Emission Constraint Profit based Unit Commitment Problem using Improved Bacterial Foraging Algorithm

K. Selvakumar*, C. S. Boopathi¹ and T. Venkatesan²

¹Department of EEE, SRM University, Kattankulathur - 603203, Tamil Nadu, India; selvakse@gmail.com, cs.bhoopathy@gmail.com
²Department of EEE, K. S. Rangasamy College of Technology, Tiruchengode - 637215, Tamil Nadu, India; pramoth99@yahoo.co.uk.

Abstract

Objectives: The main objective function is to increase the Generation Companies profit and reduce the GHG gas emission of the thermal generating units. Methods/Analysis: During the most recent few centuries, emission control has become a very big problem of worlds concern due to the frequently increasing pollution of earth’s atmosphere. In order to reach the emission control in this paper the Improved Bacterial Foraging Algorithm (IBFA) is proposed. The Bacterial Foraging Algorithm is formed by foraging behavior of E-coli Bacteria in the human intestine. But the BF algorithm leads to some convergence problem while solving the large problems. So for improving the performance of the large problems the new integer coded Improved Bacterial Foraging Algorithm is proposed. Findings: The proposed method is implemented to the IEEE 39 bus10 unit system with one day time period. This proposed algorithm is simulated using MATLAB software and the output results are compared with traditional Unit Commitment Method. Novelty/Improvement: The restructuring of electric power industry is used to reform the electric supply industry. The generation scheduling of thermal generating units in deregulated environment is named as Profit Based Unit Commitment. In PBUC problem the normal Demand constraint is changed to modified power demand constraint to increase the GENERation Companies (GENCO) profit.

Keywords: Emission Limitation, GENeration Companies (GENCO), Improved Bacterial Foraging Algorithm (IBFA), Profit Based Unit Commitment (PBUC), Unit Commitment (UC)

1. Introduction

Unit Commitment (UC) is the most important optimization task in optimal dispatch of units to the load and reserve among the committed units. In deregulated power industry, the horizontally integrated electric utilities are changed into vertically integrated electric utilities. So the traditional Commitment method wants some changes in generation schedule, to increase the GENERation COmpanies (GENCOs) profit. In deregulated power system the consumers get at lower price, higher quality and more trustworthy power. The market-based competition among generating companies creating an open market environment. Also it has the main benefit is that consumers are directly permitted to select their suppliers.

The revenue is calculated by the forecasted demand and expected market price and it plays a extremely important role in PBUC. A solution of the spot markets prices in profit based unit commitment problem is proposed. The fossil fuelled thermal units are considered as major sources of emission pollution. The type of fuel used for power generation decides the amount of GHG emission. The pulverized coal fired units produce emission two and half times higher than the natural gas-fired power plants in combined cycle configuration.

The increase in atmospheric temperature proportional to the altitude is called as temperature inversion.
There is reduction in atmospheric temperature as altitude increases. But, in some cases these processes get reversed and cold air remains near the earth surface. This implies no circulation of air pollution is trapped at earth surface causing stillness of air and smog.

The performance of PBUC problem using Genetic Algorithm (GA) is not easy to get a best solution. Particle Swarm Optimization has premature convergence problem to solve PBUC. A realistic approach for emission limitation and trade off curve in deregulated system found by varying the weighting factor between 0 and 1. From the bibliological survey, it is observed that most of the conventional methods have some restrictions to present the qualitative solution.

The Bacterial Foraging Algorithm was successfully applied to different applications like harmonic estimation, voltage stability analysis and load compensation. The BFA is proposed to solve unit commitment problem solution for IEEE 39 bus 10 units bus system in deregulated environment is proposed and the emission limitations are not considered as one of the objective function.

The proposed technique is explained with flowchart in Section 2. The formation of PBUC problem is explained in Section 3. The simulation result is discussed in Section 4 followed by a conclusion and references in Section 5 and 6.

2. Improved Bacterial Foraging Algorithm

When solving the problem in conventional Bacterial Foraging algorithm the choice of parameters linking to swarming effect and repellent bacteria may gives in too much repellent of bacteria and it will influence the convergence of the method. Furthermore, the Improved Bacterial Foraging algorithm is recommended. In the basic Bacterial Foraging method health of bacteria may not retain the greatest bacterium for the next unit generation. But the calculation of profit for any combination of generating unit commitment is time consuming.

swarming, the distance of novel chemotactic stage bacteria is calculated from global optimum bacterium.

2.1 Proposed Method Algorithm

Step 1 - Initialization of $S$, $P$, $N$, $N_c$, $N_r$, $N_e$, $P_e$, $C(i)$, $d_{attract}$, $w_{attract}$, $h_{repellent}$ and $w_{repellent}$, $j=k=l=0$.

Step 2 - Update Number of parameters by using $\theta$ and calculate $J(i,j,k,l)$.

Step 3 - Let $J_{last} = J(i,j,k,l)$ to save this value to find a better cost via number of iterations.

Step 4 - Generate a random vector $\Delta(i) \in \mathbb{R}^P$ with each element $\Delta_s(i), m = 1, 2...P$. and update $\theta$ and $J$ value by using the Equation (1) and (2).

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i) \frac{\Delta(i)}{\sqrt{\sum_{i}^{N} \Delta(i)}}$$  \hspace{1cm} (1)

$$J_{last}(i,j+1,k,l) = J(i,j+1,k,l) + J_{sw}(i,j,k,l)$$  \hspace{1cm} (2)

Step 5 - If $m = N_s$ go to next bacterium for calculation of $\theta$ and $J$.

Step 6 - If $j < N_c$, go to Step 3 to continue Chemotaxis.

Step 7 - Calculate $J_{health}$ values by using Equation (3) and arrange the values in ascending order.

$$J_{health} = \min_{j=1}^{N_c} \{J_{sw}(i,j,k,l)\}$$  \hspace{1cm} (3)

Step 8 - If $k < N_r$ go to Step 2.

Step 9. Elimination-dispersal: For $i = 1, 2,... S$, with probability $P_{ed}$, eliminates and disperses each bacterium.

Step 10. If $l < N_{ed}$, then go to Step 2 if not go to end.

3. Formulation of PBUC Problem

In PBUC problem generating units always increase the profit of the generation companies and reduce the output of all GHG gases. In order to increase GENCOs profit calculated based on forecasted load demand, spinning reserve, spot prices in the markets. Flowchart for proposed PBUC Bacterial Foraging Algorithm is shown in Figure 1.

$$\max PF = RV - TC$$  \hspace{1cm} (4)

$$\min EC_i(P_{at}) = \alpha_i + \beta_i P_{at} + \gamma_i (P_{at})^2$$

$$RV = \sum_{i=1}^{T} \sum_{i=1}^{N} P_i S_i P_i X_{it}$$  \hspace{1cm} (5)
The various constraints for the objective function

\[ TC = \sum_{t=1}^{T} \sum_{i=1}^{N} FC_i(P_i)X_{it} + ST \]  
(6)

3.1 Demand Constraint

\[ \sum_{i=1}^{N} P_{it}X_{it} \leq PD_t, \quad t = 1 \ldots T \]  
(7)

3.2 Generation Limit Constraint

\[ P_{i_{\text{min}}} \leq P_{it} \leq P_{i_{\text{max}}} \]  
(8)

\[ 0 \leq R_{it} \leq P_{i_{\text{max}}} - P_{i_{\text{min}}} \]  
(9)

3.3 Minimum Up and Down-Time Constraint

\[ T_{i_{\text{ON}}} \geq MU_i \]  
(10)

\[ T_{i_{\text{OFF}}} \geq MD_i \]  
(11)

3.4 System Power and Reserve Constraints

\[ P_{i_{\text{min}}} \leq P_{it}X_{it} + R_{it}X_{it} \leq P_{i_{\text{max}}} \]  
(12)

\[ \sum_{i=1}^{N} R_{it}X_{it} \leq R_{it_{\text{max}}} \]  
(13)

E. Ramp up and down rates

\[ P_{it_{\text{max}}} = \min\{P_{i_{\text{max}}}, P_{i_{\text{max}}}(t-1) + \tau.RU_i\} \]  
(14)

\[ P_{it_{\text{min}}} = \max\{P_{i_{\text{min}}}, P_{i_{\text{min}}}(t-1) - \tau.RD_i\} \]  
(15)

Where \( \tau = 60 \text{ min} \) is the time step.

4. Simulation Result

The proposed Improved Bacterial Foraging Algorithm (IBFA) has been implemented by using MATLAB software and tested on IEEE39 bus with 10 units system. The operator data, emission data, forecasted load demand and Spot prices for the IEEE 39 bus system is given in appendix.

To achieve the faster convergence in the proposed method occurs when \( S = 6, Nc = 30, Ns = 4, Ned = 5, Nre = 10, Ped = 0.02 \) and together with the number of scheduled hours and generating units taken in the study. The chemotactic phase is updated in the every iteration of the proposed algorithm. The fast convergence is achieved by varying the control parameters. \( S, N_c, N_s, N_{ed}, \) and \( N_{ed} \) are selected in steps and the algorithm is run for a number of times.

![Flowchart for PBUC bacterial foraging algorithm.](image)

Figure 1. Flowchart for PBUC bacterial foraging algorithm.

The computational time varies linearly with the number of chemotactic size as shown in Figure 2. System spinning reserve is taken as the fraction of reserves that the GENCO should maintain for every contract.

Table 1 shows the Traditional Unit Commitment output for the given scheduling horizon. In the TUC generation scheduling, units 7, 8, 9 and 10 gives high emission over the scheduling period. Figure 3 shows the Plot of revenue, fuel cost and profit with respect to time for PBUC by IBFA. Figure 4 shows the Comparison of profits between Traditional Unit Commitment and PBUC for IBFA. The dispatched output power demand and fore-
casted power demand comparison is given in Figure 5 and Figure 6 shows the GHG emission comparison of TUC and PBUC for 10 unit systems.

Table 2 shows the proposed PBUC generation scheduling output. In the schedules, it may appear as if up and down times limits are being not violated. From Table 3, it is understandable that the IBF algorithm gives highest profit and lowest emission output when compared to the Traditional UC methods.

5. Conclusion

The Profit Based Unit Commitment problem with operational and environmental constraints in a deregulated power system using Improved Bacterial Foraging Approach is proposed in this paper. The IBF method always gives better numerical convergence for the scheduling period in the simulation. This new integer-code Improved Bacterial Foraging Algorithm provides the maximization of GENCOs profit, reducing emission output and schedules the thermal generating units in addition to the satisfaction of various constraints like
### Table 1. Comparison of the results by LR, TUC and proposed method

| Sl. No | Method               | Profit (Rs/day) | Profit (Rs/year) | Emission (ton/day) | Emission (ton/year) |
|--------|----------------------|-----------------|------------------|-------------------|--------------------|
| 1      | Traditional UC       | 3370353         | 1230178845       | 28317.8544        | 103360616.856      |
| 2      | PBUC using BFA       | 3731192.3       | 1361885190       | 26763.7449        | 9768766.8885       |

### Table 2. Simulation result of the traditional UC method

| Units | Power Generation of Units (MW) | Generation Cost (Rs) | Start up Cost (Rs) | Revenue (Rs) | Profit (Rs) | Emission (tons) |
|-------|---------------------------------|----------------------|--------------------|---------------|-------------|----------------|
| Hour  |                                 |                      |                    |               |             |                |
| 1     |                                 | 615740.84            | 0.00               | 697725        | 81984.16    | 682.7662       |
| 2     |                                 | 654952.49            | 0.00               | 742500        | 87547.51    | 754.7842       |
| 3     |                                 | 733585.04            | 0.00               | 883575        | 149990      | 945.6202       |
| 4     |                                 | 838695.63            | 25200.00           | 968287.5      | 104391.9    | 975.0131       |
| 5     |                                 | 900900.88            | 40500.00           | 1046250       | 104849.1    | 1052.409       |
| 6     |                                 | 1002436.86           | 7650.00            | 1136025       | 125938.1    | 1231.27        |
| 7     |                                 | 1047926.01           | 0.00               | 1164375       | 116449      | 1234.564       |
| 8     |                                 | 1123836.12           | 11700.00           | 1196100       | 60563.88    | 1268.812       |
| 9     |                                 | 1254256.42           | 2700.00            | 1333800       | 76843.58    | 1356.07        |
| 10    |                                 | 1375520.09           | 0.00               | 1849050       | 473529.9    | 1360.735       |
| 11    |                                 | 1405945.77           | 24750.00           | 1967288       | 536592.2    | 1390.636       |
| 12    |                                 | 1468549.18           | 0.00               | 2136375       | 667825.8    | 1395.77        |
| 13    |                                 | 1321467.68           | 0.00               | 1549800       | 228332.3    | 1325.007       |
| 14    |                                 | 1223904.02           | 0.00               | 1433250       | 209346      | 1292.422       |
| 15    |                                 | 1191400.02           | 5400.00            | 1215000       | 181999.98   | 1358.988       |
| 16    |                                 | 1072779.16           | 0.00               | 1053675       | -19104.2    | 1105.929       |
| 17    |                                 | 1035416.60           | 0.00               | 1001250       | -34166.6    | 1021.536       |
| 18    |                                 | 1070446.82           | 0.00               | 1091475       | 21028.18    | 1273.654       |
| 19    |                                 | 1142610.58           | 25200.00           | 1198800       | 30989.42    | 1301.349       |
| 20    |                                 | 1348631.47           | 2700.00            | 1426950       | 75618.53    | 1398.146       |
| 21    |                                 | 1243280.33           | 0.00               | 1351350       | 108069.7    | 1374.143       |
| 22    |                                 | 1016857.38           | 0.00               | 1136025       | 119167.6    | 1334.318       |
| 23    |                                 | 897587.69            | 14400.00           | 921375        | 9387.31     | 901.4489       |
| 24    |                                 | 792120.15            | 2700.00            | 811800        | 16979.85    | 982.4638       |
| Total |                                 | 25778847.23          | 162900.00          | 29312100.5    | 3370353     | 28317.8544     |

### Table 3. Simulation result of the proposed method

| Units | Power Generation of Units (MW) | Generation Cost (Rs) | Start up Cost(Rs) | Revenue (Rs) | Profit (Rs) | Emission (tons) |
|-------|---------------------------------|----------------------|--------------------|---------------|-------------|----------------|
| Hour  |                                 |                      |                    |               |             |                |
| 1     |                                 | 657407.3            | 0                  | 697725        | 40317.7     | 682.7662       |
| 2     |                                 | 696619.0            | 0                  | 742500        | 45881.0     | 754.7842       |
| 3     |                                 | 775251.5            | 0                  | 883575        | 108323.5    | 945.6202       |
mission Constraint Profit based Unit Commitment Problem using Improved Bacterial Foraging Algorithm

maximum up and minimum down time limits of units without using penalty functions. The results obtained by proposed method Traditional Unit Commitment are compared with Profit Based Unit Commitment, it is clear that the production cost and emission output level in TUC is more as compared to the production cost and emission output level of PBUC. In total production cost, maintenance cost and shut down cost of the generating units is not included. From the discussion, it was concluded that the profit will be increased and emission level reduced by using IBFA method.

6. References

1. Wood J, Wollenberg BF. Power generation operation and control. 3rd ed. Wiley: New York; 1984.
2. Conejo, Antonio J, Carrión, Miguel, Morales, Juan M. Decision making under uncertainty in electricity markets. International Series in Operations Research and Management Science. 2010; 153(1):1–26.
3. Selvakumar K, Vijayakumar K, Palanisamy R, Karthikeyan D, Santhoshkumar G. SFLA to solve Short term thermal unit commitment problem with startup and shutdown ramp limits. International Review on Modelling & Simulations. 2015 Dec; 8(6):670–8.
4. Boopathi CS, Dash SS, Selvakumar K, Venkadesan A, Subramani C, Vamsikrishna D. Unit commitment problem with POZ constraint using dynamic programming method. International Review of Electrical Engineering. 2014; (9):218–25.
5. Shahidehpour SM, Yamin HY, Li Z. Market operations in electric power systems. John Wiley and Sons; 2002.
6. Effatnejad R, Rouhi F. Unit commitment in power system by combination of Dynamic Programming (DP), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). Indian Journal of Science and Technology. 2015 Jan; 8(2).
7. Balasubramanian KP, Santhi RK. Best compromised schedule for multi-objective unit commitment problems. Indian Journal of Science and Technology. 2016 Jan; 9(2). DOI:10.17485/ijst/2015/v9i2/57782.
8. Cai X, Cui Z, Zeng J, Tan Y. Dispersed particle swarm optimization. Information Proceeding Latter; 2007.
9. Dimitroulas K, Dionisios, Pavlos S, Georgilakis. A new mimetic algorithm approach for the price based unit commitment problem. Applied Energy. Dec 2011; 88(12):4687–99.
10. Erik D, Van den Bosch Pieterjan, William D. Effect of the accuracy of price forecasting on profit in a Price Based Unit Commitment. Electric Power Systems Research. 2010 Oct; 80(10):1306–13.

11. Catalao JPS, Mariano SJPS, Mendes VMF, Ferreira LAFM. A practical approach for profit-based unit commitment with emission limitation. International Journal of Electrical Power and Energy Systems. 2010 Mar; 32(3):218–24.

12. Mishra S. Hybrid least-square adaptive bacterial foraging strategy for harmonic estimation. In IEE Proc Gener, Transm, Distrib. 2005 May; 152(3):379–89.

13. Mishra S. A hybrid least square-fuzzy bacteria foraging strategy for harmonic estimation. IEEE Transactions on Evolutionary Computation. 2005 Feb; 9(1):61–73.

14. Tripathy M, Mishra S. Bacteria foraging-based solution to optimize both real power loss and voltage stability limit. IEEE Transactions Power Systems. 2007 Feb; 22(1):240–8.

15. Mishra S, Bhende CN. Bacterial foraging technique-based optimized active power filters for load compensation. IEEE Transactions in Power Delivery. 2007 Jan; 22(1):457–565.

16. Eslamian M, Hosseinian SH, Vahidi B. Bacterial foraging-based solution to the unit commitment problem. IEEE Transactions Power Systems. 2009 Aug; 24(3):1478–88.

17. Gharegozi A, Jahani R. A new approach for solving the unit commitment problem by cuckoo search algorithm. Indian Journal of Science and Technology. 2013 Sep; 6(9). DOI: 10.17485/ijst/2013/v6i9/37138.

18. Venkatesan T and Muniraj C. A solution to the profit based unit commitment problem using integer-coded bacterial foraging algorithm. International Review on modeling and simulation. 2014; 7(1):132–41.

19. Selvakumar K, Vignesh RS, Vijayabalan R. Shuffled frog leaping algorithm for solving Profit Based Unit Commitment problem. Proceedings of IEEE ICCCCA; 2012. p. 1–6.

20. Selvakumar K, Venkatesan T, Sanavullah MY. Price based unit commitment problem solution using shuffled frog leaping algorithm. Proceedings of IEEE ICAESM; 2012. p. 794–9.