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Profit based unit commitment using IPPDT and genetic algorithm

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ABSTRAC - The proposes a new methodology for solve the Profit Based Unit Commitment (PBUC) problem. The UC problem is solving to Improved Pre-prepared Power Demand (IPPD) table. In a deregulated environment, generation companies (GENCOs) schedule their generators to maximize profits rather than to satisfy power demand The proposed approach has been tested on 3- and 10 units for a scheduling horizon of 24 Comparison of results of the proposed method with the results of previous published methods shows that the proposed approach provides better qualitative solution with less computational time.

KEYWORDS -Profit Based Unit Commitment (PBUC), Improved Pre-prepared Power Demand table (IPPD)

NOMENCLATURE

PF Profit of GENCOs
RV Revenue of GENCOs
TC Total cost of GENC
$F(P_{ij})$ 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
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
a_i, b_i, c_i Coefficients of fuel cost of unit 'i'
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} Minimum up time that the j^{th} unit
T_j^{down} Minimum down time that the j^{th} unit

I. INTRODUCTION

The Profit Based Unit Commitment (PBUC) problem is one of the most important optimization problems to relating power system operation under deregulated environment. Earlier, the power generation was dominated by vertically integrated electric utilities (VIEU) that owned most of the generation, transmission and distribution sub-systems. Recently,

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the electric power utilities are un-bundling these sub-systems as part of deregulation process. Deregulation requires to unbundling of vertically integrated power system into generation (GENCOs), transmission (TRANSCOs) and distribution companies (DISCOMs). The main aim of deregulation is to create competition among generating companies and provide choice of different generation options at cheaper price to consumers. The main interest of GENCOs in the deregulation is maximization of their profit whereas in the VIEUs, the objective is to minimize the fuel cost function. This aspect leads to a change in strategies to solve existing power system problem caused under deregulation. Since the objective of GENCOs to maximization of their profit, the problem of UC needs to be termed differently as Profit Based Unit Commitment (PBUC). Generally, the GENCOs place bids depending on the 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 sub- problems. 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.

The previous efforts for solving PBUC problem were based on conventional methods such as dynamic programming and Lagrangian relaxation(LR) [3] methods. Due to the curse of dimensionality with increase in number of generating units, dynamic programming takes large amount of computational time to obtain an optimal solution. The Lagrangian Relaxation method provides fast solution but suffers from numerical convergence.

It is observed from the literature survey that most of the existing algorithms have some limitations to provide qualitative solution within considerable computational time. Therefore it is necessary to find a simple and efficient method for solving unit commitment problem independent of dimensionality and selection of solution specific parameters. In this context a table called improved prepared power demand table (IPPD) is prepared using the available information of system generation limits and coefficients of fuel cost function(s).

The proposed algorithm was implemented in MATLAB (7 Version). 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.

II. PROFIT BASED UNIT COMMITMENT PROBLEM FORMULATION

The profit-based UC problem under competitive environment is an optimization problem and can be formulated mathematically by the following equations:

a) The Objective function is maximization of profit for generating companies.

$$\text{Max PF} = \text{RV} - \text{TC} \quad (1)$$

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

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

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b) Constraints

The UC problem is subjected to equality and inequality constraints such as power balance equation, reserve constraint, limits of units, and the other constraints including the thermal constraints.

c) Power balance equation

The sum of the output powers of on line generators is equal to the forecasted system power demand in each period of time.

$$\sum_{j=1}^{N} P_{ij} X_{ij} \leq PD_i \quad i=1,2\ldots\ldots T \qquad (4)$$

d) Reserve constraint

$$\sum_{j=1}^{N} R_{ij} X_{ij} \leq SR_i \quad i=1,2,\ldots..T \qquad (5)$$

e) Limits of output powers of units

$$P^{min} \leq P \leq P^{max} \; ; \; i = 1,2,\ldots,T \qquad (6)$$

f) Minimum up/down time constraint:

Minimum up and minimum down time constraints are incorporated in the unit commitment problems as follows.

$$T_j^{on} \geq T_j^{up} \qquad (7)$$

$$T_j^{off} \geq T_j^{down} \qquad (8)$$

III. SOLUTION METHODOLOGY FOR UC

A. Solution of the UC problem is obtained in the following steps:

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.

i. 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 *,min* and *Pi max*. for each units two λ values are possible. Then arrange these λ values in ascending order and index them as λ (where $j = 1,2,\ldots.2N$) (9)

Step-2 Evaluate output powers $p_{ji} = \dfrac{(\lambda_j - b_i)}{2c_i}$

for all generators at each λ*j* value. Incorporate Pi,min and *P i max* as below.

a. Setting of the minimum output power limit

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$$\text{if } \lambda_j < \lambda_{i,\min} \text{ then } p_{j,i} = 0 \quad (10)$$

$$\text{if } \lambda_j < \lambda_{i,\min} \text{ then } p_{j,i} = \text{Pij} \quad (11)$$

But, for must run generators

$$\text{if } \lambda_j < \lambda_{i,\min} \text{ then set } p_{j,i} = p_{i,\min} \quad (12)$$

b. Setting of the maximum output power limit

$$\text{if } \lambda_j \geq \lambda_j \ max \text{ then set } p_{j,i} = p_i \max \quad (13)$$

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 Preprepared Power Demand (IPPD) table.

ii *The structure of IPPD table is as follows:*

a. Entries of Column-1 of IPPD table are evaluated λ values arranged in ascending order.
b. 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 IPPD table consists of sum of output powers (SOP) of the generating units at each of the evaluated λ value.

Here, λ values are evaluated at minimum and maximum output powers. For 'N' units system, 2N lambda values are calculated. Thus the IPPD table has 2N rows and N+2 columns for a system with N generating units. Assume that the power demand plus spinning reserve lies between $SOP_{j-1, N+2}$ and $SOP_{j, N+2}$ Therefore j-1th and j^{th} rows from the IPPD table are selected and form a new table. This table is called Reduced IPPD (RIPPD) table.

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

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 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.

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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 option2.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", "recommitment of units" and "Inclusion of minimum up time and minimum down time constraints" in the PBUC problem need to be addressed.

B. Incorporation Of No Load Cost

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

Step1 production cost of the units at average of minimum output power and maximum output power is evaluated for all units.

Step 2 all units are arranged in ascending order of the production cost.

Step 3 status of the units is also modified according to the ascending order of the production cost.

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 off state then it is converted as on- state unit.

C. De-commitment Of Units

The committed units may have excess spinning re- serves due to a greater gap between the selected lambda values in the RIPPD table. Therefore, de-commitment of units is necessary for getting more economical benefits.following steps are used to de-commit the units.

Step-1 Identify the committed units.

Step-2 Last unit in the above order is de-committed and spinning reserve is checked. If reserve constraint is satisfied after de-commit the unit, that unit is de-committed.

Step-3 Step -2 is repeated and possible units are de-committed without violating the reserve constraint.

Inclusion of Minimum up time and minimum down time constraints If the off time of the unit is less than the minimum down time, then status of that unit will be off. If on time of the unit is less than the up time of the unit, then that unit will be on.

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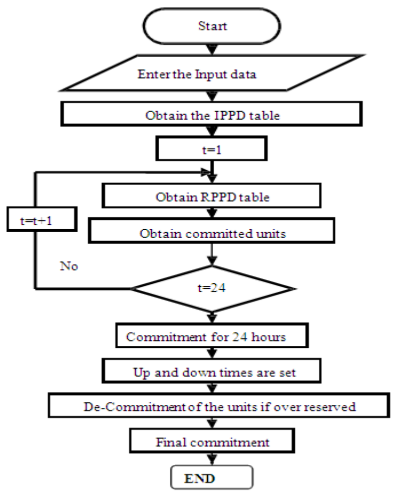

Flow chart of the proposed algorithm for solving UC problem

IV TEST CASES AND SIMULATION RESULT

The proposed approach has been implemented in MATLAB and executed .The proposed has been tested on 3 to 10 generating unit solve profit based unit commitment problems.

Example 1 In this example, a 3generating unit system is considered. The fuel cost data of this 3unit system was obtained from given TABLE 1.

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

In this example, lambda values are computed for all units at their minimum and maximum output powers and arranged in ascending order. For all lambda values, the output powers are evaluated and IPPD is formulated.

TABLE 2. IPPD TABLE FOR 3- UNITS 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

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TABLE 3. RIPPD TABLE AT 170 MW FOR 3 UNITS 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

TABLE 4.SIMULATION RESULT OF PBUC BY THE PROPOSED METHOD FOR A 3 UNIT SYSTEM

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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

TABLE 6. OUTPUT POWERS OF THE PBUC BY THE PROPOSED METHOD FOR A 10 UNITS SYSTEM.

Unit /hr	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
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	40	0	0	0	0	0	0

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5	455	455	0	90	0	0	0	0	0	0
6	455	455	112.5	77.5	0	0	0	0	0	0
7	455	455	112.5	127.5	0	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	168	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	80	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	385	130	130	0	0	0	0	0	0
23	455	455	0	0	0	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

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CONCLUSION

The Improved Pre-prepared Power Demand table has been proposed in this paper to solve Profit Based Unit Commitment (PBUC). While solving the PBUC problem. While solving the PBUC problem, information regarding the forecasted price is known. 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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