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Coordinated Bidding Strategy of a Supplier in Day-Ahead and Balancing Energy Market

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This paper presents a methodology to develop an optimal coordinated bidding strategy of a supplier in Day-Ahead Energy Market (DAEM) and Balancing Energy Market (BEM). It is assumed that each supplier bids hourly price-volume bid in DAEM and BEM (for up regulation and down regulation) for 24 hours. In this work, a bi-level optimization problem has been proposed to obtain the optimally coordinated bidding strategy of a supplier, considering rivals' bidding behavior, inter temporal constraints, and multi period auction. Lower level problem represents the market clearing process of System Operator (SO), in which DAEM and BEM are cleared separately and sequentially for all the 24 hours. 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 modified IEEE-30 bus system. Results obtained using the ABC algorithm has been compared with those obtained using a Genetic Algorithm (GA) based approach. To illustrate the effect of coordinated bidding strategy on supplier's profit, results of the coordinated bidding strategy have been compared with those obtained by uncoordinated bidding strategy.

1.0 INTRODUCTION

Electricity markets, existing in various parts of the world, have adopted separate energy and ancillary services markets. Generally, energy market is a day-ahead market and ancillary services market is a near to real time market. Imbalance between 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. 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 balancing market to keep balance between generation and demand in the system within the delivery hours.

From the supplier's view point, day-ahead energy market and balancing market are interdependent, because of the capacity limit. Thus, to maximize the expected profit by trading energy in the day-ahead and the balancing markets, a supplier faces the decision making problem to determine how to bid to achieve optimal schedule of energy for participating in both the markets, which is the main objective of this paper. Lot of research has been done for developing optimal bidding strategies in day-ahead energy markets [7–8]. A literature survey on optimal bidding strategies can be found in [9]. But very limited research

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has been carried out for the balancing services markets. The balancing services markets are two types: reserve capacity markets and balancing energy markets. Some of the research work reported in the literature has discussed the simultaneous market clearing for energy and reserve capacity markets [10–16] from ISOs view point, ensuring least cost and secure operation of the transmission systems. However, these works did not considered bidding strategies of suppliers to achieve the optimal schedule of the energy and the reserve capacity. Sequential market clearing based co optimized bidding strategy for energy and reserve markets has been investigated in [17–18]. Further, these papers did not consider ramp up/down constraints in the bidding formulation, which is necessary for the ancillary services markets. It was discussed in [19] 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 has focused on co optimized market clearing considering reserve capacity market from ISOs view point. Therefore, in this paper an optimal coordinated bidding strategy for a supplier participating in day ahead energy market and balancing energy market has been developed considering rivals' strategic bidding, inter temporal constraints and multi period auction. 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 second major purpose of this work is to explore the ability of Artificial Bee Colony (ABC) algorithm, a population based technique, in solving the bidding strategy problem. ABC algorithm has been utilized to obtain the solution of the upper level problem, which is non linear. The effectiveness of the proposed ABC algorithm has been tested on a modified IEEE-30 bus test system and the results are compared with a Genetic Algorithm (GA) based approach.

2.0 PROBLEM FORMULATION

Consider an electricity market consisting of N independent power suppliers, group of customers (loads), TSO for controlling inter connected power system network, and a Power Exchange (PX) to manage the forward electricity market. It is assumed that a supplier-i *is* required to submit hourly price ($/MWh)-volume (MW) bid in DAEM and BEM. The objective of the supplier-i is 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 either by forecasting it or by simulating the day ahead and the balancing market clearing process. 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.

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

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

The strategic bidding price of an 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.

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

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

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

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

where, ρ_{jd}^{t} and ρ_{is}^{t} are the bid prices of buyer-*j* and supplier-*i* at time-t in \$/MW, respectively, P_{jd}^{t} is the demand of buyer-*j* to be fulfilled at time-t, P_{is}^{t} is the dispatch output of supplier-*i* at time-t in day-ahead market, $P_{is\min}^{t}$ and $P_{is\max}^{t}$ are minimum and maximum generating capacity of supplier-*i* at time-t, $P_{jd\max}^{t}$ 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

The system operator is responsible for managing the real time balancing energy market. 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 (8–11).

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

subject to,

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

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

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

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

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

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

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.

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.

The solution of the above optimization problem gives the hourly balancing (upward/downward) dispatch output of all the generators, balancing upward/downward uniform market clearing price, which is the Lagrange multiplier associated with the power balance constraint, and the information regarding the increased/decreased loads to be met.

2.3 Proposed Bi-level Optimization Problem (BLOP)

The profit maximization problem of supplier-*i,* for coordinated bidding strategy in day-ahead and balancing energy markets is modeled as bi level optimization problem, in which upper level optimization problem represents the profit maximization for the supplier-*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

$$\text{Max} \sum_{t=1}^{24} \begin{bmatrix} \left\{ MCP^{t} \times P_{is}^{t} - C(P_{is}^{t}) \right\} + \\ U_1^t \times \left\{ MCP^{t+} \times \Delta P_{is}^{t+} - C(\Delta P_{is}^{t+}) \right\} + \\ U_2^t \times \left\{ MCP^{t-} \times \Delta P_{is}^{t-} - C(\Delta P_{is}^{t-}) \right\} \end{bmatrix} \quad (15)$$

subject to,

$$\left. \begin{array}{l} S_i^{min} \le S_i \le S_i^{max} \\ (4)-(7) \\ (8)-(11) \end{array} \right\} \quad (16)$$

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 balancing energy markets, and dispatch outputs of the day-ahead and the balancing energy markets are obtained from the lower level problem, and utilized by the supplier-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 supplier-*i*, for the day-ahead and the balancing energy markets. Though the bid prices of the suppliers' 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 [23]. 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, to satisfy the conditions associated with the optimization problem (15,16).

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. For each rival generator $j \in J$, the possible strategies and their associated probabilities estimated by the ith generator, for which bidding is to be framed, can be denoted by matrices [20],

$$\begin{pmatrix} S_{j11} & \cdot & \cdot & \cdot & S_{j1G_j} \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ S_{jk_j1} & \cdot & \cdot & \cdot & S_{jk_jG_j} \end{pmatrix} \text{ and }$$

$$\begin{pmatrix} pr_{j11} & \cdot & \cdot & \cdot & pr_{j1G_j} \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ pr_{jk_j1} & \cdot & \cdot & \cdot & pr_{jk_jG_j} \end{pmatrix} \quad (17)$$

respectively, where j={1,2,... i-1, i–1,…N } is the reduced set of generators excluding i[th] generator. K_j is the maximum number of blocks to bid and G_j is the maximum number of strategies for jth Gen Co. For each opponent Gen Coj, there is N_j number of possible strategic combinations, defined as $\Phi_j = \{\Phi_{j1}, \Phi_{j2}, ...\Phi_{jnj}, ..., \Phi_{jNj}\}$ and their probabilities are represented as

$$\eta_j = \{\eta_{j1}, \eta_{j2}, ..., \eta_{jnj}, ..., \eta_{jNj}\},$$

where, $N_j = K_j \times G_j$. The set of all possible strategic combinations of opponents $\Psi = \{\Psi_1, \Psi_2, ..., \Psi_M\}$, is defined as cross product of all j sets $\varphi_1, \varphi_2 .... \varphi_j$ denoted by $\Phi_1 \times \Phi_2 \times ..., \times \Phi_j$. This consists of all ordered j tuples $\{\varphi_1, \varphi_2, ..., \varphi\}$.

where, $\varphi_1 \in \Phi_1, \varphi_2 \in \Phi_2, ... \varphi_j \in \Phi_j$. If probability of φ_j is defined as $PR(\varphi_j)$, then the respective probability of each strategic combination is expressed as,

$$\Omega_m = \prod_{j \in J} PR(\phi_j), \ \forall \psi_m \subset \psi, \ \forall m \subset M \quad (18)$$

where, M is total number of possible strategic combinations of the rivals, given by:

$$M = \prod_{j \in J} N_j \ j = \{1, 2, ..., i-1, i+1, ..., N\} \quad (19)$$

After incorporating the rivals' bidding strategies, the BLMOOP of ith generator (15) will be modified as,

$$\text{Max} \sum_{m=1}^{M} \sum_{t=1}^{24} \Omega_m \times \begin{bmatrix} \{MCP_m^t \times P_{ism}^t - C(P_{ism}^t)\} + \\ U_{1m}^t \times \\ \{MCP_m^{t+} \times \Delta P_{ism}^{t+} - C(\Delta P_{ism}^{t+})\} + \\ U_{2m}^t \times \\ \{MCP_m^{t-} \times \Delta P_{ism}^{t-} - C(\Delta P_{ism}^{t-})\} \end{bmatrix} \quad (20)$$

subject to,

$$\left. \begin{array}{l} S_i^{min} \le S_i \le S_i^{max} \\ (1)-(4) \\ (5)-(8) \end{array} \right\} \quad (21)$$

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 ith generator in DAEM, up regulation and down regulation market, for mth strategic combination of the rivals.

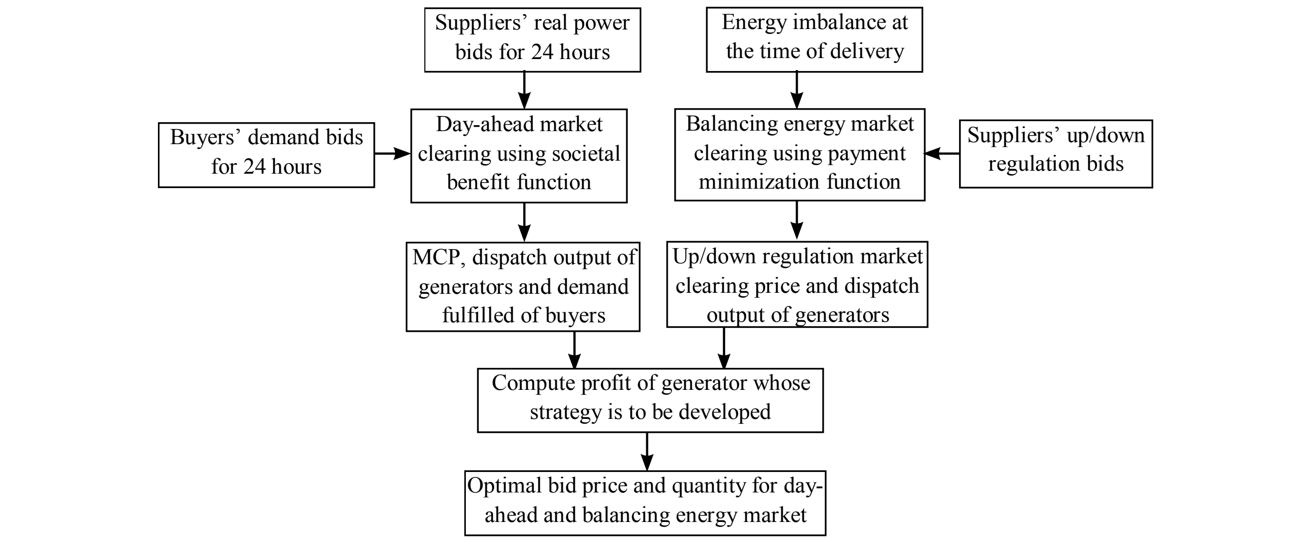

FIG. 1 BLOCK DIAGRAM OF PROPOSED COORDINATED BIDDING STRATEGY

3.0 SOLUTION ALGORITHM

The block diagram depicting the working of the coordinated bidding strategy is shown in Figure 1. The BLOP, formulated in s ection 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 by a FMINCON optimization function of MATLAB. A flow chart for the proposed ABC based optimal bidding strategy is given in Figure 2.

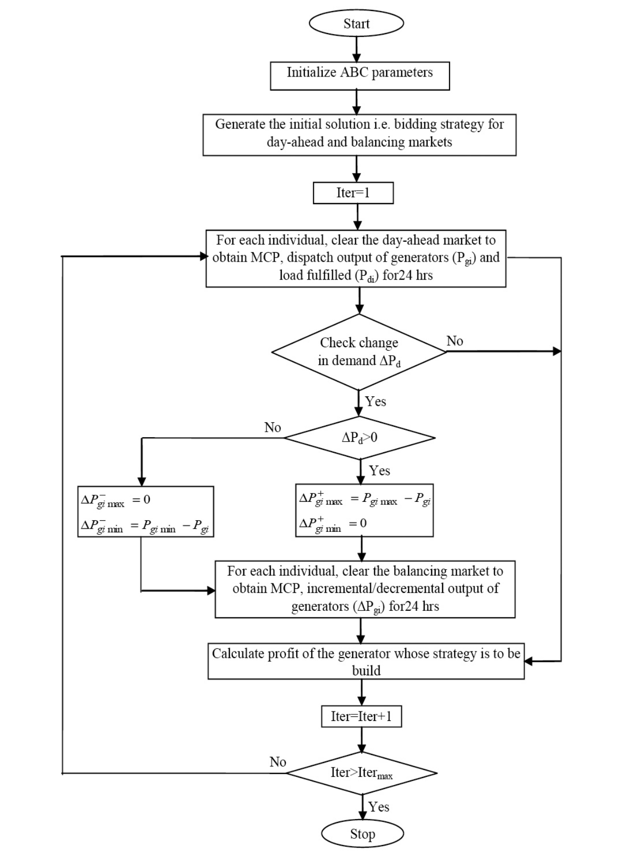

FIG. 2 FLOW CHART FOR PROPOSED COORDINATED BIDDING STRATEGY USING ABC ALGORITHM

4.0 RESULTS AND DISCUSSION

The effectiveness of the proposed methodology for developing coordinated optimal bidding strategy has been tested on a modified IEEE-30 bus system [21]. An optimally coordinated bidding strategy of a supplier has been obtained using a bi-level optimization model, where lower level (market clearing) problem is formulated as a linear programming problem, for both DAEM and BEM. Further, the day-ahead market is considered to be a double sided bidding market, where suppliers and buyers are assumed to give hourly price-volume bid. BEM is considered to be a single sided bidding market, where suppliers are assumed to give hourly price-volume bid for up/down regulation. 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. These assumptions are valid for several electricity markets, including the Nordic market [1] and PJM [5]. The rivals' bidding behavior has been predicted using the method explained in section 2.4. In the proposed approach, FMINCON optimization function 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 [22] 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 performance of the GA and the ABC algorithms depends on the optimal settings of their control parameters. The control parameters in the GA are the population size, number of generations, crossover probability and migration probability whereas, in the ABC algorithm, the control parameters are the colony size, maximum cycles and limit. In this work, the optimal values of these control parameters have been decided by hit and trial and the parameters, which resulted in the maximum value of the fitness function, were selected as the optimal. The population in the GA and colony size in the ABC is initialized randomly within the operating range of the strategic bid variables.

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 three cases assuming that the demand for the DAEM and the BEM, in all the three cases, are the same throughout the 24-hours.

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: This case is same as Case I except that all the rivals are withholding 20 % capacity.

Case-III: Rivals are assumed to bid strategically in the DAEM and the BEM, and all the rivals are with holding 20 % capacity.

The real power generation cost function coefficients and capacity limits of the suppliers are taken from [21]. Forecasted demand for the DAEM and the BEM for 24 hours is shown in Figure 3.

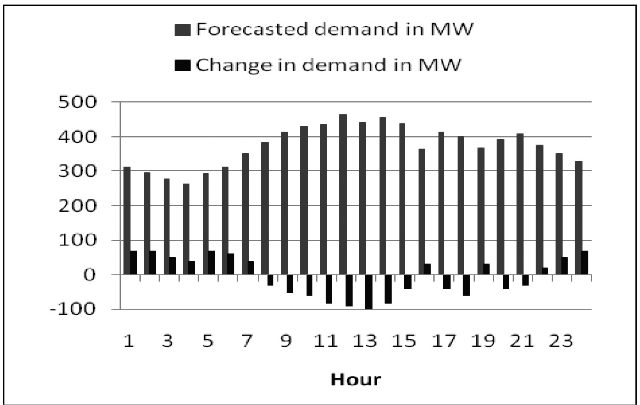

FIG. 3 FORECASTED DEMAND IN 30-BUS SYSTEM

(a) Case-I simulation results

Results obtained for optimal bid variable and dispatched output of supplier-1 is given in Table 1. From the results, it is observed that supplier-1 has optimized its bid value in such a way that it is not participating in the DAEM in hours 1–3 and 5–6 , whereas in hours 4, 7, 16, 19, 22–24 it is dispatching less quantity in the DAEM. The reason is that in these hours supplier-1 wants to participate in up regulation market to take advantage of higher up regulation prices.

TABLE 1						
OPTIMAL BID VARIABLE AND DISPATCHED OUTPUT OF SUPPLIER-1 USING ABC FOR CASE-I						
Hour	**Results for coordinated bidding strategy in DAEM and BEM**			**Optimal bid variable dispatch output (MW)**		
	Day-ahead	**Up regulation**	**Down regulation**	**Day-ahead**	**Up regulation**	**Down regulation**
1	1.30	2.95	0.74	00	70	–
2	1.14	2.99	0.72	00	70	–
3	1.44	2.99	0.76	00	50	–
4	1.06	1.90	0.73	44	36	–
5	1.28	2.99	0.77	00	70	–
6	1.20	2.91	0.74	00	60	–
7	1.24	2.97	0.73	31	40	–
8	1.04	2.16	0.72	80	–	00
9	1.08	2.39	0.72	80	–	00
10	1.04	1.68	0.79	80	–	00
11	1.25	2.58	0.70	80	–	00
12	1.07	1.93	0.72	80	–	00
13	1.20	2.79	0.75	80	–	00
14	1.48	1.86	0.79	80	–	00
15	1.03	1.53	0.76	80	–	00
16	1.22	2.97	0.77	43	30	–
17	1.06	2.74	0.70	80	–	00
18	1.22	2.15	0.79	79	–	00
19	1.24	2.86	0.78	46	30	–
20	1.22	2.09	0.73	72	–	00
21	1.18	2.46	0.76	80	–	00
22	1.23	2.98	0.71	55	20	–
23	1.23	2.98	0.72	29	50	–
24	1.14	2.94	0.77	08	70	–

Further, BEM results show that despite the low bid price of suppliers 2–6 in up regulation market compared to supplier-1, they could not participate in up regulation market because they have exhausted their full capacity in the DAEM.

Down regulation market exits in periods 8, 15, 17, 18, 20 and 21. To avoid the financial loss, supplier-1 is bidding lower than the costliest supplier in the down regulation market. Only supplier-2 is participating in down regulation BEM due to higher bid value than the rivals'.

(b) Case-II simulation results

Simulation results, given in Table 2, shows that due to capacity withholding strategy of the rivals, dispatched output of supplier-1 in the up regulation market has been decreased in comparison to case-I. Now, all the rivals', except supplier-2 which is bidding highest in up regulation market, are participating in up regulation market. Supplier-2 bid price is highest in down regulation market, therefore, in hours 8–15, 17–18, and 20–21 its output is decreased. In hours 12–13, dispatched output of supplier-3 has also been reduced to

10 MW and 20 MW respectively. Because, in these hours, demand reduction in forecasted load was 90 MW and 100 MW respectively. Supplier-2 can reduce maximum 80 MW in any hour, therefore, second highest bidder i.e. supplier-3 is called to reduce the desired output.

(c) Case-III simulation results

The estimated bidding strategies of rivals' for the DAEM and BEM are given in Table 3. Results obtained for optimal value of bid variable and dispatched output are given in Table 4. From the results, it has been observed that all the rival suppliers, except supplier-3, have dispatched their full offered capacity in the DAEM. Supplier-3 has dispatched 1.4 MW and 0 MW in hours 3-4, respectively. In these hours, it has happened because some load did not qualified due to low bid value as compared to bid price of marginal supplier-3. Results show that dispatched output of supplier-1 in the BEM has decreased in comparison to cases-I and II due to strategic

TABLE 2

OPTIMAL BID VARIABLE AND DISPATCHED OUTPUT OF SUPPLIER-1 USING ABC FOR CASE-II

Hour	Optimal bid variable			Dispatched output (MW)		
	Day-ahead	Up regulation	Down regulation	Day-ahead	Up regulation	Down regulation
1	1.47	1.59	0.71	22.7	57.3	–
2	1.43	2.02	0.72	11.7	68.3	–
3	1.25	2.43	0.73	20.0	50.0	–
4	1.25	2.40	0.71	08.0	40.0	–
5	1.36	1.77	0.73	13.0	61.1	–
6	1.47	1.67	0.76	22.7	57.3	–
7	1.46	2.08	0.75	57.7	22.3	–
8	1.04	2.51	0.75	80.0	–	00
9	1.09	1.61	0.70	80.0	–	00
10	1.01	1.62	0.72	80.0	–	00
11	1.40	2.44	0.79	80.0	–	00
12	1.17	2.96	0.74	80.0	–	00
13	1.28	1.96	0.71	80.0	–	00
14	1.06	1.90	0.79	80.0	–	00
15	1.42	2.49	0.76	80.0	–	00
16	1.49	2.43	0.70	68.4	11.6	–
17	1.48	2.39	0.73	80.0	–	00
18	1.07	2.61	0.72	80.0	–	00
19	1.48	1.86	0.75	70.7	09.3	–
20	1.13	1.60	0.75	80.0	–	00
21	1.03	2.51	0.76	80.0	–	00
22	1.48	2.02	0.71	78.9	01.1	–
23	1.44	2.75	0.74	60.0	19.1	–
24	1.44	2.92	0.78	41.4	38.6	–

TABLE 3												
STRATEGIES OF RIVALS' ESTIMATED BY SUPPLIER-1IN DAEM AND RTBEM FOR CASE-III												
Supplier (j)	DAEM				Up regulation strategy				Down regulation strategy			
	S_{j11}	P_{rj11}	S_{j12}	P_{rj12}	S_{j11}	P_{rj11}	S_{j12}	P_{rj12}	S_{j11}	P_{rj11}	S_{j12}	P_{rj12}
1	1.1	0.6	1.2	0.4	2.4	0.6	2.6	0.4	0.74	0.6	0.77	0.4
2	1.15	0.7	1.25	0.3	2.3	0.7	2.25	0.3	0.78	0.7	0.73	0.3
3	1	1	–	–	3	1	–	–	0.8	1	–	–
4	1	1	–	–	3	1	–	–	0.8	1	–	–
5	1	1	–	–	3	1	–	–	0.8	1	–	–

TABLE 4								
OPTIMAL BID VARIABLE AND DISPATCH OUTPUT OF SUPPLIER-1 USING ABC FOR CASE-III								
HR	**Results for coordinated bidding strategy in DAEM and BEM**						**Results for DAEM only**	
	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	1.35	1.85	0.77	38	42	–	1.26	69.0
2	1.30	2.21	0.76	25.5	42	–	1.25	55.0
3	1.25	2.20	0.70	80	00	–	1.26	33.4
4	1.25	2.16	0.79	69.5	10.5	–	1.25	21.5
5	1.29	2.29	0.74	22.6	26	–	1.25	49.2
6	1.28	2.17	0.79	44.7	32	–	1.25	69.0
7	1.39	2.23	0.79	67.1	12	–	1.25	80.0
8	1.45	2.64	0.72	80	–	00	1.26	60.3
9	1.31	2.64	0.70	80	–	00	1.25	80.0
10	1.27	2.79	0.79	80	–	00	1.27	80.0
11	1.45	2.81	0.78	80	–	00	1.38	79.3
12	1.39	1.80	0.71	80	–	00	1.25	80.0
13	1.46	1.50	0.76	80	–	00	1.34	80.0
14	1.32	2.25	0.71	80	–	00	1.36	80.0
15	1.32	2.16	0.72	80	–	00	1.25	80.0
16	1.41	1.54	0.70	73.5	2	–	1.25	80.0
17	1.45	2.53	0.71	80	–	00	1.34	71.5
18	1.35	1.64	0.71	80	–	00	1.25	80.0
19	1.44	2.24	0.73	75.8	2	–	1.25	80.0
20	1.33	2.63	0.76	80	–	00	1.25	80.0
21	1.29	1.65	0.77	80	–	00	1.26	80.0
22	1.49	2.65	0.76	78.9	00	–	1.25	80.0
23	1.44	1.94	0.72	60.9	19.1	–	1.25	80.0
24	1.40	1.65	0.72	41.4	38.6	–	1.26	04.8

bidding and capacity withholding of the rivals' suppliers. Now, participation of suppliers 4–6 has increased in up regulation and down regulation market as compared to cases-I and II.

The profit of suppler-1 obtained using ABC and GA is given in Figure 4 for all the cases considering coordinated bidding strategy. From the Figure 4, it can be seen that the profit of supplier-1 obtained using ABC is higher as compared to GA in all the cases.

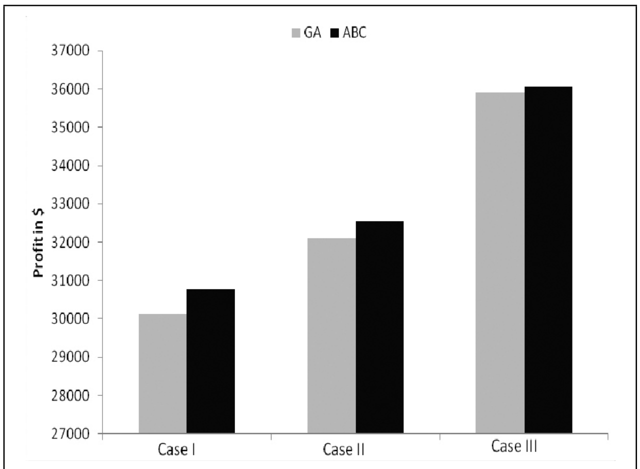

FIG. 4 COMPARISON OF PROFIT USING GA AND ABC

Table 5 compares the profit obtained with coordinated bidding strategy with that obtained for uncoordinated bidding strategy, in which the supplier is assumed to bid only in DAEM, for all the cases. It can be observed that the profit obtained using coordinated bidding strategy is higher than the profit obtained using uncoordinated bidding strategy in all the cases. The high profit obtained in coordinated bidding strategy is due to the higher up regulation prices.

TABLE 5

COMPARISON OF PROFIT FOR COORDINATED AND UNCOORDINATED BIDDING STRATEGY

Cases	Profit in $	
	Coordinated bidding strategy	**Uncoordinated bidding strategy**
Case-I	30784	18895
Case-II	30784	18895
Case-III	28587.8	17642

5.0 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 for each operating hour. Results obtained using the ABC algorithm have been compared with those obtained from GA. From the results, It is observed that

- Profit of a supplier depends on the rivals' bidding strategies.
- Coordinated bidding strategy is more profitable as compared to bid in uncoordinated bidding strategy only.
- 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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