A HYBRID APPROACHES FOR THE PROFIT BASED UNIT COMMITMENT PROBLEM IN THE DEREGULATED MARKETS

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Abstract: *In this paper, two hybrid models between Lagrange Relaxation (LR) with Evolutionary Programming (EP) and Lagrange Relaxation (LR) with particle swarm optimization (PSO) are used to solve the profit based unit commitment problem in a deregulated electricity market. In recent days, operation and control of generating unit is modified because of the revolution in power system structure. Energy price becomes an important parameter to make a decision in this restructured system. Unit commitment (UC) in such a competitive environment is not the same as the traditional one. The objective of UC is not only to minimize production cost as before but also to find the solution that produces a maximum profit for generation company (GENCO). A modest attempt has been made in this paper presents a simulated case study for the profit based unit commitment problem and demonstrates the effectiveness of the proposed approaches.*

Key words: *profit-based Unit Commitment, Lagrange Relaxation, Evolutionary Programming, particle swarm.*

1. Introduction

Unit commitment is the process of deciding when and which generating units at each power station to start-up and shut-down[1].Unit commitment (UC) is an important task in the power system operation, which should determine the start-up and shut-down schedule of thermal units to meet system demand over a short term period. The restructuring of electric power systems has resulted in market-based competition by creating an open market environment. A restructured system allows the power supply to function competitively, as well as allowing consumers to choose suppliers of electric energy. According to this change, traditional methods for power generation, operation as well as control need some modification [7].

UC algorithms can be applied to large-scale power systems and have reasonable storage and computation time requirements. For the vertically integrated monopolistic environment in the past, UC is defined as schedule generating units to be in service (on/off) in order to minimize total production cost while meeting all constraints such as power demand, minimum up and down time, spinning reserve. On the other hand, UC under deregulated environment is more complex and more competitive than the traditional unit commitment. A UC algorithm that maximizes profit will play an essential role in developing successful bidding strategies for the competitive generator (GENCO's). Moreover in the past, utilities had an obligation to serve their customers so that means all demand and spinning reserve constraints can met. However, it is not necessary in the restructured system. A day-ahead power exchange is looked at. Market participants are free to submit supply or demand bids at their preferred price, for each hour of the next day. These auctions are then cleared simultaneously, resulting in a price of electricity for each hour of the next day, revealing which bids are accepted and which not. In order to gain as much profit as possible, a GENCO will try to make an adequate forecast of this spot price of electricity [8, 9, 15, 16].

The PBUC problem is a mixed integer and continuous nonlinear optimization problem, which is very complex to solve. Many solution techniques such as mixed integer programming, dynamic programming, Lagrangian relaxation and genetic algorithm are used to solve the PBUC. Because of the inherent limitation of these methods, which have some one or another drawback for the solution of PBUC.In this paper LR, EP methods are used to update the lambda and maximize the profit for generation company (GENCO's) in deregulated electricity market [11-13].

2. Problem formulation for Profit based UC

The objective of PBUC is to maximize the generation company profit subject to all kinds of constraints. The optimization problem can be formulated mathematically by the following equations
The objective function

Max. *Profit* = *RV-TC* (1)

(or)

Min operating Cost= *TC-RV* (2)

Subject to constraints

1) Real Power Constraints

$$\sum_{i=1}^{N} P_{it} * U_{it} \le P_{dt} \quad \text{for} \quad t=1....T \qquad (3)$$

2) Reserve Constraints

$$\sum_{i=1}^{N} R_{it} * U_{it} \le SR_t \quad \text{for} \quad t=1....T \qquad (4)$$

3) Real and Reserve power operating limits

$$P_{i\min} \le P_i \le P_{i\max} \quad \text{for } i=1...N \qquad (5)$$

$$0 \le R_i \le P_{i\max} - P_{i\min} \quad \text{for } i=1... N \qquad (6)$$

$$R_i + P_i \le P_{i\max} \quad \text{for } i=1.... N \qquad (7)$$

4) Minimum Up and Downtime constraint (8)

The amount of power and reserve sold depends on the way reserve payments are made. In this paper, we focused on selling of real power in the deregulated electricity market with the help of forecasted demand and spot prices [9].

LR optimization is done for the equation (9)

$$L(P,R,\lambda) = TC - RV - \sum_{t=1}^{T} \lambda t(P_{dt} - \sum_{i=1}^{N} P_{it} * U_{it}) \qquad (9)$$

$$RV = \sum_{i=1}^{N} \sum_{t=1}^{T} (P_{it} * SP_t)U_{it} + \sum_{i=1}^{N} \sum_{t=1}^{T} r(RP_t * R_{it})U_{it} \qquad (10)$$

$$TC = (1-r)\sum_{i=1}^{NT} \sum_{t=1}^{T} F(P_{it})U_{it} + r\sum_{i=1}^{NT} \sum_{t=1}^{T} F(P_{it} * R_{it})U_{it} + ST_i * U_{it} \qquad (11)$$

3. Solution Methodologies

A) Lagrangian Relaxation Method

Algorithm for LR Method

Step (1) : Assume λ_t (lamda) value for all hours t

Step (2) : if $\min[(F(P) - \lambda(P)] < 0 : U = 1$

$\min[(F(P) - \lambda(P)] > 0 : U = 0$

Step(3) : Find the optimum generation

$$P_i = \lambda - b_i / 2a_i \qquad (12)$$

If $P_i > P_{i\max}$,then $P_i = P_{i\max}$

$P_i < P_{i\min}$, then $P_i = P_{i\min}$

Step(4) : Find the loading constraints

$$L_{at} = P_{dt} - \sum_{i=1}^{N} P_{it} * U_{it}$$

Step(5) : Calculate the economic dispatch

Step(6) : Calculate the dual function (maximizing λ) Using

$$q(\lambda) = F(P_{it} * U_{it}) - \sum_{t=1}^{T} \lambda t(P_{dt} - \sum_{i=1}^{N} P_{it} * U_{it}) \qquad (13)$$

Step(7): Calculate the primal function (minimizing F)

$$J = F(\sum_{t=1}^{T} P_{iedc} * U_{it}) \qquad (14)$$

Step (8) : Calculate the Relative Duality Gap

$$RDG = (j - q^* / q^*) \qquad (15)$$

Step(9): Check for RDG ≤ 0.005 for convergence, if converged stop otherwise update lambda.

Step (9): Update the lambda value of using the following equation

$$\lambda_{t+1} = L_{at} + [dq / d\lambda] * \alpha \qquad (16)$$

Where $\alpha = 0.01$ for $dq / d\lambda > 0$ and

0.002 For $dq / d\lambda < 0$

In this paper, we proposed EP and PSO methods to update λ for the better convergence in the PBUC.

Step (10): Continue from the step 2 till it get converged

B) Evolutionary Programming Algorithm

More than 45 years ago, several researchers from US and Europe independently came up with the idea of mimicking the mechanism of biological evolution in order to develop powerful algorithms for optimization and adaptation problems.This set of algorithms is known as Evolutionary Algorithms (EA). One of the most commonly used evolutionary algorithms is EP.This technique was originally conceived by Fogel in the year 1960. The schematic diagram of the EP algorithm is depicted in Fig 1.The general scheme of the EP follows the sequence below [12, 14]:

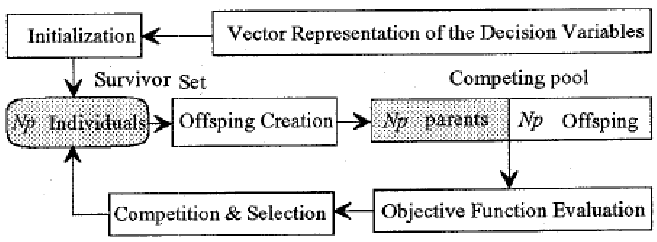

Fig. 1: Schematic diagram of the Evolutionary Programming algorithm

1. Initialization: An initial population of parent individuals Pi, i=1, NP, is selected randomly from a feasible range in each dimension. Typically, the distribution of initial trials is uniform.
2. Creation of Offspring: Equal number of offspring Pi *, i=1, …, NP, is generated by adding a Gaussian random variable with zero mean and pre selected standard deviation to each component of Pi. Therefore, individuals including parents and offspring exist in the competing pool.
3. Competition & Selection: Each individual in the competing pool must stochastically strive against other members of the pool based on the functions f (Pi) and f (Pi *). The Np individuals with the best function values (minimum for the minimization problem) are selected to form a survivor set

according to a decision rule. The individuals in the survivor set are new parents for the next generation.

Where,

Pi : Initial Population,

Pi* : Offspring Population,

NP : Number of Population,

f (Pi) : Fitness value of initial population

f (Pi*) : Fitness value of offspring population

4. Stopping Rule: The process of generating new trials and selecting those with best function values are continued until the function values are not obviously improved or the given count of total generations is reached

C) EP Implementation in to PBUC

The adjustment of the Lagrange multipliers must be done so as to maximize the profit so that we used EP and PSO methods to achieve this task. At first components of EP are described below and Fig 2 shows flow chart for the updating lambda using both methods

a) *Initialization*

For intervals in the scheduling periods, an array of control variable and vectors can be shown as Lagrange multiplier

$$\lambda = [\lambda_1, \lambda_2 \ ...\lambda_T] \quad (17)$$

Where T = Total no of hours,

To begin, the population of chromosomes is uniformly random initialized. This population of chromosome is called parent.

b) *Fitness Function*

The value q is used to indicate the fitness of the candidate solution of each individual

c) *Creation of offspring*

The initial parent population produces 'n' number of offspring vectors λ_{it} and P_{it} is created from each parents λ_t and P_{it} by adding to each components of λ_t and P_{it} a Gaussian random variable with zero mean and a standard deviation proportional to the scaled values of the parent trial solution,

$$\lambda_{t'} = \lambda_t + N\ (0,\sigma\ t2) \quad (18)$$

Where N(0,σ2t) represents a Gaussian random variable with mean μ and standard deviation σ_i .The standard deviation σ_i indicates the range the offspring is created around the parent trial solution σ_i is given according to the following equation:

$$\sigma_i = \beta * (\lambda_{it} / \lambda_{min}) * (P_{max} - P_{min}) \quad (19)$$

where β is a scaling factor, which can be tuned during the process of search for optimum. After adding a Gaussian random number to parents, the element of offspring may violate real power constraints.

d) Competition & Selection

The parent trial vectors and their corresponding offspring and contend for survive with each other within the competing pool. The score for each trial vector after a stochastic competition is given by

$$W_{pi} = \sum_{t=1}^{Np} W_t$$

$$\text{Where} \quad W_t = 1; \text{if} : u_1 > f_{pi} / f_{pr} + f_{pi}; \quad (20)$$

$$= 0, \text{otherwise}$$

Where the competitor Pr selected at random from among the 2Np trial solutions based on r = [2Np u2+ 1].u_1, u_2 are uniform random number ranging over[0, 1].After competing, the 2Np trial solutions, including the parents and the offspring, are ranked in the descending order of the score obtained. The first Np trial solutions survive and are transcribed along with their objective functions f_{pi} into the survivor set as the basis of the next generation. A maximum number of generations (i.e., iterations) N, is given.

e) Next generation and the terminating criteria

Steps c and d are repeated until terminating criteria is satisfied and the terminating criteria RDG = (J − q*) / q* or at least check for the RDG ≤ 0.005 for convergence

D) Particle Swarm Optimization

PSO is an evolutionary computation technique developed by Kennedy and Eberhart. It is an exciting new methodology in evolutionary computation which is similar to Genetic Algorithm GA and EP in that the system is initialized with a population of random solutions. In addition, it searches for the optimum by updating generations, and population evolution is based on the previous generations. In PSO, the potential solutions, called particles are "flown" through the problem space by following the current optimal particles. Each particle adjusts its flying according to its own flying experience and its companion's flying experience [11].

The update of the particles is accomplished by the following which calculates a new velocity for each particle (potential solution) based on its previous velocity (V_{id}), the particle's location at which the best fitness so far has been achieved (pbestid),and the population global location (gbestd) at which the best fitness so far has been achieved. Equation (21) updates each particle's position in the solution hyperspace. The modified velocity and position of each particle can be calculated using the current velocity and distance from pbestid to gbestd as shown in the following equations:

$$V_{id}^{(t+1)} = [w * V_{id}^{t} + C_1 * rand_1() * (Pbest_{id} - X_{id}) + C_2 * rand_2() * (gbestd - X_{id}^{t})] \quad \text{--} \quad (21)$$

$$X_{id}^{(t+1)} = X_{id}^{(t)} + V_{id}^{(t+1)} \quad (22)$$

Where xi (dt) : current position of particle i at iteration w : inertia weight factor,

t	: number of iterations,
n	: number of particles in a group,
m	: number of members in a particle,
k	: constriction factor ,
C1, C2	: acceleration constant,
rand ( )	: random number between 0 and 1.

The velocity value of each dimension is clamped to the range. ($-v_{id}$ max , x_{id} max). Here, v_{id} max is usually chosen to be k* x_{id} max , with 0.1 < k < 1, where x_{id} *max* denotes the domain of search space

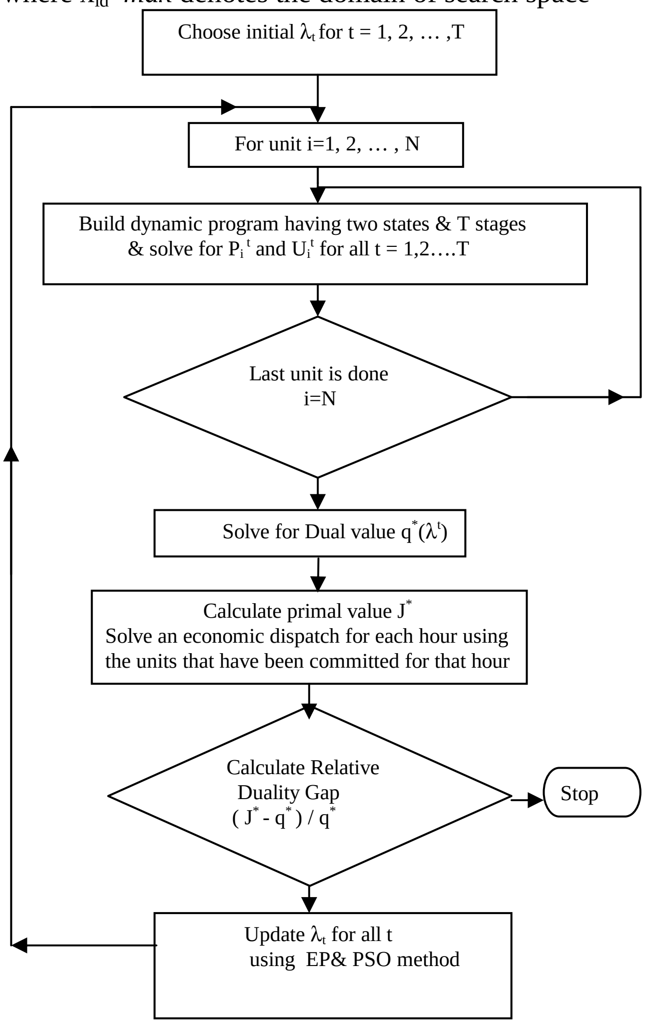

Fig 2: Flow Chart for update the λ using EP and PSO method

E) PSO Implementation in to PBUC

step (1) :Set the *n* number of the particle population, acceleration coefficients c1 and c2, inertia weight w, maximum be:

n=500, c1 = 1.9, c2 =1.8, w =0.75, Max.Iter=15.

Step(2**)**:Set particles maximum and minimum velocity and position range. Positions of all particles are generated randomly.

Step (3):According to the position of each particle, calculate the power generation .If for any article, a new particle should be yielded randomly to replace this one and the power generation should be calculated again until the particle position satisfies the load bus generation limit.

Step (4):Based on the result of power generation, calculate the fitness of each particle. According to the fitness of particles update the global best position of the population and personal best position of each particle.

Step (5) :Update the velocity and position of all particles using eqn. 21 and eqn. 22

Step (6): Evaluate whether maximum iteration has reached. If not, go to Step 3.

Step (7): Acquire the global optimization solution. All saved best position values are compared and the best one is as the optimum. Calculate the power generation corresponding to this best particle position.

4. **Test System and Results**

The PBUC problem solution method is implemented in Mat lab-7.3.We use a generation company with 3 generating units to illustrate the proposed method. In our implementation, energy and reserve are considered simultaneously in the formulation 12 h scheduling period is considered. Fuel cost function of each generating unit is estimated into quadratic form .Unit data, forecasted demand, reserve and market prices are given in Tables 1, 2 and which is obtained from Reference [14].

Table – 1 : Generating Unit Data

	Unit 1	Unit 2	Unit 3
Pimin (MW)	600	400	200
Pimax (MW)	100	100	50
a($/h)	500	300	100
b($/MW-h)	10	8	6
c($/MW^{2-}h)	0.002	0.0025	0.005
Min up time (h)	3	3	3
Min down time (h)	3	3	3
Start up cost($)	450	400	300
Initial status(h)	-3	3	3

Table -2 : Demand Forecasting and Spot Price

Time t (hours)	P_{dt} (load demand in MW at hour t)	SPOT PRICE (RS/MW-h)
1	170	10.55
2	250	10.35
3	400	09.00
4	520	09.45
5	700	10.00
6	1050	11.25
7	1100	11.30
8	800	10.65
9	650	10.35
10	330	11.20
11	400	10.75
12	550	10.60

Table -3 : Results Obtained using Hybrid LR-EP &LR – PSO Method

λ_t t=1 to 12 Hrs	Unit status			Economic power dispatch(MW)		
	U1	U_2	U_3	P1edc	P2edc	P3edc
08.5031	0	1	1	0	0	170
10.0158	0	1	1	0	50	200
10.0074	0	1	1	0	200	200
10.4119	0	1	1	0	320	200
10.0049	1	1	1	100	400	200
15.1053	1	1	1	450	400	200
16.1638	1	1	1	500	400	200
14.0124	1	1	1	200	400	200
13.0092	1	1	1	50	400	200
09.9067	0	1	1	0	130	200
10.0074	0	1	1	0	200	200
11.0176	0	1	1	0	350	200

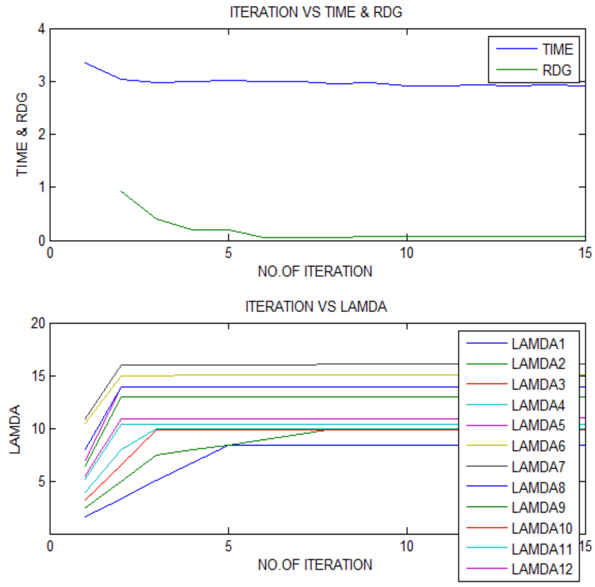

Fig 3. Convergence Characteristics of Hybrid LR and EP method

The profit using LR –EP and PSO method is $ 5387.5 and the corresponding profit using traditional unit commitment in Ref [14] is $ 4262.7.The profit using the LR-EP and PSO is 0.3 % than that of traditional unit commitment and it converges quickly than that of traditional unit commitment. Fig 3,4 shows convergence characteristics of LR-EP and PSO method.

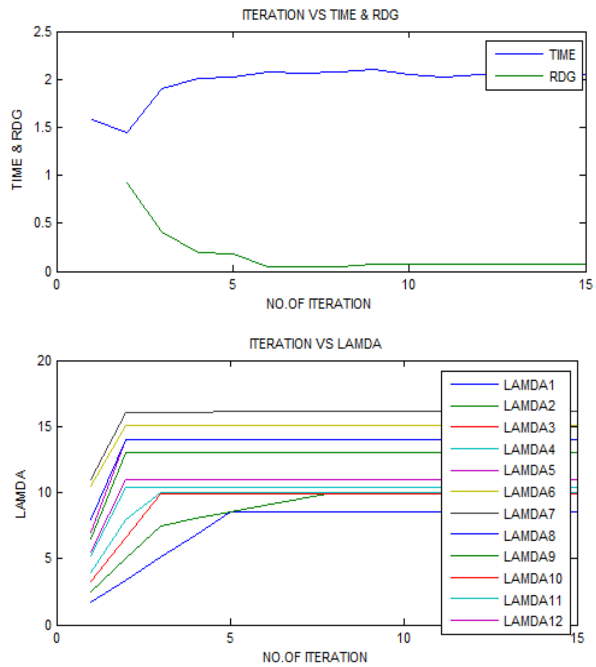

Fig 4 .Convergence Characteristics of Hybrid LR and EP method

5. Conclusion

In this paper, we have established a model of the unit commitment problem based on profit under the deregulated electricity market environment. Moreover, in case of PBUC objective ,the flexibility in the demand constraint both in terms of possibility of buying and selling in the market gives better indication of the likely future scenarios so that better bidding strategy can be made. The numerical results on the generation company with 3 units demonstrate the quick speed convergence and higher accuracy of proposed approach, so it provides a new effective method of profit based unit commitment in deregulated electricity market.

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APPENDIX

P_{it} : real power output of generator i at hour t,

U_{it} : the ON/OFF status of generator i at hour t,

ST_i : startup cost of generator i,

F_i : fuel cost function of generator i,

N : the total number of generator units,

P_{dt} : load demand at hour t,

P_{imin} : minimum generation limit of generator i ,

P_{imax} : maximum generation limit of generator i ,

Sp_t : the forecasted spot price at hour t ,

SR_t : the spinning reserve requirement at hour t

R_{it} : reserve power output of generator i at hour t,

P_i : real power output of generator i

R_i : real power output of generator i

λ^t : Lagrangian multiplier at hour t

r : the probability of calling

P_{iedc} : economic power output of generator

Bibliographies:

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