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

S.CHITRA SELVI   R.P.KUMUDINI DEVI
Department of Electrical and Electronics Engineering, College of Engineering, Anna University, Chennai, India.
prakasini2004@yahoo.co.in, kumudinidevi@annauniv.edu

C.CHISTOBER ASIR RAJAN
Department of Electrical and Electronics Engineering, Pondicherry Engineering College, Pondicherry, India.
Email-asir_70@hotmail.com

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 
(or) 
Min. operating Cost = TC-RV

Subject to constraints

1) Real Power Constraints

\[ \sum_{i=1}^{N} P_{it} \cdot U_{it} \leq P_{i} \] for \( t=1 \ldots T \) \hspace{1cm} (3)

2) Reserve Constraints

\[ \sum_{i=1}^{N} R_{it} \cdot U_{it} \leq S_{Rt} \] for \( t=1 \ldots T \) \hspace{1cm} (4)

3) Real and Reserve power operating limits

\[ P_{i}^{min} \leq P_{i} \leq P_{i}^{max} \] for \( i=1 \ldots N \) \hspace{1cm} (5)

\[ 0 \leq R_{i} \leq P_{i}^{max} - P_{i}^{min} \] for \( i=1 \ldots N \) \hspace{1cm} (6)

\[ R_{i} + P_{i} \leq P_{i}^{max} \] for \( i=1 \ldots N \) \hspace{1cm} (7)

4) Minimum Up and Downtime constraint \hspace{1cm} (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)

\[ L(P, R, \lambda) = TC - RV - \sum_{t=1}^{T} \lambda(P_{dt} - \sum_{i=1}^{N} P_{it} \cdot U_{it}) \] \hspace{1cm} (9)

\[ RV = \sum_{i=1}^{N} \sum_{t=1}^{T} (P_{it} \cdot SP) \cdot U_{it} \] \hspace{1cm} (10)

\[ TC = (1-r) \sum_{i=1}^{N} \sum_{t=1}^{T} (P_{it} \cdot RP) \cdot U_{it} + r \sum_{i=1}^{N} \sum_{t=1}^{T} (P_{it} \cdot RS) \cdot U_{it} \] \hspace{1cm} (11)

3. Solution Methodologies

A) Lagrangian Relaxation Method

Algorithm for LR Method

Step (1) : Assume \( \lambda_{i} \) (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

\[ P_{i} = \frac{\lambda - b_{i}}{2a_{i}} \] \hspace{1cm} (12)

If \( P_{i} > P_{i}^{max} \), then \( P_{i} = P_{i}^{max} \)

If \( P_{i} < P_{i}^{min} \), then \( P_{i} = P_{i}^{min} \)

Step (4) : Find the loading constraints

\[ L_{at} = P_{dt} - \sum_{i=1}^{N} P_{it} \cdot U_{it} \]

Step (5) : Calculate the economic dispatch

Step (6) : Calculate the dual function (maximizing \( \lambda \))

\[ q(\lambda) = F(P_{it} \cdot U_{it}) - \sum_{t=1}^{T} \lambda(P_{dt} - \sum_{i=1}^{N} P_{it} \cdot U_{it}) \] \hspace{1cm} (13)

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

\[ J = F(\sum_{i=1}^{T} P_{i} \cdot U_{it}) \] \hspace{1cm} (14)

Step (8) : Calculate the Relative Duality Gap

\[ RDG = (j-q^{*})/q^{*} \] \hspace{1cm} (15)

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

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]:

![Evolutionary Programming Algorithm](image)

1. Initialization: An initial population of parent individuals \( P_{i}, i=1, NP \), 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 \( P_{i}, i=1, \ldots, NP \), is generated by adding a Gaussian random variable with zero mean and pre selected standard deviation to each component of \( P_{i} \). 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 \( f(P_{i}) \) and \( f(P_{i}^{*}) \). 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,

- \( \text{Pi} \) : Initial Population,
- \( \text{Pi}^* \) : Offspring Population,
- \( \text{NP} \) : Number of Population,
- \( f(\text{Pi}) \) : Fitness value of initial population
- \( f(\text{Pi}^*) \) : 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 a Lagrange multiplier :

\[
\lambda = [\lambda_1, \lambda_2, ..., \lambda_T]
\]

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 \( \lambda_u \) and \( P_a \) is created from each parents \( \lambda \) and \( P_a \) by adding to each components of \( \lambda \) and \( P_a \) a Gaussian random variable with zero mean and a standard deviation proportional to the scaled values of the parent trial solution,

\[
\lambda_i = \lambda_i + N(0, \sigma_{12})
\]

Where \( N(0, \sigma_{12}) \) represents a Gaussian random variable with mean \( \mu \) and standard deviation \( \sigma_{1} \). The standard deviation \( \sigma_{1} \) indicates the range the offspring is created around the parent trial solution \( \sigma_{1} \) is given according to the following equation:

\[
\sigma_{1} = \beta \times (\lambda_{\text{max}} / \lambda_{\text{min}}) \times (P_{\text{max}} - P_{\text{min}})
\]

where \( \beta \) 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

\[
W_{it} = \sum_{i=1}^{\text{NP}} W_{it}
\]

Where \( W_{it} = \begin{cases} 1; & \text{if } u_{it} > f_{Pi} / f_{Pi} + f_{Pi}^* \quad \text{or } RDG = 0, \text{otherwise} \\ \end{cases}
\]

Where the competitor Pr selected at random from among the 2Np trial solutions based on \( r = \lfloor 2Np u_{2+1} \rfloor \), \( u_1 \), \( u_2 \) 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 \( \leq 0.005 \) 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 \( V_{it} \), the particle's location at which the best fitness so far has been achieved \( (\text{pbest}id) \), and the population global location \( (\text{gbest}d) \) 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 gbestid as shown in the following equations:

\[
V_{it}^{(t+1)} = wV_{it}^{(t)} + C_1 \cdot r_1 \cdot (\text{pbest}_{it} - X_{it}^{(t)}) + C_2 \cdot r_2 \cdot (\text{gbest} - X_{it}^{(t)})
\]

\[
X_{it}^{(t+1)} = X_{it}^{(t)} + V_{it}^{(t+1)}
\]

Where \( X_{it} \) : current position of particle i at iteration \( t \), \( W \) : 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. \(-v_{id}^{\text{max}}, x_{id}^{\text{max}}\). Here, \(v_{id}^{\text{max}}\) is usually chosen to be \(k \cdot x_{id}^{\text{max}}\), with \(0.1 < k < 1\), where \(x_{id}^{\text{max}}\) denotes the domain of search space.

**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:

\(n = 500, c1 = 1.9, c2 = 1.8, w = 0.75, \text{Max.Iter} = 15\).

**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 MATLAB 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>
<thead>
<tr>
<th>Table – 1 : Generating Unit Data</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pimin (MW)</td>
<td>600</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>Pimax (MW)</td>
<td>100</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>a($/h)</td>
<td>500</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>b($/MW-h)</td>
<td>10</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>c($/MW^2h)</td>
<td>0.002</td>
<td>0.0025</td>
<td>0.005</td>
</tr>
<tr>
<td>Min up time (h)</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Min down time (h)</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Start up cost($)</td>
<td>450</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>Initial status(h)</td>
<td>-3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Table -2 : Demand Forecasting and Spot Price

<table>
<thead>
<tr>
<th>Time t (hours)</th>
<th>$P_d(t)$ (load demand in MW at hour t)</th>
<th>SPOT PRICE (RS/MW-h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>170</td>
<td>10.55</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>10.35</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>09.00</td>
</tr>
<tr>
<td>4</td>
<td>520</td>
<td>09.45</td>
</tr>
<tr>
<td>5</td>
<td>700</td>
<td>10.00</td>
</tr>
<tr>
<td>6</td>
<td>1050</td>
<td>11.25</td>
</tr>
<tr>
<td>7</td>
<td>1100</td>
<td>11.30</td>
</tr>
<tr>
<td>8</td>
<td>800</td>
<td>10.65</td>
</tr>
<tr>
<td>9</td>
<td>650</td>
<td>10.35</td>
</tr>
<tr>
<td>10</td>
<td>330</td>
<td>11.20</td>
</tr>
<tr>
<td>11</td>
<td>400</td>
<td>10.75</td>
</tr>
<tr>
<td>12</td>
<td>550</td>
<td>10.60</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>$\lambda_t$</th>
<th>Unit status</th>
<th>Economic power dispatch (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t=1 to 12 Hrs</td>
<td>U1</td>
<td>U2</td>
</tr>
<tr>
<td>08.5031</td>
<td>0 1 1</td>
<td>0 0 170</td>
</tr>
<tr>
<td>10.0158</td>
<td>0 1 1</td>
<td>0 50 200</td>
</tr>
<tr>
<td>10.0074</td>
<td>0 1 1</td>
<td>0 200 200</td>
</tr>
<tr>
<td>10.4119</td>
<td>0 1 1</td>
<td>0 320 200</td>
</tr>
<tr>
<td>10.0049</td>
<td>1 1 1</td>
<td>100 400 200</td>
</tr>
<tr>
<td>15.1053</td>
<td>1 1 1</td>
<td>450 400 200</td>
</tr>
<tr>
<td>16.1638</td>
<td>1 1 1</td>
<td>500 400 200</td>
</tr>
<tr>
<td>14.0124</td>
<td>1 1 1</td>
<td>200 400 200</td>
</tr>
<tr>
<td>13.0092</td>
<td>1 1 1</td>
<td>50 400 200</td>
</tr>
<tr>
<td>09.9067</td>
<td>0 1 1</td>
<td>0 130 200</td>
</tr>
<tr>
<td>10.0074</td>
<td>0 1 1</td>
<td>0 200 200</td>
</tr>
<tr>
<td>11.0176</td>
<td>0 1 1</td>
<td>0 350 200</td>
</tr>
</tbody>
</table>

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 3. Convergence Characteristics of Hybrid LR and EP method

Fig 4. Convergence Characteristics of Hybrid LR and EP method
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,
\[ P_{th} \] : load demand at hour \( t \),
\[ P_{min} \] : minimum generation limit of generator \( i \),
\[ P_{max} \] : maximum generation limit of generator \( i \),
\[ S_P \] : the forecasted spot price at hour \( t \),
\[ SR_{it} \] : the spinning reserve requirement at hour \( t \),
\[ R_d \] : reserve power output of generator \( i \) at hour \( t \),
\[ P_i \] : real power output of generator \( i \),
\[ R_i \] : real power output of generator \( i \),
\[ \lambda^i \] : Lagrangian multiplier at hour \( t \),
\[ r \] : the probability of calling
\[ P_{edc} \] : economic power output of generator

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.

References

S. Chitra Selvi was born in 1974. She has received the B.E. (Electrical and Electronics) degree from the Bharathiar University, Coimbatore and the M.E. degree in power system from the Madurai Kamaraj University, Madurai, India, in 1995 and 1999, respectively. She is currently pursuing the Ph.D. degree in power systems engineering at College of Engineering, Guindy, Anna University, Chennai, India. She has published technical papers in national journals and international journals, conferences. Her areas of interests are power system optimization, operational planning, and control, Deregulated Power System, FACTS.

R.P. Kumudini Devi was born in 1968. She has received the B.E. (Electrical and Electronics) degree from the Andhra University, M.E. and PhD degree in power system from the Anna University, College of engineering, Guindy, Chennai, India. Currently, she is working as an Assistant Professor in the Electrical Engineering Department at Anna University. She has published technical papers in international and national journals and conferences. Her area of interest is Voltage Stability, Deregulated Power System and FACTS.

C. Christober Asir Rajan was born in 1970. He received the B.E. (hons.) electrical and electronics degree and the M.E. (hons.) degree in power system from the Madurai Kamaraj University, Madurai, India, in 1991 and 1996, respectively. He has received the PhD degree from the Anna University; College of engineering, Guindy Chennai, India. He has received the postgraduate degree in D.I.S. (Hons.) from Annamalai University, Chidambaram, India. He is currently working as Assistant Professor in Pondicherry Engineering College, Pondicherry, India. Currently, He has published technical papers in international and national journals and conferences. His areas of interest are power system optimization, operational planning, and control. Mr. Rajan is a member of ISTE and MIE in India and a student member with the Institution of Electrical Engineers, London, U.K.