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Bi-Level Optimization based Coordinated Bidding Strategy of a Supplier in Electricity Market

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Abstract:- This paper presents a methodology to develop an optimal coordinated bidding strategy of a supplier considering hourly price-volume bid in Day-Ahead Energy Market (DAEM) and Balancing Energy market (BEM). In this work, a bi-level optimization problem has been proposed considering rivals' bidding behavior, inter temporal constraints, and multi period auction. Lower level problem represents the market clearing process of System Operator (SO). Upper level problem represents the supplier's profit maximization function, which is non linear. Therefore, Artificial Bee Colony (ABC) algorithm, a modern heuristic approach, has been used to obtain the best solution of the proposed bi-level optimization problem. The effectiveness of proposed method has been tested on 5-bus system. Results obtained using the ABC algorithm has been compared with those obtained using a Genetic Algorithm (GA) based approach.

Keywords:- Bi-level optimization, artificial bee colony algorithm, coordinated bidding strategy, electricity market.

I. INTRODUCTION

Imbalance between electrical energy supply and demand, during the actual time of delivery, may occur due to various reasons like load forecast error, generator outage, transmission line outage leading to islanding of the system etc. This mismatch between supply and demand may result in frequency deviation from its nominal value, which may lead to system instability and equipment damage. Therefore, for maintaining the secure operation of the electric grid, balancing of the production and consumption is continuously required. To take care of energy imbalance, electricity markets of Nordic countries [1], Australia[2], Spain[3-4], PJM[5], and Netherland [6] include both the day ahead market and the real time balancing market to keep balance between generation and demand in the system within the delivery hours. California electricity market and new trading arrangement in England and Wales also have adopted real time balancing mechanism [7-8]. Nordic countries, Australia, Spain and Netherland uses marginal price settlement for the day ahead and the real time balancing markets.

Lot of research has been done for developing optimal bidding strategies in day- ahead energy markets [9-10]. A literature survey on optimal bidding strategies can be found in [11]. But very limited research has been carried out for the balancing services markets. Simultaneous market clearing for energy and reserve capacity markets from ISOs view point, ensuring least cost and secure operation of the transmission systems has been discussed in [12-17]. However, these works did not considered bidding strategies of suppliers to achieve the optimal schedule of the energy and the reserve capacity. Pay-as-bid pricing model for pool and reserve markets has been presented in [18]. This paper did not consider strategic bidding and inter temporal constraints for driving the pricing model. Sequential market clearing based co optimized bidding strategy for energy and reserve markets has been investigated in [19-20]. Further, these papers did not consider ramp up/down constraints in the bidding formulation, which is necessary for the ancillary services markets. In [21-22], optimal bidding strategy of a supplier has been developed for energy and reserve capacity markets simultaneously, considering perfect competitive situation. Optimal bidding strategy in day ahead, along with AGC and balancing markets have been developed in [23] considering sequential market clearing. Further, it was assumed that the supplier is price taker in day ahead and AGC market, while it is a price maker in the balancing market. However, this work did not consider rivals' bidding impact on the supplier's bidding strategy. It was discussed in [24] that purchasing the balancing energy in place of stand-by reserve would reduce ISO's purchasing cost and enhance reliability.

From the literature survey, it is observed that most of the research work have focused on co optimized market clearing from ISOs view point. A few research papers proposed co optimized bidding strategy for the day ahead and the reserve capacity markets from the suppliers' point of view, but these papers did not consider either rivals' strategic bidding or inter temporal constraints. Further, co optimized bidding strategy for the day ahead energy market and the real time balancing energy market considering rivals' strategic bidding, inter temporal constraints like ramp up/down limit and multi period auction together has not been reported in literature, to the best of authors knowledge.

The main aim of this work is to develop an optimal coordinated bidding strategy for a supplier participating in day ahead energy market and near real time balancing energy market considering double sided bidding in the DAEM, single sided bidding in the BEM, ramp up/down limits and rivals' strategic bidding behavior. Further, each supplier is considered to bid hourly price-volumes bid in the DAEM, up regulation and down regulation market separately for 24 hours. Uniform market clearing rule has been employed in both the markets, which is the current practice in the Nord pool electricity market [1]. Bidding problem has been formulated as a Bi-Level Optimization Problem (BLOP), in which lower level problem represents the market clearing process of the DAEM and the BEM, whereas the upper level problem is a profit maximization of a supplier. The transmission limit has not been considered in the formulation with an assumption that the Transmission System Operator (TSO) will resolve it in the transmission market separately.

ABC algorithm has been utilized to obtain the solution of the upper level problem, which is a non linear optimization problem. The effectiveness of the proposed ABC algorithm has been tested on a 5-bus system and the results are compared with a Genetic Algorithm (GA) based approach.

II. PROBLEM FORMULATION

It is assumed that a supplier-*i is* required to submit hourly price (*$/MWh*)-volume (*MW*) bid in DAEM and BEM with the objective to determine the optimal bid price and quantity in order to maximize its expected profit from trading energy in day ahead and balancing markets. For computing the profit, the supplier-i needs to predict the market clearing price of both the markets. In this work, the market clearing prices have been estimated by simulating the market clearing process of both the markets. Further, it is assumed that the day-ahead energy is purchased by many customers, while the balancing energy is purchased by the TSO.

Marginal cost of the supplier-i is derived from the production cost function of generator $i \in N$, which is taken as;

$$C(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{1}$$

where, P_i is the real power output of the generator-*i* , a_i, b_i, c_i are the cost coefficients of the generator-*i*, *N* is the number of generators.

The Marginal Cost (MC) of the generator-i is calculated as $\dfrac{\partial C(P_i)}{\partial P_i}$

$$MC_i = 2a_i P_i + b_i \tag{2}$$

The strategic bidding price of an $\underline{i^{th}}$ supplier is assumed to be

$$\rho_i = s_i(2a_i P_i + b_i) \tag{3}$$

The multiplier s_i is the decision variable, which is a real number and is used to formulate the bidding strategy.

2.1 Day-ahead Market Clearing Model

In double sided bidding, the system operator receives bids from suppliers as well as load entities. The market is cleared by maximizing social welfare (4), subject to physical constraints like power balance (5), maximum and minimum generation limit (6) and maximum demand (7) of the load entities.

$$Max \quad \sum_{t=1}^{T}\left(\sum_{j=1}^{N_l} \rho_{jd}^t * P_{jd}^t - \sum_{i=1}^{N_g} \rho_{is}^t * P_{is}^t\right) \tag{4}$$

$$\text{s.t.} \sum_{i=1}^{N_g} P_{is}^t - \sum_{j=1}^{N_l} P_{jd}^t = 0 \;, \forall\, t \tag{5}$$

$$P_{is\min}^t \le P_{is}^t \le P_{is\max}^t, \forall\, i, \forall\, t \tag{6}$$

$$P_{jd}^t \le P_{jd\max}^t \qquad , \forall\, j, \forall\, t \tag{7}$$

where, ρ^t_{jd} and ρ^t_{is} are the bid prices of buyer-j and supplier-i at time t in \$/MW, respectively, P^t_{jd} is the demand of buyer-j to be fulfilled at time t, P^t_{is} is the dispatch output of supplier-i at time t in day-ahead market, $P^t_{is\min}$ and $P^t_{is\max}$ are minimum and maximum generating capacity of supplier-i at time t, $P^t_{jd\max}$ is the maximum demand requirement of buyer-j at time t, N_g and N_l are the number of suppliers and buyers, respectively, and T is the scheduling horizon.

The solution of the above optimization problem gives the hourly dispatch output of all the generators, day-ahead uniform market clearing price, which is the Lagrange multiplier associated with the power balance constraint, and the information regarding the loads to be fulfilled.

2.2 Balancing Energy Market Clearing Model

In a real time balancing market, market participants submit the up regulation and the down regulation bids to the system operator for providing the balancing energy. The SO determines the balancing energy dispatch of all the suppliers by solving the following optimization problem (8)-(14).

$$Min \sum_{i=1}^{N_g}\left(U_1^t * \rho_{is}^{t+} * \Delta P_{is}^{t+} + U_2^t * \rho_{is}^{t-} * \Delta P_{is}^{t-}\right) \tag{8}$$

subject to,

$$\sum_{i=1}^{N_g}\left(U_1^t * \Delta P_{is}^{+} + U_2^t * \Delta P_{is}^{-}\right) = \sum_{j=1}^{N_l} \Delta P_{jd}^t \ , \ \ \forall t \tag{9}$$

$$0 \le \Delta P_{is}^{t+} \le P_{is\max}^t - P_{is}^t \quad , \quad \forall i, \forall t \tag{10}$$

$$P_{is\min}^t - P_{is}^t \le \Delta P_{is}^{t-} \le 0 \quad , \quad \forall i, \forall t \tag{11}$$

$$U_1^t = \begin{cases} 1 & if \ \ \Delta P_d^t > 0 \\ 0 & otherwise \end{cases} \tag{12}$$

$$U_2^t = \begin{cases} 1 & if \ \ \Delta P_d^t < 0 \\ 0 & otherwise \end{cases} \tag{13}$$

where, $\Delta P_d^t = \sum_{j=1}^{N_l} \Delta P_{jd}^t$ (14)

The objective function (8) is to minimize the customer payments in the balancing energy market. Equality constraint (9) represents the system wide power balance. The lower and upper bound on the incremental/decremental dispatch output are governed by ramping limit of generating unit-i at any hour-t. In this case, it is assumed that the generating unit-i can ramp up its output up to its maximum capacity and ramp down its output up to its minimum capacity. Thus, the inequality constraints (10)-(11) represent the ramp up and ramp down limits. In the real time balancing energy market, suppliers must obey certain technical and operating market rules. For example, in Nord pool, full response of upward/downward balancing energy is required in 15 minutes. Thus, the upward/downward balancing energy capacity of a supplier is dependent on its ramp rate. The solution of the above optimization problem gives the hourly balancing upward/downward dispatch output of all the generators, real time balancing upward/downward uniform market clearing price.

2.3 Proposed Bi-level Optimization Problem (BLOP)

The profit maximization problem of supplier-i, for coordinated bidding strategy in day-ahead and real time balancing energy markets is modeled as bi level optimization problem, in which upper level optimization problem represents the profit maximization for the generator-i and the lower level optimization problem represents the market clearing. Start up and shut down decisions are not considered because it is assumed that the on/off status of the unit is known a priori at the time of constructing bidding strategies. Thus, the proposed optimization problem is described as

$$Max \ \sum_{t=1}^{24} \begin{bmatrix} \left\{ MCP^{t} * P_{is}^{t} - C(P_{is}^{t}) \right\} + \\ U_{1}^{t} * \left\{ MCP^{t+} * \Delta P_{is}^{t+} - C(\Delta P_{is}^{t+}) \right\} + \\ U_{2}^{t} * \left\{ MCP^{t-} * \Delta P_{is}^{t-} - C(\Delta P_{is}^{t-}) \right\} \end{bmatrix} \tag{15}$$

subject to,

$$\left. \begin{array}{l} S_{i}^{\min} \le S_{i} \le S_{i}^{\max} \\ (4)-(7) \\ (8)-(14) \end{array} \right\} \tag{16}$$

The objective function (15) represents the profit of supplier-i from selling energy in the day-ahead and the balancing energy markets. The day-ahead market clearing price and upward/downward balancing energy market clearing price, which are the Lagrange multipliers associated with the power flow constraints of the day-ahead and the real time balancing energy markets, and dispatch outputs of the day-ahead and the real time balancing energy markets are obtained from the lower level problem, and utilized by the generator-i in the upper level problem for the profit maximization. Therefore, the lower level problem is modeled as constraints in (15) for the upper level problem. The optimization problem defined in (15)-(16) can be solved to obtain the bid prices and output of the generator-i, for the day-ahead and the balancing energy markets. Though the bid prices of the generators do not explicitly appear in the profit maximization function, these are implicitly included in the process of determining the day-ahead market clearing price and upward/downward balancing energy market clearing price. The lower level problem is a linear programming problem, which can be solved by the classical optimization technique. However, the upper level problem is a nonlinear problem, which can be solved by using some heuristic approach to obtain the best solution.

Binary variables are used in the proposed BLOP to select either the up regulation or the down regulation market at a time. The proposed model can be solved using MINLP. However, due to presence of binary variables and non convexities of the proposed problem, solution for this type of problem is very challenging because solution techniques may get trapped into sub optimal solutions or even fail to yield feasible points [28]. Therefore, to avoid the need of binary variables, an IF-THEN approach is used to choose only one market, i.e. either up regulation or down regulation market, to satisfy the conditions associated with the optimization problem (15)-(16).

Where, ρ_{is}^{t+} and ρ_{is}^{t-} are the incremental and decremental bid prices of supplier-i at time t, ΔP_{is}^{t+} and ΔP_{is}^{t-} are incremental and decremental dispatch output of supplier-i at time t, ΔP_{jd}^{t} is change in the demand of buyer-j at time t and ΔP_{d}^{t} is the total change in demand at time t.

2.4 Estimation of Rivals' Bidding Strategy

In the sealed bid auction day-ahead and real time balancing energy markets, each supplier knows its own generation cost but may not have such information about the rivals. Hence, suppliers do not have the necessary data needed to solve the optimization problem (15)-(16). Therefore, it is necessary for a supplier to model its rivals' unknown information i.e. bid price to maximize the profit. An immediate problem for each supplier is how to model the rivals' bidding behavior. Since, the Marginal Cost (MC) is private information of the generators in a market and may not be available as public information in formulating the optimal bidding model, it is more practical to assume that a generator builds its optimal bidding strategy based on the possible strategies of the other generators that can be estimated probabilistically from historical market data as mentioned in [25].

After incorporating the rivals' bidding strategies, the BLMOOP of i^{th} generator (15) will be modified as,

$$Max \ \sum_{m=1}^{M} \sum_{t=1}^{24} \Omega_{m} * \begin{bmatrix} \left\{ MCP_{m}^{t} * P_{ism}^{t} - C(P_{ism}^{t}) \right\} + \\ U_{1m}^{t} * \\ \left\{ MCP_{m}^{t+} * \Delta P_{ism}^{t+} - C(\Delta P_{ism}^{t+}) \right\} + \\ U_{2m}^{t} * \\ \left\{ MCP_{m}^{t-} * \Delta P_{ism}^{t-} - C(\Delta P_{ism}^{t-}) \right\} \end{bmatrix} \tag{17}$$

subject to,

$$\left.\begin{array}{l} S_i^{\min} \le S_i \le S_i^{\max} \\ (4)-(7) \\ (8)-(14) \end{array}\right\} \qquad (18)$$

where, $MCP_m^t, MCP_m^{t+}, MCP_m^{t-}$ are the market clearing prices for DAEM, up regulation and down regulation market, respectively, and $P_{ism}^t, \Delta P_{ism}^{t+}, \Delta P_{ism}^{t-}$ are the dispatched quantity of the i^{th} generator in DAEM, up regulation and down regulation market, for m^{th} strategic combination of the rivals.

III. SOLUTION ALGORITHM

The BLOP, formulated in section 2.3, is a non convex problem, which has been solved using a heuristic algorithm and a conventional optimization method to get the best solution. ABC algorithm has been used for solving the upper level problem, while the lower level problem is solved using optimization tool box of MATLAB. A flow chart for the proposed ABC based optimal bidding strategy is given in Fig 1.

IV. RESULTS AND DISCUSSION

The effectiveness of the proposed methodology for developing coordinated optimal bidding strategy has been tested on a 5-bus system [26]. In DAEM, the lower and upper bounds on the bid price of the supplier, whose strategy has been estimated, have been considered as marginal cost and 1.5 times of marginal cost, respectively. In BEM, the lower and upper bounds for incremental bid price have been considered as 1.5 times the marginal price and 3 times the marginal price, whereas decremental bid price bounds are considered as 0.7 times the marginal price and 0.8 times the marginal price, respectively. In the proposed approach, optimization toolbox of MATLAB has been used to solve the lower level problems sequentially. It determines the market clearing price and dispatch output of all the generators in the day-ahead market. Upward/downward market clearing prices and dispatch output of all generators in the BEM. These values are used as input to the upper level problem to obtain the optimally coordinated bidding strategy. In this work, ABC algorithm [27] has been used to solve the upper level problem and results obtained using the ABC algorithm have been compared with those obtained using the Genetic Algorithm (GA) based approach.

The simulations have been performed on a Dual core processor, 1GB RAM computer using MATLAB version 7.1. Optimal bidding strategy of generator-1 has been developed for the following two cases assuming that the demand for the DAEM and the BEM, in all the two cases, are the same throughout the 24-h. The fig.-2 shows the forecasted demand of the DAEM and the BEM.

Case I: Rivals are assumed to bid at their marginal cost in the DAEM, 3 times of marginal cost in up regulation and 0.8 times of marginal cost in the BEM.

Case II: Rivals are assumed to bid strategically in the DAEM and the BEM, and all the rivals are withholding 20% capacity.

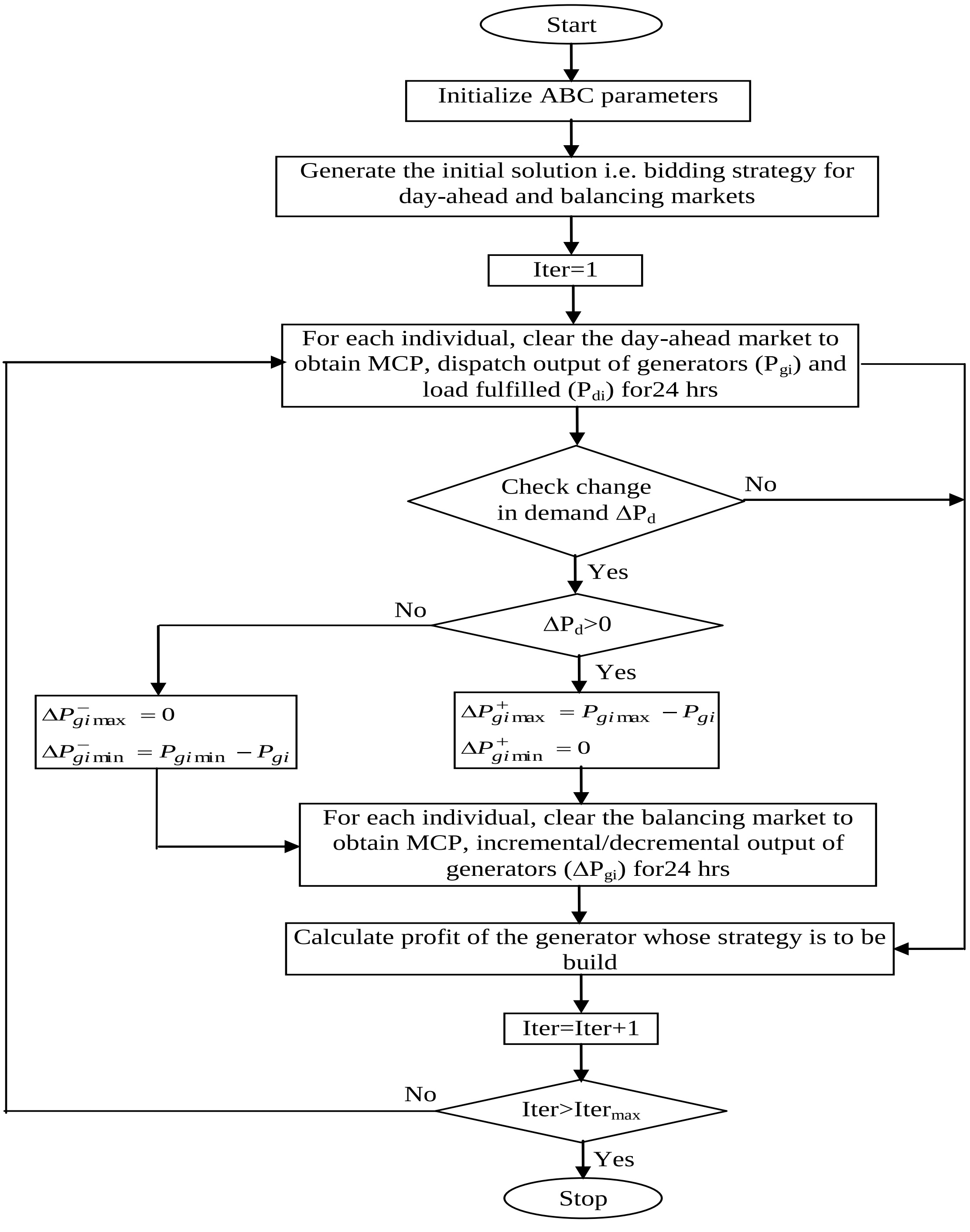

Fig.1: Flow chart for proposed coordinated bidding strategy using ABC algorithm

Case I simulation results

Table-1 shows the optimal value of the bid variable and dispatched output of supplier-1 obtained using the ABC algorithm for the DAEM, the up-regulation and the down regulation BEM. It is observed that the suppliers-2 & 3 dispatch their full capacity in the DAEM in each hour. The reason behind this is that the bid price of suppliers-2 & 3 is lower than supplier-1 and, therefore, they got preference over the supplier-1. Results obtained for the BEM show that, despite the higher bid price of supplier-1 than the rivals', it has dispatched in up-regulation BEM all the time. It happens because the suppliers- 2 & 3 have exhausted their full capacity in the DAEM. Supplier-3 is dispatched in down-regulation BEM due to bidding higher than its rivals.

The simulation results show that the supplier-1 has remained in operation during the whole 24-h in the DAEM and during the hours 1-8, 14-17, 20-24 in the up regulation BEM. The fig.3 compares the profit of supplier-1 obtained using ABC algorithm and GA in the DAEM and the BEM. It can be seen that the profit of the supplier-1, obtained using ABC algorithm, is higher as compared to that with the GA in both the DAEM and the BEM. Further, it may be noted that due to the high up regulation energy price compared to the DAEM, profit obtained in the BEM is higher than the DAEM. Thus, in this case, the optimally coordinated bidding strategy of supplier-1 is to bid higher than the rivals in the DAEM to take advantage of high up regulation prices and enhance its profit.

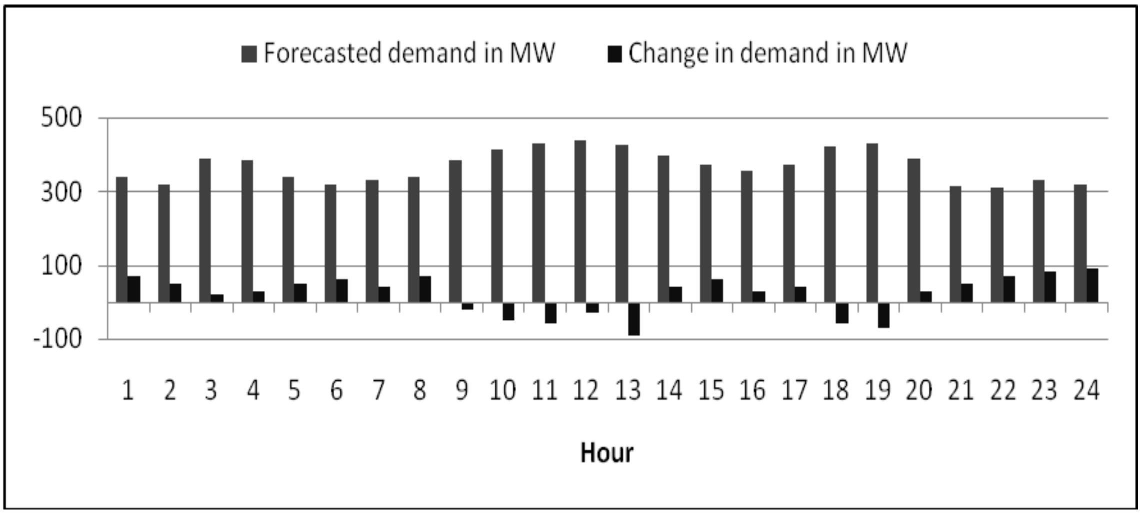

Fig.2: Forecasted demand in 5-bus system

Table 1: Optimal bid variable and dispatch output of supplier-1 using ABC for case I in 5-bus system

Hr	**Results for coordinated bidding strategy in DAEM and BEM**						**Results for DAEM**	
	Optimal bid variable			Dispatch output (MW)			Optimal bid variable	Dispatch output (MW)
	Day-ahead	Up regulation	Down regulation	Day-ahead	Up regulation	Down regulation		
1	1.46	2.99	0.72	90	70	-	1.48	90
2	1.43	2.96	0.74	70	50	-	1.47	70
3	1.49	2.82	0.77	140	20	-	1.46	140
4	1.44	2.96	0.76	135	30	-	1.45	135
5	1.46	2.74	0.78	90	50	-	1.49	90
6	1.42	2.96	0.72	70	60	-	1.48	70
7	1.46	2.95	0.75	80	40	-	1.48	80
8	1.47	2.96	0.74	90	70	-	1.45	90
9	1.43	1.89	0.74	135	-	00	1.45	135
10	1.46	2.31	0.70	165	-	00	1.41	165
11	1.47	2.92	0.72	180	-	00	1.48	180
12	1.44	2.48	0.73	190	-	00	1.47	190
13	1.48	2.85	0.75	177.5	-	00	1.49	177
14	1.48	2.99	0.74	145	40	-	1.46	145
15	1.49	2.83	0.79	120	60	-	1.49	120
16	1.46	2.94	0.77	105	30	-	1.47	105
17	1.41	2.98	0.76	122.5	40	-	1.43	122
18	1.49	2.76	0.73	170	-	00	1.45	170
19	1.46	2.37	0.73	180	-	00	1.49	180
20	1.49	2.99	0.73	140	30	-	1.49	140
21	1.46	2.92	0.75	62.5	50	-	1.46	62
22	1.47	2.82	0.72	60	70	-	1.42	60
23	1.49	2.88	0.73	80	80	-	1.37	80
24	1.38	2.80	0.71	70	90	-	1.46	70

To show the effect of coordinated bidding strategy (DAEM and BEM) on supplier's profit, results obtained using the coordinated bidding strategy has been compared with those obtained by simulating the DAEM. Profit of supplier-1 in DAEM is $ 4655.80, whereas in coordinated market the profit is $ 17121.3. This has happened because dispatched output of supplier-1 has not been increased due to marginal bid strategy of the rival suppliers. Further, the DAEM prices are lower than the up regulation prices.

Case II Simulation Results

This case is simulated considering that the rivals are bidding strategically in both the DAEM and the BEM, and withholding 20% capacity. The estimated bidding strategies of rivals are given in table 2. Table 3 shows the optimal values of the bid variable obtained using GA and ABC algorithms, and dispatched output in the DAEM and the BEM. From the results, it has been observed that value of the decision variable obtained using the ABC is optimal as compared to the GA, as the profit obtained by the ABC is higher than the profit obtained using the GA. Profit of supplier-1 is given in fig.3. In this case, profit in the DAEM is more in comparison to the cases I whereas, it has reduced in the BEM. This happens due to the increase in the DAEM price and decrease in the up regulation market price due to strategic bidding of the rivals.

Results obtained for the optimal bid variable and dispatched output of supplie-1 for the DAEM are given in table-4. Simulation is carried out assuming that all the rivals are bidding strategically without physical withholding. In this case, profit of supplier-1obtained in DAEM is $4726.10 whereas, in coordinated market, it is $ 13475.7. The reason behind this is that the dispatched output of supplier-1 in the DAEM has reduced as compared to the coordinated market strategy because by bidding strategically, rivals have been succeeded in dispatching their full capacity as, in this case, rivals are not withholding their capacity in the DAEM.

Table 2: Strategies of rivals' estimated by supplier-1in DAEM and BEM for case III in 5-bus system

	DAEM				**Up regulation strategy**				**Down regulation strategy**			
Supplier	S_{j11}	P_{rj11}	S_{j12}	P_{rj12}	S_{j11}	P_{rj11}	S_{j12}	P_{rj12}	S_{j11}	P_{rj11}	S_{j12}	P_{rj12}
2	1.2	0.70	1.4	0.30	2.4	0.70	2.6	0.3	0.74	0.7	0.77	0.3
3	1.3	0.25	1.2	0.75	2.3	0.25	2.5	0.75	0.73	0.25	0.78	0.75

Table 3: Optimal bid variable using GA and ABC, and dispatched output for case III in 5-bus system

Hr	**Optimal bid variable using GA**			**Optimal bid variable using ABC**		
	Day-ahead	Up regulation	Down regulation	Day-ahead	Up regulation	Down regulation
1	1.48	1.93	0.70	1.47	1.96	0.71
2	1.42	2.12	0.77	1.46	2.22	0.79
3	1.44	1.53	0.73	1.48	1.63	0.76
4	1.48	2.29	0.77	1.45	2.16	0.72
5	1.49	2.16	0.76	1.48	2.21	0.71
6	1.47	2.50	0.78	1.47	2.37	0.78
7	1.43	2.92	0.73	1.46	2.31	0.71
8	1.43	2.20	0.77	1.49	1.94	0.77
9	1.44	1.98	0.79	1.49	2.19	0.78
10	1.07	2.60	0.79	1.00	1.95	0.78
11	1.27	2.06	0.79	1.01	1.99	0.79
12	1.00	2.77	0.79	1.14	2.23	0.79
13	1.19	1.76	0.79	1.47	2.63	0.79
14	1.45	1.63	0.72	1.47	2.04	0.79
15	1.45	2.35	0.75	1.48	2.05	0.71
16	1.46	2.22	0.76	1.49	2.17	0.74
17	1.48	1.90	0.79	1.49	1.70	0.74
18	1.18	2.45	0.78	1.10	2.61	0.79
19	1.46	1.85	0.78	1.09	1.92	0.78
20	1.48	1.87	0.77	1.46	2.27	0.76
21	1.49	2.33	0.71	1.46	2.31	0.78
22	1.44	2.33	0.72	1.43	2.33	0.76
23	1.47	1.84	0.71	1.47	2.10	0.77
24	1.45	1.93	0.70	1.48	1.89	0.78

Table 4: Optimal bid variable and dispatched output using ABC, for DAEM

Hr	Optimal bid variable	Dispatch output (MW)	Hr	Optimal bid variable	Dispatch output (MW)	Hr	Optimal bid variable	Dispatch output (MW)
1	1.47	140	9	1.49	185	17	1.49	172.5
2	1.46	120	10	1.00	200	18	1.10	200
3	1.48	190	11	1.01	200	19	1.09	200
4	1.45	185	12	1.14	200	20	1.46	190
5	1.48	140	13	1.47	200	21	1.46	112.5
6	1.47	120	14	1.47	195	22	1.43	110
7	1.46	130	15	1.48	170	23	1.47	130
8	1.49	140	16	1.49	155	24	1.48	120

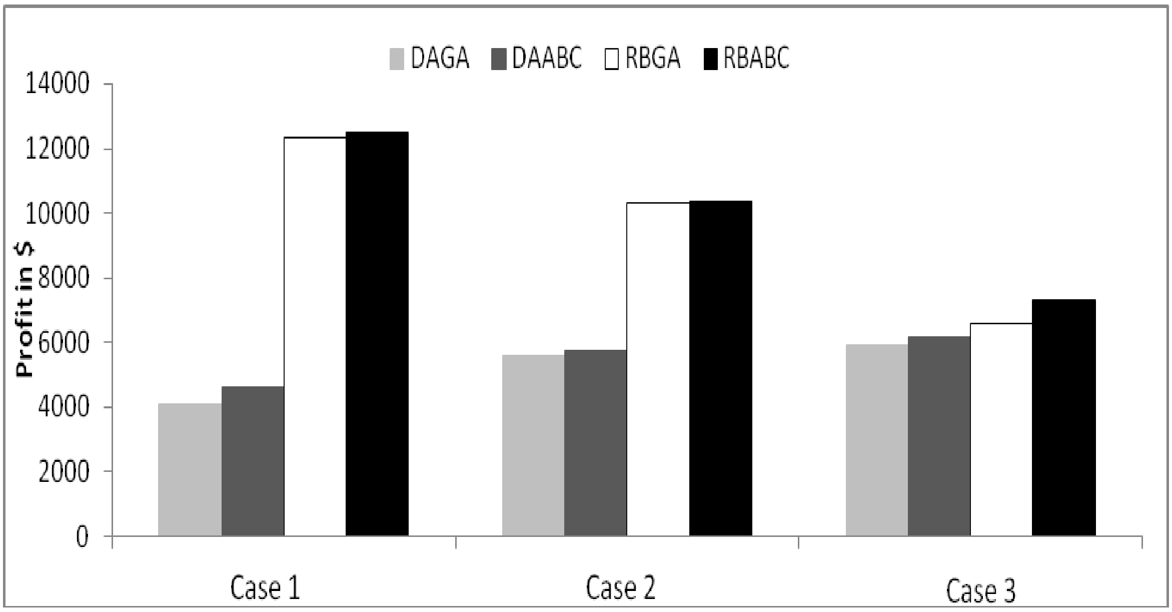

Fig.3: Comparison of profit in various cases of 5-bus system

V. CONCLUSION

The main objective of this paper has been to develop optimally coordinated bidding strategies of supplier in the Nord pool type DAEM and BEM. A bi-level optimization problem has been proposed, and ABC algorithm, a relatively new population based technique, has been used to obtain the coordinated bidding strategy in the DAEM and the BEM for each operating hour. Results obtained using the ABC algorithm have been compared with those obtained from GA. The performance of the ABC algorithm is found to be superior to the GA as the ABC algorithm combines the exploration and exploitation processes successfully. The exploration process, carried out by the artificial scouts, is good for best optimization whereas, the exploitation process carried out by the employed and the onlooker bees, in the ABC, is good for local optimization. Thus, the ABC algorithm is able to find the best optimum, which makes it suitable for obtaining optimal bidding strategy of a Genco. It is observed that the marginal or near marginal suppliers may be benefitted more by using the proposed method to develop the coordinated bidding strategy.

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