum output power. This aspect may lead to a higher operational cost for medium units. In this context, a new approach is proposed to incorporate the no-load cost in this paper and is given below.

Step 1: Calculate the cost per MW at its average output-power between minimum and maximum output power limits. The cost per MW is taken as $Cost_{Index,i}$.

$$Cost_{Index,i} = \frac{F_i(P_{average,i})}{P_{average,i}}$$

where $P_{average,i} = \dfrac{P_{i,\min} + P_{i,\max}}{2}$

This index exactly reflects the status of the operational cost of medium units at lower output power than the maximum output power.

Step 2: Arrange all units in ascending order of the $Cost_{Index,i}$

Step 3: Modify the initial commitment and input data of the units according to the ascending order of the $Cost_{Index,i}$..

Step 4: Last on-state unit at each hour is identified. Status of the units is changed as follows: If any unit on the left side of the last on-state unit is in an off state, then it is converted as an on- state unit. The Complete mechanism of incorporating the No-load cost is shown in Fig 5.2.

Initial Unit Commitment

Unit	1	0	0	1
$Cost_{Index,i}$	3	4	2	1

After arranging the units in ascending order based on $Cost_{Index,i}$

Unit	1	0	1	0
$Cost_{Index,i}$	1	2	3	4

Unit Commitment after incorporating the No-load Cost

Unit	1	**1**	1	0
$Cost_{Index,i}$	1	2	3	4

Fig. 1. Complete mechanism of incorporating the No-load cost

3.1.4 Decommitment of units

The committed units may have excess spinning reserves due to a greater gap between the selected lambda values in the RIPPD table. Therefore, decommitment of units is necessary for getting more economical benefits.

When there is an excessive spinning reserve in hour't', the following steps are used to De-commit the units.

Step-1 Identify the committed units.

Step-2 De-commit the last 'ON' state unit in the Unit Commitment after incorporating the No-load Cost and check the spinning reserve. If the spinning reserve constraint is satisfied after decommitment of the unit, then decommit that unit.

Step 2 Repeated Step-2 and de-commit possible units without violating the spinning reserve constraint.

3.1.5 Inclusion of Minimum up time and minimum down time constraints

Minimum up and minimum down time constraints can be satisfied by adjusting the unit status as below.

a) Minimum Up time constraint If the on time of the unit is less than its' up time, then that unit will be on. Assume that the minimum up time of the unit is 3 hours. Fig 5.3 depicts the procedure to incorporate the minimum up time constraint.

Unit Commitment without incorporating Minimum up time

Hour			t-1	t	t+1	
Unit	0	1	1	0	0	0

⇩

Unit Commitment after incorporating Minimum up time

Hour			t-1	t	t+1	
Unit	0	1	1	1	0	0

Fig. 2. Procedure to incorporate the minimum up time constraint

b) Minimum Down time constraint If the off time of the unit is less than the minimum down time, then the status of that unit will be off in the committed unit table. Fig 5.4 provides the procedure to incorporate the Minimum up time constraint.

Unit Commitment without incorporate Minimum down time

Hour			t-1	t	t+1	
Unit	1	1	0	0	1	1

⇩

Unit Commitment after incorporate Minimum down time

Hour			t-1	t	t+1	
Unit	1	1	1	1	1	1

Fig. 3. Procedure to incorporate the Minimum up time constraint

The procedure to incorporate the minimum up time and minimum down time is obtained from [11].

3.2 Muller's method for Economic Dispatch subproblems

After getting the information of committed units at predicted power demands, the Economic Dispatch (ED) procedure is used to obtain the output powers of online units. Here, Muller's method is proposed to solve the ED subproblem.

Muller's method [9, 10] is a root finding algorithm for solving equations of the form of f(x) =0 where f(x) is a non linear function of x. It was presented by D.E. Muller in 1956 and is based on the secant method and used to find the root of the f(x) =0 when no information about the derivative exists. In this method, three points are used to find an interpolating quadratic polynomial. A parabola is constructed passing though these three points and then the quadratic formula is used to find a root of the quadratic for the next approximation.

In Muller's method, a higher order polynomial is approximated by a quadratic curve in the vicinity of a root. The roots of the quadratic equation are then assumed to be approximately equal to be the roots of the equation f(x)=0. This method is iterative and converges almost quadratically. It has been proven that near a simple root Muller's method converges faster than the secant and Newton methods. The graphical representation of Muller's method is shown in Fig.4.

Let x_{i-2}, x_{i-1}, x_i are three distinct approximations to a root of $f(x) = 0$ and y_{i-2}, y_{i-1} *and* y_i are the corresponding values of $y = f(x)$. The relation between y and x can be represented by

$$y = A(x - x_i)^2 + B(x - x_i) + y_i$$

Where

$$A = \frac{(x_{i-2} - x_{i-1})(y_{i-1} - y_i) - (x_{i-1} - x_i)(y_{i-2} - y_i)}{(x_{i-1} - x_{i-2})(x_{i-1} - x_i)(x_{i-2} - x_i)} \quad (13)$$

$$B = \frac{(x_{i-2} - x_i)^2 (y_{i-1} - y_i) - (x_{i-1} - x_i)^2 (y_{i-2} - y_i)}{(x_{i-1} - x_{i-2})(x_{i-1} - x_i)(x_{i-2} - x_i)} \quad (14)$$

$$x_{i-1}^{(1)} = x_{i-1}^{(0)} - \frac{2 \cdot y_i}{B \pm \sqrt{B^2 - 4Ay_i}} \quad (15)$$

The sign in the denominator should be chosen properly so as to make the denominator largest in magnitude. With this choice, equation (15) gives the next approximation to the root.

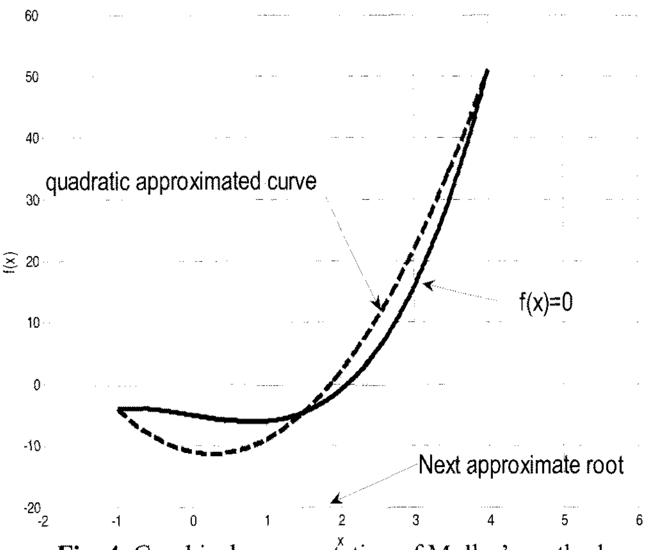

Fig. 4. Graphical representation of Muller's method

The values of $x_{k-2}, x_k, f(x_{k-2})$ and $f(x_k)$ are selected as follows

$$x_{k-2} = \lambda_{\min} \; \& \; f(x_{k-2}) = \sum_{i=1}^{ng} P_i(\lambda_{\min}) - P_D \qquad (16)$$

$$x_k = \lambda_{\max} \; \& \; f(x_k) = \sum_{i=1}^{ng} P_i(\lambda_{\max}) - P_D \qquad (17)$$

$$x_{i-1} = (x_{i-2} + x_i)/2$$

From (15), the optimal lambda is evaluated by an iterative approach.

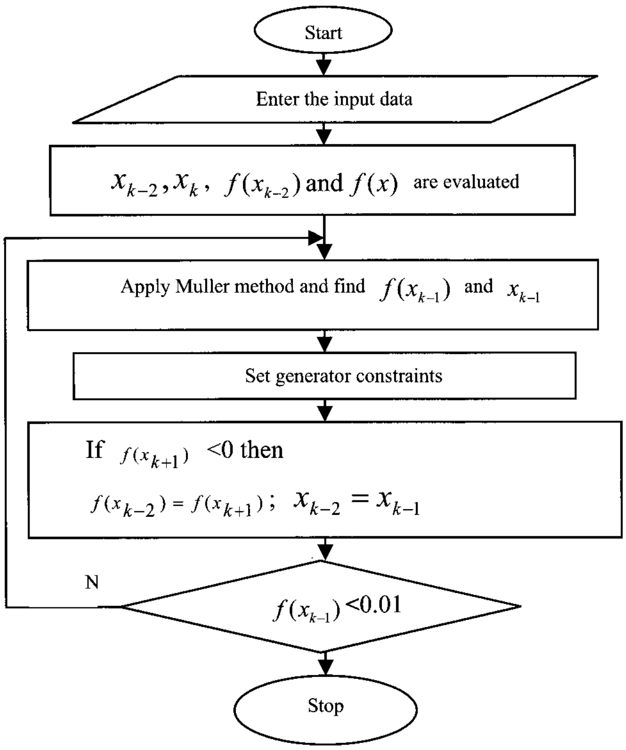

Fig. 5. Flow chart of Muller's method for solving ED problem

Flow chart of Muller's method for solving ED problems is shown in Fig 5

The following steps are involved to solve the PBUC problem by the proposed approach.

Step I IPPD table is formulated

Step II The forecasted power demand and forecasted price are read

Step III Formation of RIPPD table

Step IV Commitment of units

Step V Minimum up and down times are set

Step VI The ED subproblem is then solved by Muller's method

4. Test Cases and Simulation Results

The proposed approach has been implemented in MATLAB and executed on a Pentium IV (3 GHz) personal computer with 512MB RAM. The proposed method has been tested on 3 and 10 generating units to solve profit based unit commitment problems. Simulation results of the proposed algorithm were compared in terms of profit with traditional unit commitment methods and heuristic methods such as aTS-IRP algorithm.

Example 1 In this example, a 3 generating unit system is considered. The fuel cost data of this 3 unit system was obtained from [2] and given in Table 1.

Table 1. Fuel cost data of a 3 Unit System

S.no	a_i ($)	b_i ($/MW)	c_i ($/MW^2)	$P_{i\min}$ (MW)	$P_{i\max}$ (MW)
1	500	10	0.002	100	600
2	300	8	0.0025	100	400
3	100	6	0.005	50	200

Min up time (hr)	Min down time (hr)	Start up cost ($)	Initial status
3	3	450	-3
3	3	400	3
3	3	300	3

The information of forecasted power demands and prices is given in Table 2.

Table 2. Forecasted power demand and forecasted price for a 3 unit system

H	PD(MW)	Price($/MW)	H	PD(MW)	Price($/MW)
1	170	10.55	7	1100	11.3
2	250	10.35	8	800	10.65
3	400	9	9	650	10.35
4	520	9.45	10	330	11.2
5	700	10	11	400	10.75
6	1050	11.25	12	550	10.6

In this example, lambda values are initially calculated at their minimum and maximum output powers of the generating units, then lambda values at minimum output powers of the units are arranged in ascending order and finally the fuel cost functions of generating units are rearranged based on the ascending order of the lambda values at minimum output powers. All lambda values, the output powers are evaluated and the IPPD table is formulated and given in Table 3 for Example 1. The dimension of the IPPD table is 6×5.

Table 3. IPPD Table for a 3 unit system

S.no	Lambda ($/MW)	P1(MW)	P2(MW)	P3(MW)	SOP (MW)
1	6.5	0	0	50	50
2	8	0	0	200	200
3	8.5	0	100	200	300
4	10	0	400	200	600
5	10.4	100	400	200	700
6	12.4	600	400	200	1200

For this example, the priority order is given in Table 4 based on the lambda values at the minimum output power of the unit.

Table 4. Priority list based on lambda values at the minimum output power of units

Unit	Lambda ($/MW)	Priority order
1	10.4	3
2	8.5	2
3	6.5	1

The RIPPD table based on the predicted forecasted price is given in Table 5. Similarly, the RIPPD table based on the predicted power demand is given in Table 6.

Table 5. RIPPD Table based on the forecasted price for a 3 unit system

S.no	Lambda ($/MW)	P1 (MW)	P2 (MW)	P3 (MW)	SOP (MW)
5	10.4	100	400	200	700
6	12.4	600	400	200	1200

Table 6. RIPPD Table based on forecasted power demand for a 3 unit system

S.no	Lambda ($/MW)	P1 (MW)	P2 (MW)	P3 (MW)	SOP (MW)
1	6.5	0	0	50	50
2	8	0	0	200	200

Here, m=5 and n=1. Therefore, Table 6 can be considered as the final RIPPD table. The second row of the RIPPD gives the information of committed units. The RCU table is obtained from the RIPPD table by substituting binary values such as way that if the output power is none zero then it will be replaced as 1. The second row from the RCU table is selected as the committed units at the given power demand.

The final solution for all predicted power demands are given in Table 7.

Table 7. Simulation results of PBUC by the proposed method for a 3 unit system

Hr	P1 (MW)	P2 (MW)	P3 (MW)	RV ($)	FC ($)	Profit ($)
1	0	0	170	1793.5	1264.5	529
2	0	0	200	2070	1500	570
3	0	0	200	1800	1500	300
4	0	0	200	1890	1500	390
5	0	400	200	6000	5400	200
6	0	400	200	6750	5400	1350
7	0	400	200	6780	5400	1380
8	0	400	200	6390	5400	990
9	0	400	200	6210	5400	810
10	0	130	200	3696	2882.3	813.75
11	0	200	200	4300	3500	800
12	0	350	200	5830	4906.3	923.75
		Total Profit($)				9056.49
		Computational time (Sec)				0.078

Dispatched power demands and forecasted power demands are given in Fig 6.

The profits obtained by PBUC are compared with Traditional UC and shown in Fig.7.

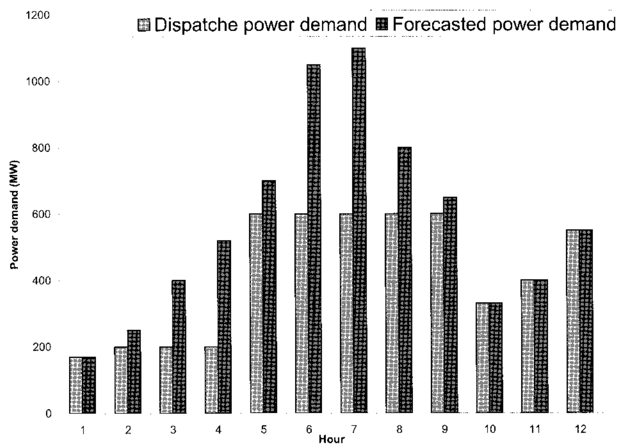

Fig. 6. Dispatched power demands and forecasted power demands

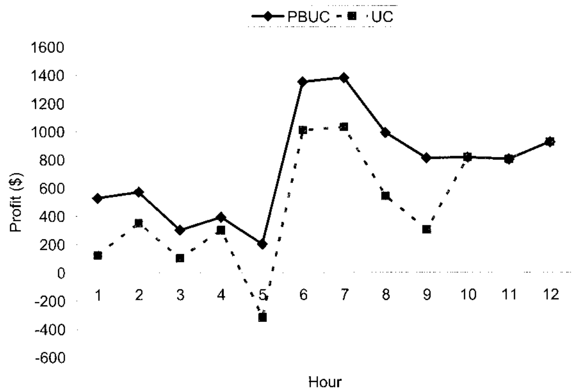

Fig. 7. comparison of profits by Traditional UC and PBUC

From Fig.7, it is clear that the PBUC provides more profit compared to Traditional UC.

Example 2 In this example, a 10 unit system is considered and the fuel cost data of this system is given in Table 7. The fuel cost data, power demands and forecasted prices were obtained from [2] and given in Table 8. In this example, the simulation result in terms of profit is compared with existing methods such as Tabu Search-Random Perturbation (TS-RP) and Tabu Search- Improved Random Perturbation (TS-IRP) available in [7].

Table 8. Power demand and Forecasted price for a 10 unit system

H	PD(MW)	Price($/MW)	H	PD(MW)	Price($/MW)
1	700	22.15	13	1400	24.6
2	750	22	14	1300	24.5
3	850	23.1	15	1200	22.5
4	950	22.65	16	1050	22.3
5	1000	23.25	17	1000	22.25
6	1100	22.95	18	1100	22.05
7	1150	22.5	19	1200	22.2
8	1200	22.15	20	1400	22.65
9	1300	22.8	21	1300	23.1
10	1400	29.35	22	1100	22.95
11	1450	30.15	23	900	22.75
12	1500	31.65	24	800	22.55

The output powers obtained from the proposed approach are shown in Table 9.

Table 9. Output powers of the PBUC by the proposed method for a 10 units system

H	Units									
	1	2	3	4	5	6	7	8	9	10
1	455	245	0	0	0	0	0	0	0	0
2	455	295	0	0	0	0	0	0	0	0
3	455	395	0	0	0	0	0	0	0	0
4	455	455	0	0	40	0	0	0	0	0
5	455	455	0	0	90	0	0	0	0	0
6	455	455	0	130	60	0	0	0	0	0
7	455	455	0	130	110	0	0	0	0	0
8	455	455	130	130	30	0	0	0	0	0
9	455	455	130	130	130	0	0	0	0	0
10	455	455	130	130	162	68	0	0	0	0
11	455	455	130	130	162	80	0	0	0	0
12	455	455	130	130	162	80	0	0	0	0
13	455	455	130	130	162	68	0	0	0	0
14	455	455	130	130	130	0	0	0	0	0
15	455	455	130	130	0	0	0	0	0	0
16	455	335	130	130	0	0	0	0	0	0
17	455	285	130	130	0	0	0	0	0	0
18	455	385	130	130	0	0	0	0	0	0
19	455	455	130	130	0	0	0	0	0	0
20	455	455	130	130	0	0	0	0	0	0
21	455	455	130	130	0	0	0	0	0	0
22	455	455	0	130	0	0	0	0	0	0
23	455	445	0	0	0	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

The simulation results of the proposed method and the existing method are given in Table 10.

Table 10. Comparison of the results by TS-RP,TS-IRP and the proposed method

S.no	Method	Profit
1	TS-RP [7]	101086
2	TS-IRP [7]	103261
3	Proposed method	105164

From Table 10, it is clear that the proposed method provides maximum profits compared to existing methods. Also, the computational time of the proposed method is much less because the proposed approach is a conventional approach (the combinatorial subproblem is solved by the IPPD table and ED subproblem is solved by Muller's method).

5. Conclusion

The Improved Pre-prepared Power Demand table and Muller's method have been proposed in this paper to solve Profit Based Unit Commitment (PBUC). While solving the PBUC problem, information regarding the forecasted price is known. The PBUC problem is solved in two stages in the proposed approach. Initially, information regarding the committed units is obtained by a simple approach and finally Muller's method is used to find the non-linear programming subproblem of Economic Dispatch. Simulation results for the proposed method have been compared with existing methods and also with traditional unit commitment. It is observed from the simulation results that the proposed algorithm provides maximum profit with less computational time compared to existing methods and is thus amenable for the real-time operation required in a deregulated environment.

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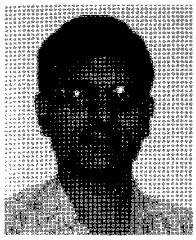

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