Electrical Power and Energy Systems 44 (2013) 880–888

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Profit based unit commitment and economic dispatch of IPPs with new technique

H. Tehzeeb-ul-Hassan [a], Ayaz Ahmad [b,*]

[a] Department of Electrical Engineering, University of Engineering and Technology, Lahore, Pakistan
[b] National Transmission and Despatch Company Limited, Muzaffargarh, Pakistan

ARTICLE INFO

Article history:
Received 7 April 2012
Received in revised form 21 July 2012
Accepted 19 August 2012
Available online 26 September 2012

Keywords:
Unit commitment
Economic dispatch
Profit based unit commitment
Competitive power market

ABSTRACT

Each generation company may have number of generating units of different fuel consumption characteristics, some generating units consume more fuel as compared to other units this directly effects the production cost and profit of the company. Production cost and profit of the company is also affected by unit commitment and economic dispatch. Each and every power generation company wants to maximize/increase profit, same is the case for independent power producers (IPPs). Profit can be maximized by changing the unit commitment and economic dispatch strategy. Previously it was achieved in such a way that production cost goes to minimum level. But as the competition in power market is going to increase day by day IPPs trend of UC solution is toward achieving maximum profit. Previously achieved solution by LR–PBUC is slow and may face convergence problem. In this paper, we will see the way how a GENCO or IPP can earn more by UC on the base of profit, with minimum computational time and always with some final solution. Hamiltonian method has been used for ED. To demonstrate the effectiveness of the PBUC achieved and Hamiltonian economic dispatch, it will be tested on two test cases. Profit and computational time comparison of proposed technique with already available/techniques for evaluation of performance are also presented.

1. Introduction

With the advent of restructured system it is possible for power generation companies and independent power producers (IPPs) to consider such a scheme/schedule in which they supply the amount of power that is near to the predicted load demand and spinning reserve [1]. The objective of the generation companies and IPPs is to generate and sale the energy with maximum profit to survive in the competitive environment [2,3]. This leads us to develop and implement those techniques of committing the units that are based on maximizing the profit instead of minimizing the production cost as the case was in previous years [4]. This technique is known as profit based unit commitment (PBUC). It increases the profit of company; as a result Power Company can compete in a better way.

2. Profit based unit commitment

With the idea of PBUC, unit commitment problem (UCP) defined in a new way and with modified constraints because now our target is to maximize profit instead of minimizing production cost. Different techniques were proposed by researchers for PBUC. A hybrid method of Lagrange Relaxation (LR) and Evolutionary Programming (EP) has been used by Pathom Attaviriyanupap for profit based unit commitment in competitive power market environment [5]. Yuan and Yuan implemented the Particle Swarm Optimization (PSO) technique for profit based UC under deregulated electricity market [6]. Chandram and Subrahmanyam introduced new approach with Muller method for PBUC with small execution time [7]. For generating units having nonlinear cost function Mori and Okawa proposed the new hybrid Meta-heuristic technique for profit based unit commitment [8]. Amudha and Christober Asir Rajan presented effect of reserve in PBUC using Worst Fit Algorithm [9].

According to the above discussion in PBUC, our objective is to maximize Power Company's profit. So:

$$\text{Max. profit} = \text{Revenue} - \text{Total production cost} \tag{2.1}$$

Modified and unchanged constraints in achieving above objective for IPPs according to the new scenario can be defined as:

(i) Demand constraints

$$\sum_{i=1}^{N} A_{it} \cdot B_{it} \leqslant C_t, \quad t = 1, 2, 3, 4, \ldots, T \tag{2.2}$$

(ii) Reserve constraints are

$$\sum_{i=1}^{N} D_{it} \cdot B_{it} \leqslant SRt, \quad t = 1, 2, 3, 4, \ldots, T \tag{2.3}$$

---

* Corresponding author. Tel.: +92 312 4971533/3334971533/662512220; fax: +92 4299250202.

E-mail addresses: tehzibulhasan@gmail.com (H. Tehzeeb-ul-Hassan), hello_ayaz@yahoo.com (A. Ahmad).

0142-0615/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2012.08.039

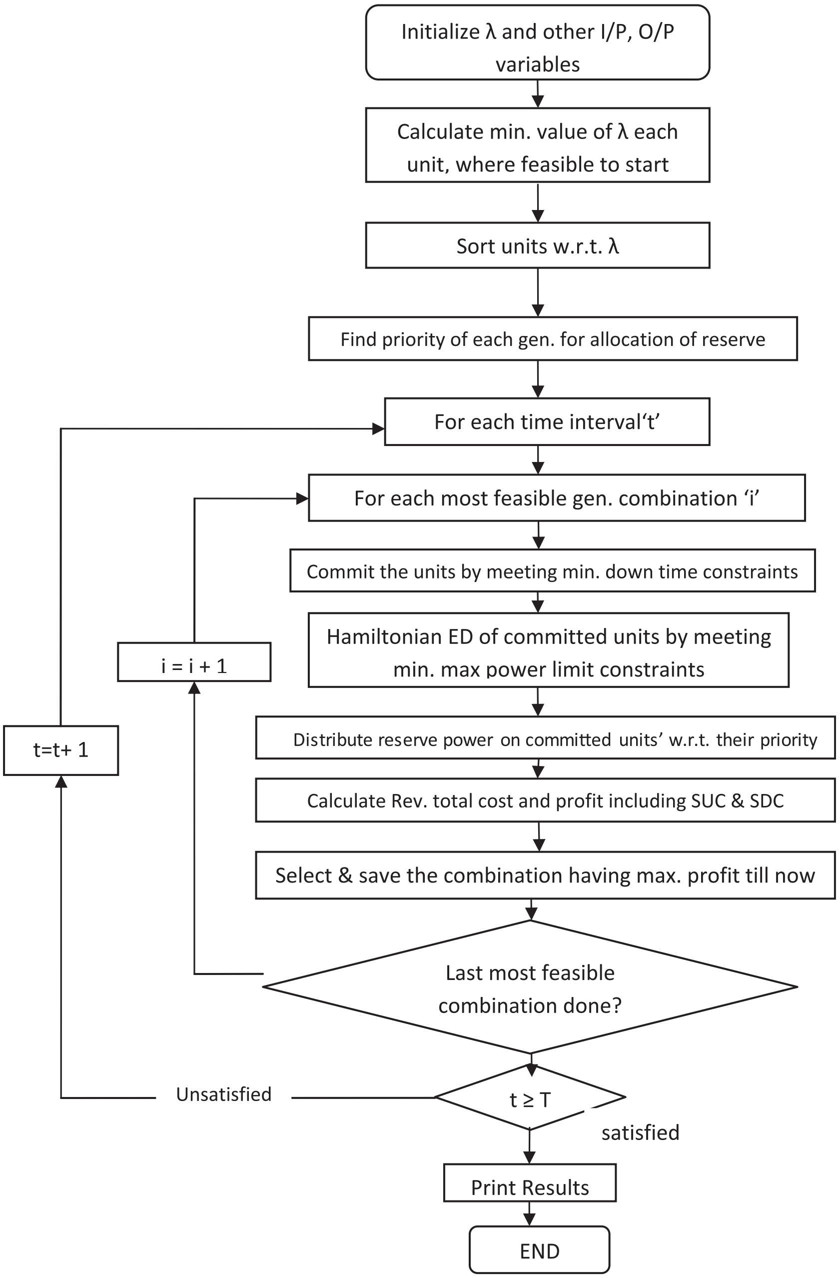

Fig. 1. Flow chart of complete strategy.

(iii) Power limit constraints

$$0 \leqslant D \leqslant A_{i\max} - A_{i\min}, \quad i = 1, 2, 3, 4, \ldots, N \tag{2.4}$$

$$D_i + A_i \leqslant A_{i\max}, \quad i = 1, 2, 3, 4, \ldots, N \tag{2.5}$$

(iv) Minimum down times constraints

$$B_{it} = 0 \quad \text{for} \sum_{t-T_{down=1}}^{t-1} (1 - B_{it}) < T_{idown} \tag{2.6}$$

(v) Minimum up time constraints

$$B_{it} = 1 \quad \text{for} \sum_{t-T_{up}}^{t-1} B_{it} < T_{up} \tag{2.7}$$

(vi) Start up cost constraints

$$\mathrm{SUC} = \text{constant} \quad \text{if } B_i, (t-1) = 0 \quad \text{and } B_{it} = 1 \tag{2.8}$$

(vii) Shut down cost constraints

$$\mathrm{SDC} = \text{constant} \quad \text{if } B_i, (t-1) = 1 \text{ and } B_{it} = 0 \tag{2.9}$$

There are many types of payments in power market. We have only considered the Payment for Power Delivered. In this case payment will be made when power will be used actually; revenue and cost can be calculated as [1]:

$$\text{Revenue} = \sum_{i=1}^{N}\sum_{t=1}^{T}(A_{it} \cdot SPt)B_{it} + \sum_{i=1}^{N}\sum_{t=1}^{T} r \cdot RPt \cdot D_{it} \cdot B_{it} \tag{2.10}$$

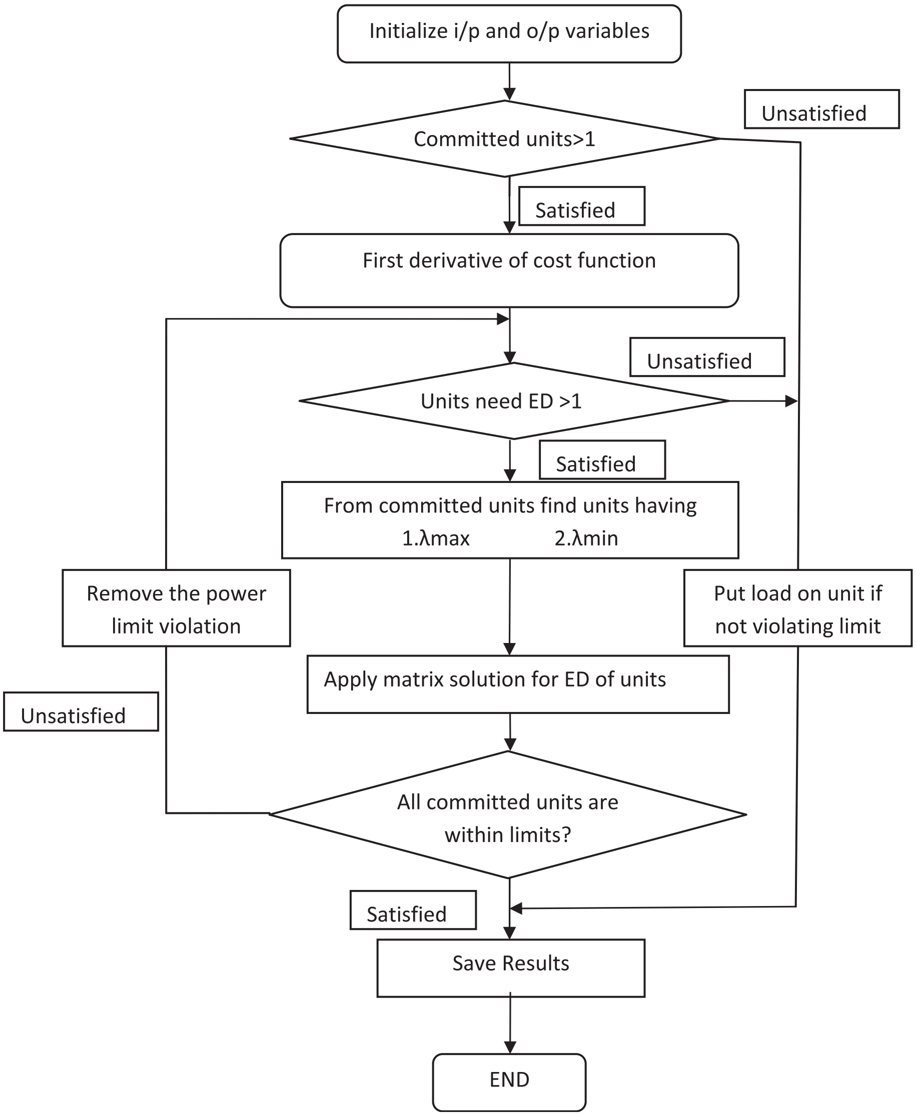

Fig. 2. Flow chart of economic dispatch strategy.

$$\text{Cost} = (1-r)\sum_{i=1}^{N}\sum_{t=1}^{T}F(A_{it})B_{it} + r\sum_{i=1}^{N}\sum_{t=1}^{T}F(A_{it}+D_{it})\cdot B_{it} + SUC\cdot B_{it} \tag{2.11}$$

where A_{it} is the power output of generator 'i' at 't' hour, B_{it} is the on/off status of generator 'i' at 't' hour, C_t is the total demand at 't' hour, D_{it} is the reserve generation of generator 'i' at 't' hour, SRt is the spinning reserve at 't' hour, SPt is forecasted spot price at 't' hour, RPt is forecasted reserve price at 't' hour, SUC is startup cost, λ_t and μ_t are Lagrange multipliers, r is the probability of calling the reserve.

LR looks to be the most appropriate method for the solution of large scale PBUC problems but it is hard to always get the final solution and with reasonable computational time, because of convergence and large number of iterations [10]. Lagrange function is formed by taking/assuming λ_t and μ_t as Lagrange multipliers to the demand and reserve constraints:

$$L(A,D,\lambda,\mu) = \text{cost} - \text{revenue} - \sum_{t=1}^{T}\lambda t\Big(C_t - \sum_{i=1}^{N}A_{it}\cdot B_{it}\Big) - \sum_{t=1}^{T}\mu t\Big(SRt - \sum_{i=1}^{N}D_{it}\cdot B_{it}\Big) \tag{2.12}$$

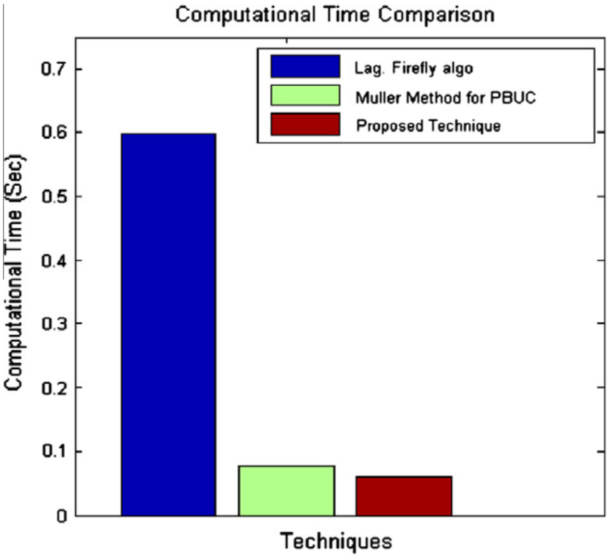

Fig. 3. Computational/execution time comparison of different techniques with proposed technique.

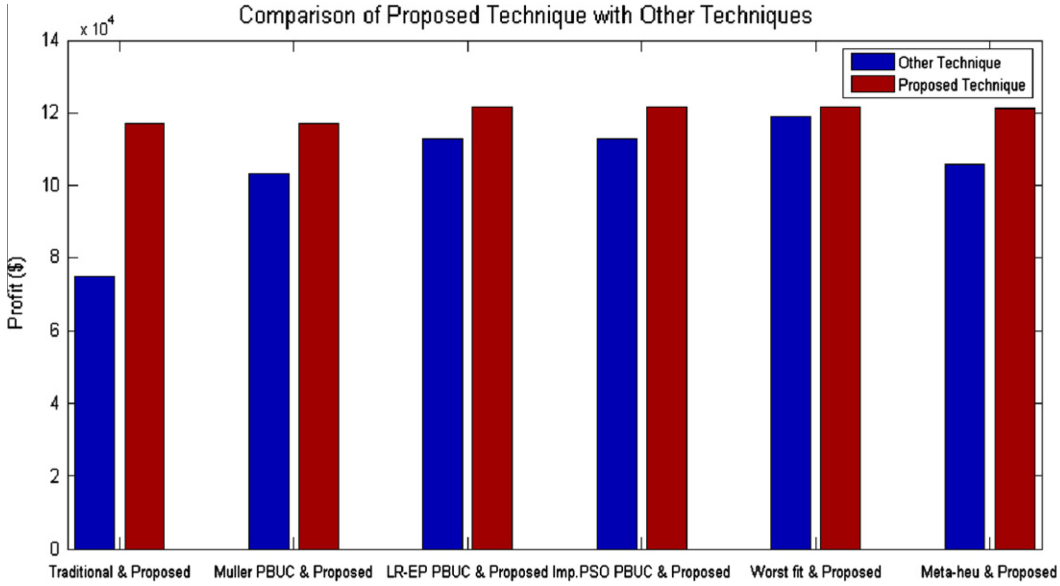

Fig. 4. Profit comparison of proposed technique with other techniques.

Table 1
Forecasted spot and reserve price of each interval (hour) for three unit 12 h system [5].

Hour	Forecasted spot-price ($/MW h)	Forecasted reserve-price ($/MW h)	Hour	Forecasted spot-price ($/MW h)	Forecasted reserve-price ($/MW h)
1	10.55	31.65	7	11.30	33.9
2	10.35	31.05	8	10.65	31.95
3	9	27	9	10.35	31.05
4	9.45	28.35	10	11.2	33.6
5	10	30	11	10.75	32.25
6	11.25	33.75	12	10.6	31.8

Table 2
Forecasted demand and reserve of each interval for three unit 12 h system (hour) [5].

Hour	Forecasted demand (MW)	Forecasted reserve (MW)	Hour	Forecasted demand (MW)	Forecasted reserve (MW)
1	170	20	7	1100	100
2	250	25	8	800	80
3	400	40	9	650	65
4	520	55	10	330	35
5	700	70	11	400	40
6	1050	95	12	550	55

Table 3
Units constraints of IEEE 3unit 12 h test system.

Unit	$P_{\max}$	$P_{\min}$	Start up cost ($)	Min down time (h)	Min up time (h)
Unit1	600	100	450	3	3
Unit2	400	100	400	3	3
Unit3	200	50	300	3	3

Table 4
Fuel cost function parameters of IEEE 3unit 12 h system.

Unit	*A*	*B*	*C*
Unit1	0.002	10	500
Unit2	0.0025	8	300
Unit3	0.005	6	100

Using the dual optimization technique coupling constraints are relaxed and reach the optimum by maximizing Lagrange function L with respect to the Lagrange multipliers λ_t and μ_t, while minimize with respect to the control variable A_{it}, D_{it} and B_{it}, that is:

$$q = \max(\lambda_t, \mu_t) \tag{2.13}$$

$$q(\lambda_t, \mu_r) = \min \text{w.r.t } B, A, D\ L(B, A, D, \lambda, \mu) \tag{2.14}$$

Over all time periods by solving the minimum for each generating unit, we get minimum of Lagrange function. Accuracy/quality of result depends on the procedure that is used for updating the multipliers. In LR for unit commitment (UC), problem is divided into sub problems. By attaining the solution of each sub problem we reach to the actual or final solution of the problem. By just taking objective function information and initiating from different points we use stochastic optimization techniques like EP for searching the solution. A combined technique of LR and EP is used for solving the PBUC problem. It is done by dual optimization technique and where coupling constraints are relaxed/ignored. For enhancing the efficiency of LR, LR multipliers are updated by EP. Though it enhances the efficiency but still it may take large execution time and can face convergence problem [1].

Table 5
Active power and reserve generation of Proposed PBUC and HED.

Proposed technique of PBUC and HED															
Hour	Power (MW)			Reserve (MW)			Profit ($)	Hour	Power(MW)			Reserve(MW)			Profit($)
	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3			Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3	
1	0	0	170	0	0	20	531.385	7	0	400	200	0	0	0	1380
2	0	0	200	0	0	0	570	8	0	400	200	0	0	0	990
3	0	0	200	0	0	0	300	9	0	400	200	0	0	0	810
4	0	0	200	0	0	0	390	10	0	130	200	0	35	0	818.101
5	0	0	200	0	0	0	500	11	0	200	200	0	40	0	804.63
6	0	400	200	0	0	0	950	12	0	350	200	0	50	0	929.231
Total															8973.3
Computational time (s)															0.06

Table 6
Generated and reserve power of traditional UC [1].

Traditional unit commitment															
Hour	Power (MW)			Reserve (MW)			Profit ($)	Hour	Power (MW)			Reserve (MW)			Profit ($)
	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3			Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3	
1	0	100	70	0	0	20	126.5	7	500	400	200	100	0	0	1040.9
2	0	100	150	0	0	25	352.9	8	200	400	200	80	0	0	548.4
3	0	200	200	0	40	0	103.6	9	100	350	200	15	50	0	308.1
4	0	320	200	0	55	0	303.1	10	100	100	130	0	0	35	91.1
5	100	400	200	70	0	0	−363.2	11	100	100	200	0	40	0	159.7
6	450	400	200	95	0	0	1017.8	12	100	250	200	0	55	0	359.9
Total															4048.8

Table 7
Active Power generation of Muller Method of PBUC [7].

Time (h)	Muller Method for PBUC Unit Commitment Without Reserve			Profit ($)	Time (h)	Muller Method for PBUC Unit commitment Without Reserve			Profit ($)
	Power(MW)					Power(MW)			
	Unit 1	Unit 2	Unit 3			Unit 1	Unit 2	Unit 3	
1	0	0	170	529	7	0	400	200	1380
2	0	0	200	570	8	0	400	200	990
3	0	0	200	300	9	0	400	200	810
4	0	0	200	390	10	0	130	200	813.75
5	0	400	200	200	11	0	200	200	800
6	0	400	200	1350	12	0	350	200	923.75
Total									9030.5
Computational time (s)									0.078

Table 8
Forecasted spot and reserve price of each interval (hour) for ten unit 24 h system [5].

Hour	Forecasted spot price ($/MW h)	Forecasted reserve price ($/MW h)	Hour	Forecasted spot price ($/MW h)	Forecasted reserve price ($/MW h)
1	22.15	110.75	13	24.6	123
2	22	110	14	24.5	122.5
3	23.1	115.5	15	22.5	112.5
4	22.65	113.25	16	22.3	111.5
5	23.25	116.25	17	22.25	111.25
6	22.95	114.75	18	22.05	110.25
7	22.5	112.5	19	22.2	111
8	22.15	110.75	20	22.65	113.25
9	22.8	114	21	23.1	115.5
10	29.35	146.75	22	22.95	114.75
11	30.15	150.75	23	22.75	113.75
12	31.65	158.25	24	22.55	112.75

3. Economic dispatch

After profit based unit commitment the second step is distribution of load on committed units. Load distribution on committed units must be optimum. The distribution of power demand on generating units to supply the load with minimum operational cost is known as Economic Dispatch (ED) [11]. In economic dispatch individual machine efficiency may not be maximum, but overall this

Table 9
Forecasted demand and reserve of each interval (hour) for ten unit 24 h system [9].

Hour	Forecasted demand (MW)	Forecasted reserve (MW)	Hour	Forecasted demand (MW)	Forecasted reserve (MW)
1	700	70	13	1400	140
2	750	75	14	1300	130
3	850	85	15	1200	120
4	950	95	16	1050	105
5	1000	100	17	1000	100
6	1100	110	18	1100	110
7	1150	115	19	1200	120
8	1200	120	20	1400	140
9	1300	130	21	1300	130
10	1400	140	22	1100	110
11	1450	145	23	900	90
12	1500	150	24	800	80

Table 10
Unit constraints data of 10 unit test system.

Unit	$P_{\max}$	$P_{\min}$	Start up cost ($)	Min down time (h)	Min up time (h)
Unit1	455	150	4500	8	8
Unit2	455	150	5000	8	8
Unit3	130	20	550	5	5
Unit4	130	20	560	5	5
Unit5	162	25	900	6	6
Unit6	80	20	170	3	3
Unit7	85	25	260	3	3
Unit8	55	10	30	1	1
Unit9	55	10	30	1	1
Unit10	55	10	30	1	1

Table 11
Fuel cost function parameters data of 10 unit test system.

Unit	A	B	C
Unit1	0.00048	16.19	1000
Unit2	0.00031	16.26	970
Unit3	0.00200	16.6	700
Unit4	0.00211	16.5	680
Unit5	0.00398	19.7	450
Unit6	0.00712	22.26	370
Unit7	0.00079	27.74	480
Unit8	0.00413	25.92	660
Unit9	0.00222	27.27	665
Unit10	0.00173	27.79	670

load distribution by economic dispatch will provide maximum/increased profit. Hamiltonian optimization is one of the important optimization techniques to solve dynamic, deterministic optimization problems. The Maximum Principle/Hamiltonian is also used for the solution of Economic Growth problems. The Hamiltonian principle has vide application in physics as well. We used the Hamiltonian technique for the solution of ED part.

First of all problem is converted according to the general set up as discussed above. Then we have to follow seven steps for getting solution by this method. Each step is described below.

3.1. Step1

Develop the Hamiltonian function according to your specific problem. Add the felicity function to the Lagrange multiplier times the RHS of transition equation for generating the Hamiltonian function.

$$H = v(k, c, t) + \mu(t) f(k, c, t) \tag{3.1}$$

In our case, felicity function is the sum of cost function of all committed generating units and transition equation consist of load and reserve demand constraints. Where load demand constraint for ED is equality constraint while reserve demand constraint is inequality constraint. But according to our proposal, we call only the ED function when load is less than the total generation capacity of the committed units.

3.2. Step2

Differentiate '*H*' Hamiltonian function partially with respect to '*c*' control variable and put it equal to zero. Mathematically it can be written as:

$$\frac{\partial H}{\partial c} = \frac{\partial v}{\partial c} + \mu \frac{\partial f}{\partial c} = 0 \tag{3.2}$$

In our case, '*p*' is the control variable. So, differentiate the function w.r.t. '*p*'.

In third step, take derivative of Hamiltonian function with respect to state variable and we have already value of state variable from PBUC solution. In rest of the steps either we have to follow the previous steps or need time derivative. We evaluate ED for each time interval independently so, we need not to follow third and remaining steps. We get the solution by only following the first two steps.

4. Solution strategy

For solution of PBUC and Hamiltonian ED, first step is to initialize I/P, O/P variables also assign the values to fixed parameters. Active, reserve power, on/off status, profit variables and λ are initialized with zero value. Rest of the variables and fixed parameters are defined by input file. After initialization of the variables we calculate lambda for each generating unit where it is feasible to start. This value is calculated by the following formula:

$$\lambda_i = \frac{\text{cost of unit at } P_{\max,i}}{P_{\max,i}} + 0.00001 \tag{4.1}$$

Table 12
Generation and Reserve Plan of 10 Units for Proposed technique.

Time	Generation (MW)										Reserve allocation (MW)									
Hour	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	319	381	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0
2	338.6	411.4	0	0	0	0	0	0	0	0	31.4	43.6	0	0	0	0	0	0	0	0
3	395	455	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0
4	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	455	455	130	130	162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	455	455	130	130	162	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	455	455	130	130	162	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	455	455	130	130	162	68	0	0	0	0	0	0	0	0	0	12	0	0	0	0
14	455	455	130	130	130	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0
15	455	455	130	130	30	0	0	0	0	0	0	0	0	0	120	0	0	0	0	0
16	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	455	455	0	90	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0
18	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	358.2	441.8	0	0	0	0	0	0	0	0	66.8	13.2	0	0	0	0	0	0	0	0

Table 13
Hourly total generation, reserve and profit of proposed technique.

Hour	λ	Load (MW)	Generation (MW)	Reserve demand	Reserve allocated	Profit ($)	Hour	λ	Load (MW)	Generation (MW)	Reserve demand	Reserve allocated	Profit ($)
1	18.6062	700	700	70	70	2411.3	13	23.1225	1400	1400	140	12	6186.6
2	18.6062	750	750	75	75	2601.72	14	27.4546	1300	1300	130	32	6283.6
3	18.6062	850	850	85	60	4029.29	15	23.1225	1200	1200	120	120	3857.16
4	18.6062	950	910	95	0	3713.2	16	22.0051	1050	1040	105	0	3433.04
5	18.6062	1000	910	100	0	4259.2	17	23.1225	1000	1000	100	40	3358.18
6	18.6062	1100	910	110	0	3986.2	18	22.2446	1100	1040	110	0	3173.04
7	18.6062	1150	910	115	0	3576.7	19	22.0051	1200	1040	120	0	3329.04
8	18.6062	1200	910	120	0	3258.2	20	22.0051	1400	1040	140	0	3797.04
9	18.6062	1300	910	130	0	3849.7	21	22.0051	1300	1040	130	0	4265.04
10	23.1225	1400	1332	140	0	10687.6	22	22.0051	1100	1040	110	0	4109.04
11	27.4546	1450	1412	145	0	13808.8	23	18.6062	900	900	90	10	3791.48
12	27.4546	1500	1412	150	0	16096.8	24	22.0051	800	800	80	80	3349.73
Total													121211.74

Now, sort lambda in ascending order, so that the most economical unit should be committed first, then second most economical unit and so on. Priority of the units is also required, so that for allocation of reserve most economical units must be selected instead of their simple order. It is found and saved. For each time interval (hour), each most feasible combination of units is taken by meeting minimum down time and up time constraints and then ED is done by Hamiltonian technique meeting the power limit constraints. For Hamiltonian ED a function "Ed_method" has been prepared separately. We call this function in main program for each most feasible combination. The complete strategy for PBUC and Hamiltonian ED is explained with the help of two flow charts. Flow chart of main program is given in Fig. 1 and flow chart of "Ed_method" is shown in Fig. 2.

Compare this profit to the previous maximum profit. If current combination profit is more than previous maximum profit combination save the current combination otherwise retain the previous combination for maximum profit. Repeat the above for each most feasible combination, till we reach last most feasible combination. These most feasible combinations are almost equal to the number of generators. When we evaluate all most feasible combinations we have only one best combination providing maximum profit for that time interval.

Then reserve power is allocated to the committed units according to their capacity and priority. Revenue, total cost and profit are calculated by meeting start up and shutdown cost constraints. Repeat the above strategy till last time interval, and find the best combination and load distribution on units providing maximum profit for each time interval. In Fig. 1 flow chart, inner loop is for combination of generators and outer loop is for time interval.

Detailed Hamiltonian ED strategy is shown in Fig. 2. When we call Hamiltonian ED function we give two inputs one is the "data" and other is the "x" (status of the units). The input "data" contains load, generator cost curves and other necessary data required for economic dispatch. Also initialize other variables according to requirement of the function. Now check if only one unit is committed then put the load on this unit and go to the end of .the function otherwise take the first derivative of cost functions, calculate incremental cost at $P_{\max}$ and $P_{\min}$ of each unit.

Now check more than one unit need ED? If no then set the load on that unit save the results and go to the end of the program, else find generators having maximum and minimum incremental cost from the committed units. Apply matrix solution for load distribution on committed units. Now check if load distribution on all units is within limits then save the results and end the function otherwise remove the power limit violation by considering one unit at

Table 14
Profit comparison of proposed technique with other techniques.

S. No.	Other technique	Profit of proposed	Profit of Other technique	Percentage Improvement
1	Traditional UC [7]	$118869.76	$75093	58.30
2	Muller PBUC [7]	$116689.76	$103296	12.97
3	LR-EP PBUC [5]	$121211.74	$112818.9	7.44
4	Improved PSO PBUC [6]	$121211.74	$113018.7	7.25
5	Worst fit Algorithm [9]	$121211.74	$119066.3	1.8
6	Meta-heuristic PBUC [8]	$120888.73	$105873.8	14.18

Table 15
Estimated execution time.

Power system	Hour	PBUC + HED (s)
3 Units	12	0.06
10 Units	24	0.85

a time. Now again go back to the step for checking, more than one unit need ED? Repeat the above strategy till we get active power values of all the units within limits. Now save the results (active power values of all the committed units) and go to the end of the function. An active power value of each unit is our output of this function. This output is provided to the main program from where this function was being called.

This technique always leads toward some final solution with small computational time, hence no stopping criterion is required for the main program.

5. Simulation results

The simulation of proposed technique carried out on two simple test system adapted by different researchers [1,5,6–9]. The first system is of three units while the second system consists of ten units. Scheduling periods of 12 h is for the first system and 24 h for the second system. Unit data for each system is given in Appendix. Forecasted price, forecasted load and forecasted reserve power are also given in Appendix. Value of '*r*' is set 0.005 for three unit test system and different values are taken for ten unit test system according to the case.

5.1. Test system1: three unit 12 h test system

Forecasted spot and reserve price data of three unit 12 h test system is given in Table 1 while forecasted demand and reserve power is given in Table 2. Constraints of each unit in the system are given in Table 3 and fuel cost function parameters in Table 4. For evaluation and comparison proposed technique implemented on three units 12 h test system. Allocation of power for generation and reserve to each generating unit is obtained and given in Table 5. Results obtained by conventional technique, Muller method and proposed technique are also given in tabular form. Execution/computational time comparison of proposed technique and Muller method is also presented.

Table 6 contains the results obtained by traditional unit commitment. Load and reserve power demand for each and every time interval has been met by the units. Total profit obtained by this technique is $4048.8. Profit for each time interval is also given in Table 6.

Results from Muller method for profit based unit commitment are given in Table 7. Total profit by this technique is $9030.5 as given in the table. This profit is almost double than the conventional technique. Computational time for this technique is also given in Table 7. The complete execution of the Muller method program took 0.078 s that is very small. This execution time can further be reduced.

Proposed technique results are presented in Table 5. Total profit by the proposed technique is $8973.3 that is 2.2 times higher than the profit of traditional unit commitment technique. Table 5 also shows the computational/execution time of the proposed technique. After executing the proposed technique MATLAB program ten times, calculated the average computational/execution time. The average computational/execution time found 0.06 s. This computational/execution time for the solution of the problem is small even as compared to the Muller profit based unit commitment.

Lagrange firefly PBUC takes 0.6 s for solution of three units problem for only 4 time intervals [5]. Muller method computational time is less than the LR–EP PBUC and Lagrange firefly PBUC techniques, and above results show that proposed technique computational time is less than Muller method of PBUC [7]. This is because we find and save the lambda values directly where unit becomes feasible for commitment and use these values for committing the units. The graphical comparison with respect to computational/execution time of proposed technique and above mentioned techniques is shown in Fig. 3.

It is clear from above discussion, tabular and graphical comparisons that with respect to computational time proposed technique is better than the LR–EP PBUC, Lagrange firefly PBUC and Muller method of PBUC while it is better than traditional technique with respect to profit.

5.2. Test system2: ten units 24 h test system

Proposed method is also implemented on ten units 24 h test system to solve the PBUC problem. Forecasted spot and reserve price data of the test system is given in Table 8 while forecasted demand and reserve power is given in Table 9. Constraints of each unit in the system are given in Table 10 and fuel cost function parameters in Table 11. Results achieved by traditional UC, Muller PBUC, LR-EP PBUC, improved PSO PBUC, worst fit algorithm, Meta-heuristic PBUC and proposed technique are presented. Profit comparison by IEEE 10 units 24 h test system, of proposed technique with traditional and other techniques is described with the help of tables and graphical data. Execution/computational time comparison of proposed technique with other techniques is also exposed for IEEE 10 units 24 h test system. The complete power generation plan and allocated reserve of each unit for 24 h by proposed technique is shown in Table 12 for all the time intervals (hours). Table 13 contains lambda, load demand, total generation, reserve demand and total reserve allocation and profit for each time interval (hour) calculated by proposed technique.

Profit obtained by different techniques and proposed technique for 10 units 24 h test system is presented in Table 14. In some cases reserve, spot price and reserve price conditions may be different from conditions given in Table 9 but the profit of proposed technique and other technique at each row of Table 14 is with same conditions. This is why each technique profit is compared independently. Detailed results and conditions can be viewed by the reference mentioned with each technique in Table 14. Profit obtained by techniques mentioned at S. No. 1 of Table 14 is with zero reserve condition for all the time intervals. It is also clear that proposed technique improved the profit by 58.30% than the traditional technique. The graphical comparison of total profit by proposed and traditional technique is also presented in Fig. 4. Results at S. No. 2 are with the condition of defined hot and cold start up cost of each unit and zero reserve requirement for all the time periods. With these conditions improvement in profit by proposed method is 12.97% than the Muller PBUC method. The comparison of both techniques with respect to profit is shown in Fig. 4 graphically. For the load and reserve conditions mentioned in Table 9, total profit achieved by techniques mentioned at S. No. 3, 4 and 5 is presented for 10 unit system. The improvement of profit by proposed technique came out 7.44%, 7.25% and 1.8% as compared to LR-EP PBUC, Improved PSO PBUC and Worst fit Algorithm techniques respectively. This comparison is also shown graphically in Fig. 4. At S. No. 6 of the table, profit by Meta-heuristic PBUC and proposed technique presented with 80% spinning reserve mentioned in Table 9. Improvement of profit for this problem by proposed technique as compared to Meta-heuristic PBUC for 10 unit system observed 14.18%.

Literature shows that LR PBUC takes number of iterations for their final solution thus its computational time is large and sometimes suffers convergence problem. Meta heuristic technique takes 131 s for the solution of the same problem [8]. Proposed technique solves the problem in less than one second (most of the time 0.8–0.9 s) as shown in Table 15.

6. Conclusion

This paper presented the solution of UC and ED problem. PBUC and Hamiltonian Economic Dispatch (HED) have been implemented for the solution of unit commitment and economic dispatch of IPPs. The proposed technique is tested on IEEE 3 unit 12 h and 10 unit 24 h systems. Different techniques have been used in past for the solution of unit commitment and economic dispatch problem. In this paper, for getting maximum profit for each time interval PBUC is used and Hamiltonian technique is used first time for economic dispatch. The obtained results by using PBUC and HED are better than some previous results reported in research papers both for execution time and profit. This reflects that the implementation of this work is better than most of the previous implementations. This implementation is favorable specially, where cost curves of generating units are close to each other or sudden changes in load and reserve demand. In proposed technique, analysis of most feasible combinations of the generating units with respect to profit carried out including HED. This technique always produces the solution of the problem while LR PBUC may face convergence problem in some cases. Execution time of PBUC and HED is less than most of the PBUC techniques mentioned in literature. Profit of the proposed technique is comparable to the traditional technique. Results conclude that the proposed technique is more attractive for IPPs with respect to the profit as compared to traditional techniques and with respect to execution time as compared to some advance techniques as well. Results also show that in order to find the near global solution for UC and ED as an objective function, PBUC–HED can be counted among some efficient techniques.

7. Future work

For future, proposed technique instead of traditional UC and ED can be implemented for planning with respect to profit before installation of generating units for IPPs. Some other constraints according to the environment, unit characteristics, market trends and power system of the country can also be included for more realistic and practical analysis. For online application, PBUC–HED can be used because its computational time is small and can be improved by different methods or programming it in some other language i.e. assembly language. For large power systems where computational time becomes of more significance proposed technique can be utilized. Moreover, computational time of proposed technique can further be reduced by using the already done analysis during the solution of the problem. In this way, it can be used for very large power systems as well.

Appendix A

See Tables 1–15.

References

[1] Attaviriyanupap P, Kita H, Tanaka E, Hasegawa J. A new profit based UC considering power and reserve generating. IEEE; 2002.

[2] Allen E, Ilic M. Price-based commitment decisions in the electricity market. London: Springer; 1999.

[3] Hassan HT, Imran K, Akbar MS, Ahmad I, Siddiqi YM, Impacts of proposed utilization of various indigenous coal reserves for power generation on production cost and environment. Proceeding of institution mechanical engineers, Part A. J Pow Energy 2010;1(1).

[4] Contreras-Hernández EJ, Cedeño-Maldonado JR. A sequential evolutionary programming approach to profit based Unit commitment. In: IEEE PES transmission and distribution conference and exposition Latin America, Venezuela; 2006.

[5] Pathom Attaviriyanupap, Hiroyuki Kita, Eiichi Tanaka, Jun Hasegawa. A hybrid LR–EP for solving new profit-based UC problem under competitive environment. IEEE Trans Pow Syst 2003;18(1).

[6] Yuan Xiaohui, Yuan Yanbin, Wang Cheng and Zhang Xiaopan. An improved PSO approach for profit-based unit commitment in electricity market. IEEE/PES transmission and distribution conference & exhibition: Asia and Pacific Dalian, China; 2005.

[7] Chandram K, Subrahmanyam N, Sydulu M. New approach with Muller method for Profit Based Unit, Commitment, ©IEEE; 2008.

[8] Mori H, Okawa K. A New Meta-heuristic Method for Profit-Based Unit Commitment under Competitive Environment. [978-1-4244-2235-7/09/$25.00 ©2010 IEEE].

[9] Amudha A, Christober Asir Rajan C. Effect of reserve in profit based unit commitment using worst fit algorithm. [978-1-61284-764-1/11/$26.00 ©2011 IEEE].

[10] Allen J. Wood, Bruce F. Wollenberg. Power generation operation and control. 2nd edition. Jhon Wiley & Sons Inc.; 1996.

[11] Carpentier J. Optimal power flow. Electr Pow Energy Syst 1979;1(1):3–36.