American-Eurasian Journal of Scientific Research 10 (2): 93-97, 2015
ISSN 1818-6785

DOI: 10.5829/idosi.aejsr.2015.10.2.22014

Day Ahead Energy Market Using Firefly Algorithm

L. Dhinesh Babu, R. Santhosh Kumar and V. Purushothaman

Veltech, Chennai, India

Abstract: In this paper, the bidding strategy is discussed to achieve maximum profit of generating companies (GENCO's) in deregulated market. The profit is maximized by changing their bid coefficient value based on the market demand. The rival values are predicted by the probability density function (PDF). The GENCO's which is trying to maximize its profit, optimize its bid value using Firefly Algorithm (FA). This algorithm is applied for single sided auction markets to maximize the social welfare. The effectiveness of this algorithm is tested for six generating units with single and multi hour trading period.

Key words: Firefly Algorithm (FA) · Generating companies (GENCO's) · Independent System Operator (ISO) · Market Clearing Price (MCP) · Probability Density Function (PDF)

INTRODUCTION

The competitions of power producers and customer choice have made the electric power industry to move from regulated to deregulated environment. In deregulated environment, the power industry has led into separation among generation, transmission and distribution. The competition among the GENCOS's either through the auction or market type [1]. The main aim of traditional unit commitment is to minimize the total operating cost while satisfying system operating constraints [2].

The supplier profit maximization is solved by determining the bidding parameters of each participant. Some researchers have used Monte Carlo and probability density analysis to determine the rivals value [3]. These analyses need more historic data to solve the optimization problem [4-5]. The stochastic optimization techniques using Evolutionary Programming (EP) was discussed to optimize the bidding parameters [6]. The bidding parameters are treated as fuzzy sets and rather crisp sets and provide preliminary results [7].

The variety of restructured models is implemented in many countries. In power pool structure, the Independent System Operator (ISO) acts as decision maker [8-9]. The ISO arrives schedule based on Market Clearing Price (MCP). MCP is based on bid price and selected participant paid MCP to the power pool [10].

Each supplier submits sealed bid to the ISO for the forecasted load. The GENCO's maximize their own profit by strategic bidding [11]. In this paper, it is assumed that the bidding parameter values of rivals' are not known. Their values are predicted by PDF using past historic data. The optimal supplier bid coefficient values are obtained by FA with the objective function of profit maximization. The rivals' values are approximated by PDF and corresponding GENCO's bid values are generated using FA.

The FA is a meta-heuristic algorithm, inspired by the flashing behavior of fireflies and it was developed by Xin-She Yang [12]. FA uses the following three idealized rules: 1) All fireflies are able to attract other fireflies. 2) The degree of the attractiveness of a firefly is proportion to its brightness, thus for any two flashing fireflies, the less brighter one will move towards the more brighter one and the more brightness means the less distance between two fireflies. If there is no brighter one than a particular firefly, it will move randomly. 3) The brightness of a firefly is determined by the value of the objective function. The FA algorithm is computationally effective and easier to implement than other heuristic methods. Compared to earlier meta-heuristic algorithms, FA imposes a fewer mathematical requirements that can be easily adapted for various engineering optimization problems. FA proves its capability by solving permutation flow shop scheduling problems [13] and thus it is extended to solve the UC problem of a deregulated power system.

This paper is organized as follows: Section 2 presents problem formulation of bidding strategy and Section 3 presents profit maximization and Section 4 presents Solution methodology for profit maximization of the supplier, Section 5 presents result and discussion and Section 6 concludes.

Corresponding Author: L. Dhinesh Babu, Veltech, Chennai, India.

Problem Formulation

Bidding Strategy: Consider *n* independent generating companies participate in single sided auction. They submit sealed bid to the ISO for forecasted load and the supply function of GENCO's is:

$$B_i\,(P_i) = \alpha_i + \beta_i P_i \qquad (1)$$

where P_i is the generation output and α_i, β_i are bidding coefficients. Upon receiving bid from the supplier, the ISO determines a set of participant to meet the demand. Based on the bid value MCP is calculated by ISO [3, 4].

$$MCP_i = \frac{PD_t + \sum_{i=1}^{N}(\alpha_i / \beta_i)}{\sum_{i=1}^{N}(1/\beta_i)} \qquad (2)$$

$$P_i = \frac{(MCP_i - \alpha_i)}{\beta_i} \qquad (3)$$

If $P_i < P_{i\min}$, $P_i = 0$, the corresponding GENCO value is considered as zero and removed from the competition for that particular hour only.

If $P_i > P_{i\max}$, $P_i = P_{i\max}$ and the corresponding GENCO provide maximum power value on that hour since it is not a marginal generator.

The market price is fixed by the ISO. The power dispatched from each supplier is checked by the capacity limit of their individual generators.

Supplier Profit Maximization: The main aim of generating companies is to maximizing their own profit. The profit maximization objective is stated as

$$Maximizi\ RF = RV - TC \qquad (4)$$

where *PF* is the profit and *RV* is the Revenue, *TC* is total operating cost.

$$PF = \sum_{i=1}^{N}\sum_{t=1}^{T}\left[MCP_i P_{it} - C_i(P_{it})\right] \qquad (5)$$

where *N* is the number of GENCO's participate in the market and they are decided by their own bidding parameters.

Demand Constraints: The demand constraint is an equality constraint. The total system generation must be equal to the forecasted load.

$$\sum_{i=1}^{N} P_i = \sum_{t=1}^{T} PD_t \qquad (6)$$

Capacity Limit Constraints: Each generator have minimum and maximum capacity limit. These bounds can be defined as pair of inequality constraints.

$$P_{i\min} \le P_i \le P_{i\max} \qquad (7)$$

Probability Desity Function: In single sided auction, the main aim of the supplier is to maximize their own profit. The profit maximization of the GENCO' is based on their bid value and their rivals' bid value. In the sealed bid auction, the data of rivals' values are kept confidential. Hence, the supplier tries to estimate the rivals' value but it is difficult to predict the rivals' value. Using the past data through the PDF, the rivals' values are predicted. The predicted values must obey the joint normal distribution with PDF [3]. The PDF can be expressed as:

$$(\alpha_i, \beta_i) \sim N\left\{\begin{bmatrix}\mu_{i,t}^{(\alpha)} \\ \mu_{i,t}^{\beta}\end{bmatrix}, \begin{bmatrix}(\sigma_{i,t}^{(\alpha)})^2 & \rho_{i,t}\sigma_{i,t}^{(\alpha)}\sigma_{i,t}^{(\beta)} \\ \rho_{i,t}\sigma_{i,t}^{(\alpha)}\sigma_{i,t}^{(\beta)} & (\sigma_{i,t}^{(\beta)})^2\end{bmatrix}\right\} \qquad (8)$$

where $\rho_{i,t}$ is the correlation between α_i and β_i, $\mu_{i,t}^{(\alpha)}$ and $\mu_{i,t}^{(\beta)}$ are mean values, $\sigma_{i,t}^{(\alpha)}$ and $\sigma_{i,t}^{(\beta)}$ are the standard deviation of the marginal distribution α_i and β_i. Each rival value is assumed using joint normal distribution for the bidding coefficients. The supplier bid values are estimated as:

$$\begin{aligned} &\mu_{1,t}^{(\alpha)} = 1.2b_i \ , \ \mu_{i,t}^{(\beta)} = 1.2\times 2c_i \\ &4\sigma_{i,t}^{(\alpha)} = 0.15b_i \ , \ 4\sigma_{i,t}^{(\beta)} = 0.15c_i \\ &\rho_{i,t} = -0.1 \end{aligned} \qquad (9)$$

The supplier expects the rival value 20% above operating cost. By mean and standard deviation the α_i and β_i are specified as $\left[\mu_{i,t}^{(\alpha)} - 4\sigma_{i,t}^{(\alpha)}, \mu_{i,t}^{(\alpha)} + 4\sigma_{i,t}^{(\alpha)}\right]$ and $\left[\mu_{i,t}^{(\beta)} - 4\sigma_{i,t}^{(\beta)}, \mu_{i,t}^{(\beta)} + 4\sigma_{i,t}^{(\beta)}\right]$ respectively, with the probability of 0.999. In supplier profit maximization problem, β is varied through an optimization technique.

Solution Methodology:

Optimizing the Bid Value Using FA: The bid value is optimized for maximizing supplier profit. The FA is used to optimize the corresponding GENCO's β value and $\alpha = a$.

Step 1: Set iteration count as 1. The bidding parameter of corresponding GENCO β_i value is varied using FA and α_i is fixed. The rival values are assumed by PDF.

Step 2: In iteration count 1, the initial populations of fireflies are generated randomly within their limit.

$\beta_{id} = rand(1, d)[\beta_{max} - \beta_{min}] + \beta_{min}$ for i=1,……n, d=1,…..T

Step 3: With the generated values of β_i, the MCP value is calculated. Based on the MCP value $P_{i,t}$ is calculated and the limit values are checked.

Step 4: The intensity I_{id} is calculated form (4). Each firefly attracts the other firefly with more light intensity. Attractiveness function is $\beta = \beta_0 \exp(-\gamma r_k)$: $(I_k > I_i)$ The firefly k attract i and the distance $k = \sqrt{(\beta_i - \beta_k)^2}$

Step 5: The movement of firefly is determined as $\beta_{id} = (1 - \lambda)\beta_{id} + \lambda\beta_{id} + u_{id}$. where the random step size is given by $u_{id} = \eta\left(rand - \frac{1}{2}\right)$ and η is the randomization parameter and rand is used to generate random number between [0,1].

Step 6: The corresponding firefly with maximum value of fitness function with respect to profit maximization is the winning population and steps are repeated until maximum number of iteration is reached.

RESULTS AND DISCUSSION

To illustrate the bidding strategy, test system is discussed for single and multi hour. A six GENCO's system is considered to illustrate the solution methodology. The test system data is given in Appendix as Table A1. The first five GENCO's are considered as rivals'. This system is worked-out for both single and multi hour trading cases. The best values of FA are chosen by experiments carried-out with different values of parameters and are set as: Maximum attractiveness, λ_o=1, Random step size, α=0.01, Absorption coefficient, γ=0.8 and population m=40. The proposed methodology is implemented using MATLAB 7.12, in a Laptop with INTEL core, i3 processor, 3GB RAM environment.

Case A: Single Trading Hour

The GENCO-6 participates in the competition with the aim of maximizing its profit. It attempts to calculate the rivals' bidding data with PDF. This example system is utilized for single hour demand of 500 MW. The fuel cost equation and the revenue generated are expressed as:

$$C_i(P_{it}) = a_i(P_{it})^2 + b_iP_{it} + c_i \tag{10}$$

$$RV = MCP_i \times P_{it} \tag{11}$$

The rival bid values and GENCO-6 bid values are generated using PDF as described in section 3. With these bid values, the MCP, power dispatch, revenue generated, cost spent for this generation and profit is calculated and tabulated. Table 1 shows the results of the six GENCO system without optimizing the bidding strategies.

Table 2 shows the results of six GENCO system with optimized bidding strategies using FA technique.

Table 1: Profit Maximization without optimizing bidding strategy

	Bid quantities						
Unit	α	β	Power (MW)	MCP ($)	Revenue ($)	Cost ($)	Profit ($)
1	2	0.0333	99.4299	5.3050	526.5227	321.6315	204.8912
2	1.75	0.0468	75.9620		402.9799	233.9124	169.0676
3	1.5	0.054	70.4634		373.8096	204.9967	168.8129
4	1.9	0.0333	102.2529		542.4537	324.9761	217.4776
5	1.8	0.0333	105.2559		558.3847	327.9456	230.4391
6	1.85	0.0738	46.8160		248.3599	146.8824	43.4775

Table 2: Profit maximization with optimized bidding strategies using FA

	Bid quantities						
Unit	α	β	Power (MW)	MCP ($)	Revenue ($)	Cost ($)	Profit ($)
1	0	0.0333	97.6055	5.2503	512.4582	314.2964	198.3974
2	0	0.0468	74.7919		392.6799	228.7778	163.9021
3	0	0.054	69.4493		364.6297	200.6381	163.9916
4	0	0.0333	100.6085		528.2248	317.6820	210.5428
5	0	0.0333	103.6115		543.9915	320.6925	223.2990
6	58	0.0630	53.9333		283.1660	237.7686	45.3975

Table 3: UC schedule and power dispatch of GENCO-6 for 24 hours using FA

Hour	β_6	Power (MW)	MCP ($)	Revenue ($)	Cost ($)	Profit ($)
1	0.0716	0	4.3224	0	0	0
2	0.0611	0	4.4614	0	0	0
3	0.0680	0	4.6003	0	0	0
4	0.0606	40.3486	4.7393	191.2241	177.4152	13.8089
5	0.0625	0	4.6351	0	0	0
6	0.0581	42.2889	4.8782	206.2937	185.4147	20.8796
7	0.0693	47.1398	5.2256	246.3337	206.3181	40.0157
8	0.0735	55.8715	5.8508	326.8980	247.2069	79.6860
9	0.0701	67.5137	6.6845	451.2953	308.2481	143.0472
10	0.0702	72.3646	7.0319	508.8606	335.8820	172.9786
11	0.0667	72.3646	7.0319	508.8606	335.8820	172.8687
12	0.0624	68.4838	6.7540	462.5396	313.6709	148.8685
13	0.0618	66.5435	6.6151	440.1919	302.8765	137.3154
14	0.0625	67.5137	6.6845	451.2953	308.2481	143.0472
15	0.0736	70.4242	6.8929	485.4270	324.6729	160.7541
16	0.0616	69.4540	6.8235	473.9194	319.1460	154.7734
17	0.0666	65.5733	6.5456	426.2166	297.5567	131.6599
18	0.0611	58.7820	6.0593	356.1778	261.7681	94.4097
19	0.0649	60.7224	6.1982	376.3696	271.7347	104.6349
20	0.0601	63.6329	6.4066	407.6705	287.0724	120.5982
21	0.0639	59.7522	6.1287	366.2033	266.7255	99.4778
22	0.0708	53.9311	5.7119	308.0491	237.7580	70.2910
23	0.0712	46.1697	5.1561	238.0556	202.0341	36.0215
24	0.0727	41.3187	4.8088	198.6934	181.3886	17.3048

Since the bids are optimized, the sixth GENCO achieves a profit of $ 45.3975. But without bid optimization, it can achieve profit of only $ 43.4775. It is clear that the profit of sixth GENCO value is increased by using FA.

Case B: Multi Trading Hour

The same six unit GENCO's are utilized to show the capability of FA technique for multi hour trading period. The 24 hour load/demand profile is given in Appendix as Table A2. Table 3 shows the commitment of GENCO-6 for all the 24 hours and the power dispatch and profit obtained in all the trading hours.

It is observed that in the first 3 hours and in 5th hour, GENCO-6 is in OFF condition, due to bidding scheme and it cannot supply even minimum requirement. Suppose if ISO allow GENCO-6 to enter into competition, then economic loss will occur at these hours.

Appendix:

Table A1: Six GENCO Data

Unit	a_i	b_i	c_i	P_{max}(MW)	P_{min}(MW)
1	0	2	0.0125	160	40
2	0	1.75	0.0175	140	40
3	0	1.5	0.02	120	30
4	0	1.9	0.0125	170	40
5	0	1.8	0.0125	180	40
6	58	1.85	0.0275	100	40

Table A2: 24 hour load/ demand profile

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Load	360	380	400	420	405	440	490	580	700	750	750	710
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Load	690	700	730	720	680	610	630	660	620	560	480	430

CONCLUSION

FA to build bidding strategy for power suppliers in single hour and multi hour energy market is proposed. The power dispatch level and profit of the supplier participating in electricity market are determined. Simulation results are obtained using the proposed method can be used by GENCO's for maximizing their own profit. However, bidding in double side auction mechanism will be incorporated as future work.

ACKNOWLEDGEMENT

The authors are grateful to acknowledge the support from veltech,Chennai.

REFERENCES

1. Kankar Bhattacharya, Math H.J. Bollen and Jaap E. Daalder, 2001. Operation of restructured power systems, Kluwar academic publishers, 101 Philip Drive, Assinippi Park, Norwell, Massachusetts.

2. Allen, J. Wood and Bruce F. Wollenberg, 1996. Power generation, operation and control, 2nd Edition, John Wiley & Sons, Inc publishers, 605 Third Avenue, New York, 10158-0012, ISBN 0-471-58699-4.
3. Fushuan, Wen and A. Kumar David, 2001. Optimal bidding strategies and modeling 0f imperfect information among competitive generators, IEEE Transactions on Power System, 16(1): 15-21.
4. Fushuan, Wen and A.K. David, 2002. Coordination of bidding strategies in day-ahead energy and spinning reserve markets" Electrical Power and Energy System, 24: 251-261.
5. Rajathy, R. and R. Gnanadass, 2010. Bidding strategy using differential evolution in a day-ahead market considering unit commitment problem, Proc.of International conference on Control, Communication and Power Engineering, pp: 103-110.
6. Pathom Attaviriyanupap, Hiroyuki Kita, Eiichi Tanaka and Jun Hasegawa, 2005. New bidding strategy formulation for day ahead energy and reserve markets based on evolutionary programming, Electrical Power and Energy System, 27: 157-167.
7. Mattson, C., D. Lucarella and C.C. Liu, 2001. Modeling a competitor's bidding behavior using fuzzy interface networks, in Proc.of international conference on Intelligent Systems Applications in Power Systems (ISAP), Hungary.
8. Shangyou Hao, 2000. A Study of Basic Bidding Strategy in Clearing Pricing Auctions" IEEE Transactions on Power Systems, 15(3): 975-980.
9. Fushuan, Wen and A.K. David, 2000. Stratic Bidding in Reserve Market, Proceedings of the 5th International Conference on Advances in power system control, Operation and management, APSCOM 2000, Hong Kong, pp: 80-85.
10. Charles W. Richter, Jr. Gerald B. Sheble and Dan Ashlock, 1999. Comprehensive Bidding Strategies with Genetic Programming/Finite State Automata, IEEE Transactions on Power Systems, 14(4): 1207-1212.
11. Jose Manuel, Arroyo and Antonio J. Conejo, 2002. Multiperiod Auction for a Pool-Based Electricity Market, IEEE Transactions on Power Systems, 17(4): 1225-1231.
12. Szymon, Lukasik and Slawomir Zak, 2009. Firefly Algorithm for Continuous Constrained Optimization Tasks, Lecture Notes in Computer Science, Springer Link, 5796.
13. Mohammad Kazem Sayadi, Reza Ramezanian and Nader Ghaffari-Nasab, 2010. A discrete firefly meta-heuristic with local search for makespan minimization in permutation flow shop scheduling problem, Int. J. Industrial Engg Computations, 1(1): 1-10.