

A New Hybrid Approach For Profit-Based Unit Commitment Using Particle Swarm Optimization With Lagrangian Relaxation

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Abstract

This paper presents a new solution to profit based unit commitment (PBUC) problem based on hybrid particle swarm optimization (HPSO) and Lagrangian Relaxation (LR). In traditional electricity market unit commitment is done to reduce the operating cost. In this paper, the algorithm is proposed to solve PBUC under deregulated environment with the objective of maximizing GENCO's profit and minimizing the operating cost. The problem formulation of the unit commitment takes into consideration the minimum up and down time constraints, start-up cost, and spinning reserve. Economic Dispatch is obtained with Priority List and Lagrangian Relaxation based methods. UC schedule depends on the market price in the deregulated market. However demand satisfaction is not an obligation. GENCO can consider a schedule that produce less than the predicted load demand and reserve but creates maximum profit. More number of units are committed when the market price is higher. When more number of generating units are brought online more power is generated and participated in the deregulated market to get maximum profit. The proposed hybrid algorithm is developed for IEEE 10 unit system as an individual GENCO and the performance is compared. Simulations are carried out using MATLAB and the results shows that the proposed approach effectively maximizes the profit in the deregulated environment when compared with other existing methods.

Keywords: Deregulation, Economic Dispatch, GENCO, Lagrangian Relaxation, Market Price, Particle Swarm Optimization, Priority List, Profit Based Unit Commitment (PBUC)

Introduction

Unit Commitment (UC) is an optimization problem in power systems that involves determining the start-up and shut-down schedules of thermal units over a short term period. The objective of the UC problem is the minimization of total production cost [1]. The UC solution is to determine two types of basic decision variables – the unit operating status (on/off), which is binary variable and the economic load dispatch (ELD), which is a real variable denoting the power generated by the committed units in each hour. Therefore, UC problem combines two constrained optimization problems – optimal commitment and economic generation dispatch of the units during the scheduling period. UC problem is considered to be a most complex combinatorial optimization problems in power system economics. Many mathematical approaches exist in literature like Priority List [2]-[3] Lagrangian Relaxation [4] Mixed Integer Programming (MIP) [5], Branch and Bound [B&B] [6], Bender's Decomposition [7] and Dynamic Programming [8]-[14]. Various other approaches to solve the UC problem can be found from [15]-[16]. As the electrical industry restructures, many of the traditional algorithms for controlling generating units need modification or replacement. In the restructured environment, generation companies (GENCOS) schedule their generators with objective to maximize their own profit with the relaxation of demand fulfilment constraint. This is known to be the profit based unit commitment problem [17]-[20]. UC under deregulated environment is more complex and more competitive than traditional one. There are many solution techniques to solve the PBUC problem [21-28]. In [26] C. Christopher Columbus et.al developed and implemented a Nodal Ant Colony Optimization which yielded an increase in profit greater than 1.5% in comparison with the basic Ant Colony Optimization and Hybrid LR-GA. In [27] Charles W. Richter et.al proposed enhanced UC-GA to provide the user with additional information that identifies which schedules allow the user more market flexibility for a given level of profit. In [28] Pathom attaviriyapap et.al proposed the hybrid LR-EP approach to make a decision that how much power and reserve should be sold in market and how to schedule generators in order to receive maximum profit. Various PSO based approaches are proposed in the literature [29]-[30]. In [31] Jacob Raglend et.al discussed the profit based unit commitment problem using various PSO techniques such as Chaotic PSO (CPSO), New PSO (NPSO) and Dispersed PSO (DPSO) and the results are compared. The paper is organized as follows. Part II briefly describes the UC problem and formulation. It highlights the modifications needed for the restructured environment. Part III describes the solution to PBUC problem using Particle Swarm Optimization. Part IV describes the LR method for obtaining the dispatch for the committed units. Part V presents the application of PSO with LR to obtain the profit maximization considering 10 unit system as an individual GENCO. The result is compared with the other approaches stated in the literature.

Problem Formulation

A. Unit Commitment Problem

The objective of the UC problem is to minimize the total operating cost subjected to a set of system and unit constraints over the scheduling horizon. The fuel cost for the unit i at any given time interval is assumed as a quadratic function of the generator power output, p_i at that time. The objective function is

$$\text{Min TFC} = \left[\sum_{t=1}^T \sum_{i=1}^n (a_i + b_i P_{it} + c_i P_{it}^2) \right] + \text{SUC} \quad (1)$$

Subject To System Constraints

(a) Unit Initial conditions

First hour schedule is based on the unit initial status

(b) Unit status restrictions

Certain units under all load conditions are assigned with the must run status.

$$(c) \sum_{i=1}^n P_{it} = PD_t \quad (2)$$

is the power balance constraint

$$(d) \sum_{i=1}^n P_i^{\max} \geq PD_t + R_{it} \quad (3)$$

is the reserve constraint

Subject To Local Constraints

$$(e) P_i^{\min} \leq P_i \leq P_i^{\max} \quad (4)$$

(f) Minimum Up and Minimum Down time constraints indicate that a unit must be ON/OFF for a certain number of hours before it can be committed or decommitted.

$$T_{it}^{ON} \geq T_i^{UP} \quad (5)$$

$$T_{it}^{OFF} \geq T_i^{DOWN} \quad (6)$$

(g) Start Up Cost (SUC)

$$\text{SUC}_{it} = \begin{cases} \text{hot startup cost, if downtime} \leq \text{coldstart hours} \\ \text{cold startup cost, otherwise} \end{cases} \quad (7)$$

With an assumption that the shut-down cost is zero, the total operating cost for the scheduling period T is the sum of fuel costs and start-up costs for n units.

B. Profit Based Unit Commitment Problem

Profit Based Unit Commitment problem in deregulated power system determines the generating unit schedules for maximizing the profit of GENCO's in addition to cost minimization. The PBUC problem can be mathematically formulated by the following equations.

$$\max \text{PF} = \text{RV} - \text{TC} \quad (8)$$

$$\text{RV} = \sum_{i=1}^N \sum_{t=1}^T (P_{it} \cdot SP_t) U_{it} \quad (9)$$

$$\text{TC} = \sum_{i=1}^N \sum_{t=1}^T (C_{it}(P_{it}) + S_{it}) P_{it} \quad (10)$$

Subjected to the following constraints

Demand Constraint

$$\sum_{i=1}^N P_{it} U_{it} \leq PD_t \text{ for } t=1 \text{ to } T \quad (11)$$

Reserve Constraint

$$\sum_{i=1}^N R_{it} U_{it} \leq SR_t \text{ for } t=1 \text{ to } T \quad (12)$$

Power Balance Constraint

$$P_i^{\min} \leq P_i \leq P_i^{\max} \text{ for } i=1 \text{ to } N \quad (13)$$

Minimum Up/Down time constraints

Minimum Up and Minimum Down time constraints indicate that a unit must be ON/OFF for a certain number of hours before it can be committed or decommitted.

Where

TFC	-	Total Fuel Cost
a_i, b_i, c_i	-	Cost coefficients
t	-	Time Interval (1 to 24 hrs)
n	-	Number of generating units
PF	-	Profit of the GENCO
RV	-	Revenue
TC	-	Total Operating Cost
P_{it}	-	Power Generation of i^{th} unit at time t
SP_t	-	Spot Price at hour t
U_{it}	-	Unit ON/OFF status of unit i at hour t
$C_{it}(P_{it})$	-	Cost of power generation of unit i at hour t
S_{it}	-	Startup cost of Unit i
PD_t	-	Power Demand at time t
R_{it}	-	Reserve generation of unit i at time t
SR_t	-	Forecasted reserve at time t
P_i^{\min}	-	Minlimit of power generation of unit i
P_i^{\max}	-	Maxlimit of power generation of unit i
T_{it}^{ON}	-	ON time of unit i at time t
T_{it}^{OFF}	-	OFF time of unit i at time t
T_i^{UP}	-	Minimum ON time of unit i
T_i^{DOWN}	-	Minimum OFF time of unit i

Hybrid PSO and LR Approach To PBUC

Particle swarm optimization (PSO) was first proposed by Kennedy and Eberhart as an alternative technique to Genetic Algorithm. PSO is population based stochastic optimization such as bird flocking or fish schooling. The individuals in a PSO have their own position (x) and velocities (v). These individuals are denoted as particles. Each particle remembers its own best positions found so far in the exploration. This position is called personal best (*pbest*). Among these *pbests*, the particle which has the best fitness value is called as global best (*gbest*). During the flight, the particles are attracted stochastically towards their own *pbest* and *gbest* achieved so far. Therefore, the particles are manipulated according to the following equations.

$$V_i^{t+1} = w * V_i^t + \rho_1 * rand() * (g_{best} - X_i^t) + \rho_2 * rand() * (l_{best} - X_i^t) \tag{14}$$

$$X_i^{t+1} = X_i^t + V_i^{t+1} \tag{15}$$

Where *w* is known as the inertia weight, which controls the exploration properties of the algorithm and it has the range between (0, 1). The parameters ρ_1 and ρ_2 are two positive constants which keep the balance between local and global behavior of the particles and *rand* is uniformly distributed random number in the range between [0, 1]. The flowchart for the basic PSO is shown below in Figure 1.

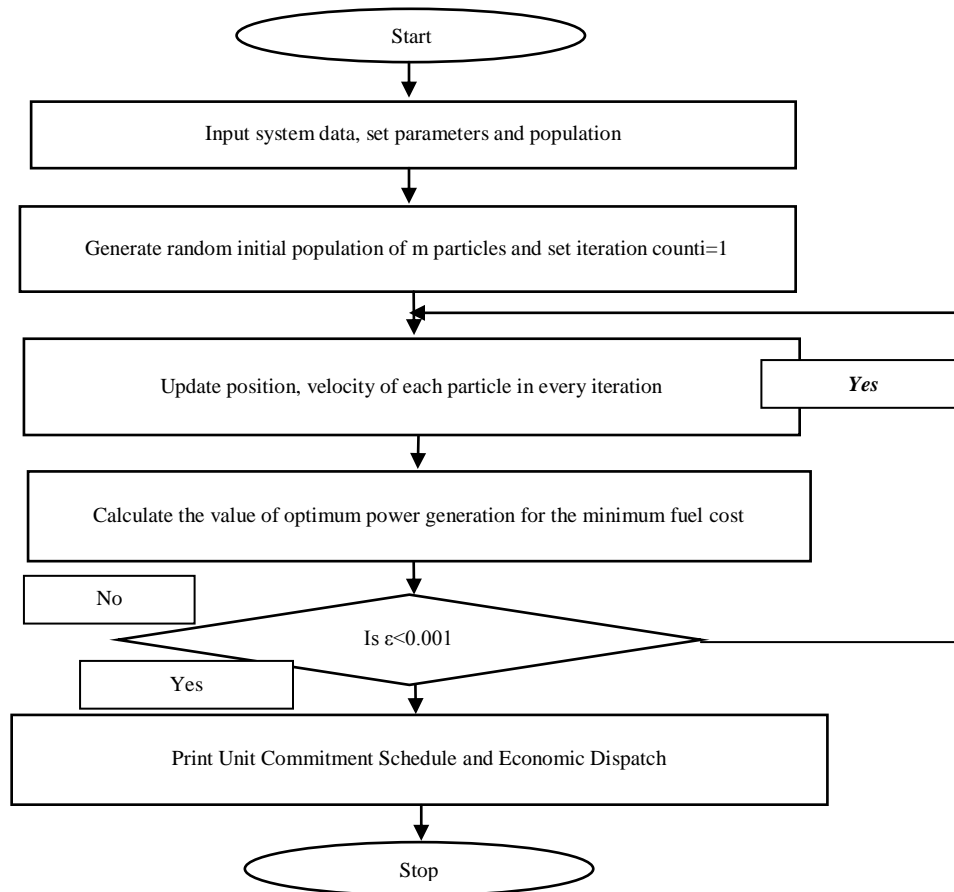


Figure 1: Flowchart of PSO

Binary particle swarm optimization is a simple modification to the original version of PSO. In Binary particle swarm optimization the position X , $pbest$ and $gbest$ are binary numbers while velocity V_i is a real number and limited by $\pm V_{max}$. The velocity V_i will determine a probability of threshold using logistic functions below.

$$s(V_i) = \frac{1}{1 + \exp(-V_i)} \quad (16)$$

$$\text{If random} < s(V_i), \text{ then } X_i = 1 \quad (17)$$

Else $X_i = 0$

A random number between [0,1] is generated and X is set 1 if the random number is smaller than the value from the sigmoid function. The Dynamic Programming (DP) approach for solving unit commitment problem has many disadvantages for large power systems with many generating units as it suffers from the curse of dimensionality. Hence, it is required to limit the commitments considered at any hour through some simplification techniques such as truncation and fixed priority ordering. This simplification, particularly for large scale systems, can lead to suboptimal schedules. This problem is resolved in the Lagrange relaxation technique. This method is based on a dual optimization approach. The constraints to be satisfied are

- 1) Power balance constraint
- 2) Capacity limits constraints
- 3) Unit minimum up and downtime constraints.

Other constraints can easily be formulated and added to the unit commitment problem. These include transmission security constraints, generator fuel limit constraints, and system air quality constraints in the form of limits on emissions from fossil-fired plants, spinning-reserve constraints, etc.

The Lagrangian function for the economic dispatch problem is

$$L(P, U, \lambda) = F(P_{it}, U_{it}) + \sum_{t=1}^T \lambda^t (PD_t - \sum_{i=1}^n P_{it} U_{it}) \quad (18)$$

The unit commitment problem requires that we minimize this Lagrange function, subject to local unit constraints (2) and (3). Each of these constraints can be applied separately.

The cost function $F(P_{it}, U_{it})$ together with constraints 2 and 3 are each separable over units. That is, what is done with one unit does not affect the cost of running another unit, as far as the cost function and the unit limits (constraint 2) and the unit up and downtime (constraint 3) are concerned. Constraint 1 is coupling constraint across the units so that what we do to one unit affects other units if the coupling constraints are to be met.

Implementation of Hybrid PSO-LR to PBUC

The PBUC problem is solved by Particle Swarm Optimization and Lagrangian Relaxation method. Two initial solution are formed randomly with 1 and 0 representing on and off status of units. The random solution is modified according to the limits of the generating units. These initial solutions are used to generate 10 iterations for each hour using PSO. At the same time the solution from PSO should meet various constraints such as power balance, minimum up time, minimum down time, spinning reserve, and start-up cost respectively. Unit up time and down time are

considered for the initial solution and accordingly the solution is changed. Final solution is obtained from the local and global best schedule obtained for all hours. The Economic dispatch is obtained by Lagrangian Relaxation method. The algorithmic steps are given below

Algorithm

- Step 1:** Start the program and initialize the generator data and variables.
- Step 2:** Generate two initial random solutions with 1s and 0s.
- Step 3:** Modify the random solutions according to the limits of generator.
- Step 4:** Determine the first iteration value according to (16) and (17).
- Step 5:** Update the position and velocity of particle (unit) using equations (14) and (15).
- Step 6:** Apply up time, down time, capacity limit constraint and power balance constraint.
- Step 7:** Repeat steps 5 and 6 for 10 iterations and determine local best and global best solutions
- Step 8:** Determine Unit Commitment schedule using global best solution.
- Step 9:** Perform the economic dispatch for the particular hour, for hour 1 and calculate the optimum power to be generated from each unit in the system. The starting value of lambda is taken as per unit (p.u) of the load and the iteration is started. This gives the dispatch for the first iteration.
- Step 10:** Now, compare the primal value (j) with the optimal value $q(\lambda)$, the difference between the two values is taken as the relative duality gap. Relative duality gap = $(j^* - q^*)/q^*$
- Step 11:** Check for duality gap convergence. If converged stop otherwise update the value of λ for all values of t.
- Step 12:** Make the final adjustment to Unit Commitment schedule to achieve feasible solution.
- Step 13:** Print the final solution.

The Flow chart of the PSO based LR algorithm is shown in Figure 2.

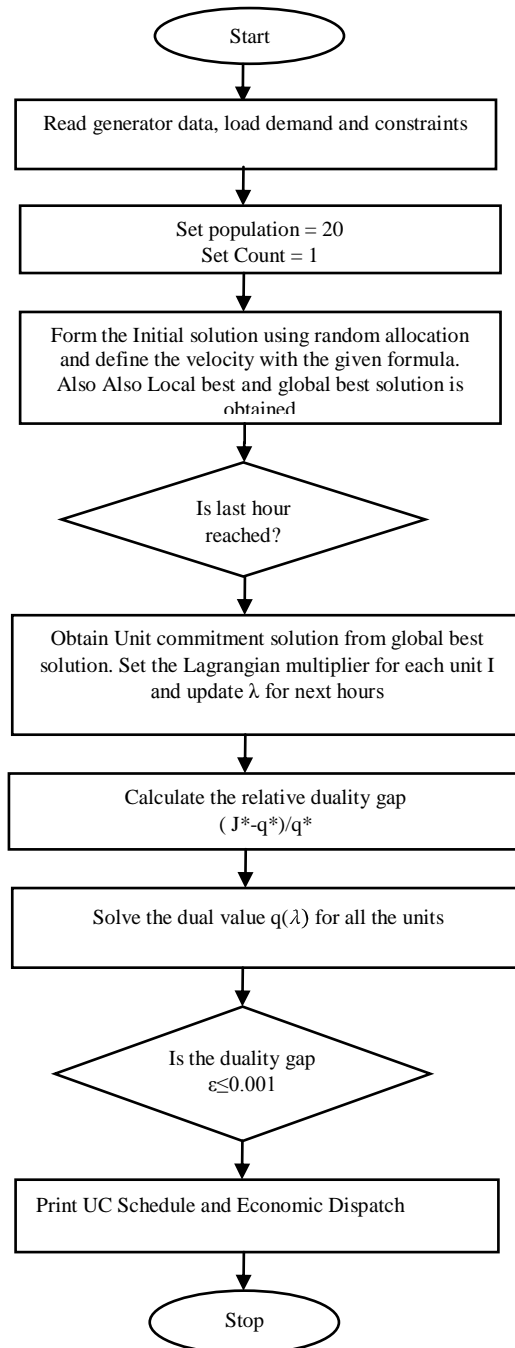


Figure 2 : Flowchart of proposed PSOLR approach

Results and Discussion

The algorithm is checked for the IEEE 10 unit system. The results obtained are checked with the previous methods and it is found that the proposed approach yields optimal solution. The required unit data for the 10-unit generating system is given in Table 1. The load data for this system is given in Table 2.

Table 1: Unit Data For The 10-Unit System

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Pmax (MW)	455	455	130	130	162
Pmin (MW)	150	150	20	20	25
a (\$/hr)	1000	970	700	680	450
b (\$/Mwh)	16.19	17.26	16.60	16.50	19.70
c (\$/Mwh ²)	0.00048	0.00031	0.002	0.00211	0.00398
MUT _i (h)	8	8	5	5	6
MDT _i (h)	8	8	5	5	6
Hcost _i (\$)	4500	5000	550	560	900
Ccost _i (\$)	9000	10000	1100	1120	1800
Chour _i (h)	5	5	4	4	4
IniState (h)	8	8	-5	-5	-6
	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Pmax(MW)	80	85	55	55	55
Pmin (MW)	20	25	10	10	10
a (\$/hr)	370	480	660	665	670
b (\$/Mwh)	22.26	27.74	25.92	27.27	27.79
c (\$/Mwh ²)	0.00712	0.00079	0.00413	0.00222	0.00173
MUT _i (h)	3	3	1	1	1
MDT _i (h)	3	3	1	1	1
Hcost _i (\$)	170	260	30	30	30
Ccost _i (\$)	340	520	60	60	60
Chour _i (h)	2	2	0	0	0
IniState (h)	-3	-3	-1	-1	-1

Table 2: Load Data of 10 Unit System For 24 Hours

Hour [h]	Load [MW]	Hour [h]	Load [MW]
1	700	13	1400
2	750	14	1300
3	850	15	1200
4	950	16	1050
5	1000	17	1000
6	1100	18	1100
7	1150	19	1200
8	1200	20	1400
9	1300	21	1300
10	1400	22	1100
11	1450	23	900
12	1500	24	800

The simulation was done by using MATLAB R2009a and the results were showing advantages and the spot pricing has been made for each hour in the power system supplied by the generators. This proves that particle swarm optimization method has been useful in estimating the optimum unit commitment of the power plant and also dispatch done by using Lagrangian relaxation method. The Unit Commitment schedule for IEEE 10 unit is given in Table 3 using PSO based Lagrangian Relaxation algorithm.

Table 3: Unit Commitment Schedule of IEEE 10 unit System by PSO and LR

UNIT	1	2	3	4	5	6	7	8	9	10	DEMAND	COST	SUC	SPOT PRICING
1	350	350	0	0	0	0	0	0	0	0	700	13774.28	0	15505
2	375	375	0	0	0	0	0	0	0	0	750	14624.84	0	16500
3	425	425	0	0	0	0	0	0	0	0	850	16328.94	0	19635
4	416	416	119	0	0	0	0	0	0	0	950	18708.58	900	22467.5
5	438	438	125	0	0	0	0	0	0	0	1000	19561.84	0	22250
6	428	428	122	122	0	0	0	0	0	0	1100	21910.68	560	25245
7	447	447	128	128	0	0	0	0	0	0	1150	22764.14	0	25875
8	410	410	117	117	146	0	0	0	0	0	1200	24537.09	0	26580
9	444	444	127	127	158	0	0	0	0	0	1300	26289.91	0	29640
10	451	451	129	129	161	79	0	0	0	0	1400	28833.32	170	41090
11	450	450	128	128	160	79	0	54	0	0	1450	30836.58	60	43717.5
12	448	448	128	128	160	79	0	54	54	0	1500	32909.74	60	47475
13	451	451	129	129	161	79	0	0	0	0	1400	28833.32	0	34440
14	444	444	127	127	158	0	0	0	0	0	1300	26289.91	0	31850
15	410	410	117	117	146	0	0	0	0	0	1200	24537.09	0	27000
16	408	408	117	117	0	0	0	0	0	0	1050	21058.08	0	23415
17	389	389	111	111	0	0	0	0	0	0	1000	20206.33	0	22250
18	428	428	122	122	0	0	0	0	0	0	1100	21910.68	0	24255
19	410	410	117	117	146	0	0	0	0	0	1200	24537.09	0	26640
20	478	478	137	137	170	0	0	0	0	0	1400	28046.53	0	31710
21	444	444	127	127	158	0	0	0	0	0	1300	26289.91	0	30030
22	376	376	107	107	134	0	0	0	0	0	1100	22788.08	0	25245
23	382	382	0	0	136	0	0	0	0	0	900	18066.02	0	20475
24	340	340	0	0	121	0	0	0	0	0	800	16308.92	0	18040
												549951.9	1750	651330

Total cost=551701.878115

Total revenue=651330.000000

Profit=99628.121885

The total cost is the sum of production cost and startup cost which accounts for Rs.551701.878115 in the proposed approach. Total revenue generated is Rs 651330 and the profit is Rs 99628.121885. Comparison of profit based unit commitment is done with other methods such as full load average production cost, priority list method and PSO based priority list. Compared to other methods the solution obtained using Hybrid PSO based LR method is optimal. Table 4 shows the comparison of PSOLR with other methods.

Table 4: Comparison of Various Methods

Method	Total Cost (Rs)	Total Revenue (Rs)	Profit (Rs)
Full load average production cost and Priority list	555416.648540	651330.000	95913.351460
PSO based Priority list	561811.03279	651330.000	89518.967210
HPSO based LR	551701.878115	651330.000	99628.121885

Conclusion

The paper proposes the profit based unit commitment problem in competitive electricity markets. A new optimization approach using PSO combined with Lagrangian method is proposed to solve the unit commitment problem by considering the constraints such as load demand, spinning reserve, generated limits and minimum up and down time constraints. The simulation results of IEEE 10 unit system shows that PSOLR approach is the promising technique for solving complicated power system optimization problem. The test results shows that the hybrid PSO based LR approach has the efficient global searching performance and the algorithm is quiet effective in solving the profit based unit commitment problem.

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