Optimal Bidding Strategies in A Restructured Competitive Electric Power Market Adopting LUS-FFA Method

Ramachandra Agrawal, Sabita Tripathy, Smita Nayak, Vipin Gupta, Manoj Kumar Debnath

Abstract*: At present, the generating firms throughout the world experience the critical problem of maximizing their own benefit under the constraint of social surplus issues. Strategic bidding can be adopted while trading power to the market controller. The electricity market has become extra competitive after deregulation having an advance market flexibility to be recognized and implemented by the participators for individual gains that is the strategy to bid. An optimization method Local Unimodal Sampling Fire-Fly algorithm (LUS-FFA) is considered to bid within the strategic limits in competitive electric power market by the power supplying and consuming participators ruling the MCP while rest of the power customers are in the aggregate load form. To win its share during the trading hour in the auction process of the market each participator bids against the opponents competing. For profit maximization, winning the auction in the hourly competitive power market to retail partially or entirely the total power demanded of a specific hour is of vital importance. The proposed optimization techniques is adopted to find the bidding strategies in modern dynamic electric power market along with the power producing firms and bulk power consuming customers. Each rival will estimate the bid parameters out of the previous market data. The consequence of the implementation of LUS_FFA technique evidenced higher gross profit over other earlier used ways when tested on IEEE-30 bus power network incorporating 6 Power producing firms and 2 bulk power consumers. A new participant's entry effect on the present market bidding behavior has also been discussed in this work. A dynamic trading day ahead market with the criteria of ramp extreme for each participator is presented thereby depicting a practical market. Additionally, the Market Clearing Price (MCP) variations are also in the pre-specified limits at every instant of the day along trading duration. Superiority was noticed throughout with the application of the LUS_FFA method irrespective of a static or dynamic market.

***Index Terms*: IPP; CEPM; MCP; DPM; PSO; FFA; LUS; LUS-FFA.**

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I. INTRODUCTION

The generating companies and the market operator are inter-reliant as the choice of one distresses the other. This suggests that the bid-ding strategies of the generating firms are a higher-level decision which has to be tracked by the market operator, but on the other hand the generating schedule levied by the market operator, a lower level decision, also impacts the generating firms. This inter-dependence gets more complicated wing to the consumer's involvement in governing the Market Clearing Price (MCP) with the intention of maximizing its self-benefit. The power to be traded on hourly duration of the next trading day in the deregulated electricity market depends on the MCP declared by the ISO.

So, the electricity market has been restructured with enough policies of regulation. This work considers sealed bid auction mechanism. So, a market participator has no information about the real bidding data reported by the rival firms to the ISO. Here, a participator's goal is to maximize its own benefit that's called as strategic bidding [1].

Lai et.al in [2], have established a dynamic bidding model for competitive electricity market which is based on supply function method. Optimal bidding along with Incomplete information modeling with the transmission constraints like congestion and line capacity etc. have been discussed in [3] and [4] respectively. Locational marginal price (LMP) and line congestion on market clearing price (MCP) has been suitably lectured in [5]. Supply function equilibrium procedure and the spot market have been reviewed in [6-7].

Basic models to bid using DP are published in ref. [8]. A bidding method based on LR in a pool of electrical market was reported in [9]. For bidding problem solution Nash equilibrium is used [10]. For advance market, Genetic Algorithm was suggested by David and Wen in ref. [11]. In [12], a stochastic model of price taker participator has been used in Nord-pool markets. PSO based bid-ding model is solved by Bajpai et. al in [13]. Decisions of bidding parameters selection in the electrical markets put in [14] using a two-level programming model along with the PSO technique. PSO is an examined approach not as GA, but it proves a quick settling with the desired optimal result as described in [15].

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In [16], various pricing ways adopted in different restructured electrical markets of the Globe were compared. Bajpai has worked on bidding supported by PSO method for market participants as in ref. [17]. At present, electrical distribution network provides open link to the grid for all [18]. Actual electricity market is totally different as compared to the commodity markets and dealt in [19]. Many works are sighted in past few years, where bidding strategies might be either for the IPPs or for large power demanding consumers or both as in the present work. A vast assessment on several optimal methods of bidding in electrical power markets are sighted in [20].

In this article, the mathematical models convoluted are nonlinear in nature like the real time problems and classical methods can't be accepted to resolve the problem. LUS in conjunction with other optimization techniques are implemented in [21-22]. Heuristic method such as a novel hybrid LUS_FFA has been suggested in this work, where the FFA method was proposed in [23] and PSO was implemented in [24]. Every participant can independently optimize its self-benefit in each step [25]. Here, LUS-FFA is implemented and the when compared to that presented in [26-27] evidences efficacy of the proposed method. The rest segments are put in the way being explained further.

Segment II comprises in detail the problem formulation dealing with the offering issues of the power organizations and the customers. Segment III demonstrates the recommended calculation method using LUS_FFA technique. Segment IV introduces the use of LUS_FFA method to get rid of the offering issues detailed in portion II. It also describes the outcomes found for the ideal offering issues considering IEEE-30 Bus power transmission framework and the dynamic market structure with the thought of the value versatility and impact of the involvement of another firm into the current power market. Segment V states the conspectus with the future extension of the present work to portray the prominence, essential for the multi-functional power markets.

II. PROBLEM FORMULATION

The structure of 'm' IPPs and 'n' major customers is supposed to participate in power trading market by bidding. Either a power provider or a major customer put in a bid of a successively increased supply and decreased load requirement for the ISO. If for ith producer the linear supply curve implied by $G_i(P_i)$, the real power production of ith IPP, and denoted as the below relation.

$$G_i(P_i) = (a_i + b_i P_i) \tag{1}$$

Here, ai and bi are the bidding factors of ith producer or IPP and i = 1, 2, 3…………………..m.For huge costumer bid steady demand curve given as $W_j(L_j)$ that's a function of Lj, the active power demanded by jth costumer, that is denoted by the given equation:

$$W_j(L_j) = (c_j - d_j L_j) \tag{2}$$

Here, cj and dj are the bidding factors of the jth costumer and j =1, 2, 3……………………..n.

Each of the bidding factors is positive. To know the production output and costumer demand the load flow restrictions, production limits and load requirement limits are enforced by ISO or PX by resolving the equations as follows:

$$a_i + b_i P_i = R \tag{3}$$

Where, R is MCP of the electricity power market to be found.

$$c_j - d_j L_j = R \tag{4}$$

$$\sum_{i=1}^{m} P_i = Q(R) + \sum_{j=1}^{n} L_j \tag{5}$$

Here, $Q(R)$ is the pool load forecasted by ISO for small costumers as given:

$$Q(R) = Q_0 - KR \tag{6}$$

$P_{min,i} \le P_i \le P_{max,i}$, where, i=1, 2, 3…….m

$L_{min,j} \le L_j \le L_{max,j}$, j=1, 2, 3……. n

Where, Pmin,i and Pmax,i are the output limits of the ith power supplier, and Lmin,j and Lmax,j are the load requirement limits of the jth huge costumer. K is the price elasticity of the small costumer's load requirement in combined form and Q0 is the constant. For now, if the factors are neglected then the solution to Equations. (1) - (3) is:

$$\left[R = \frac{Q_0 + \sum_{i=1}^{m} \frac{a_i}{b_i} + \sum_{j=1}^{n} \frac{c_j}{d_j}}{K + \sum_{i=1}^{m} \frac{1}{b_i} + \sum_{j=1}^{n} \frac{1}{d_j}} \right] \tag{7}$$

$$\left(P_i = \frac{R - a_i}{b_i} \right) \tag{8}$$

Where i=1, 2, 3……….m

$$\left(L_j = \frac{c_j - R}{d_j} \right) \tag{9}$$

Where, j=1, 2, 3……….. n

Resolving equations (7), (8) and (9) we found that, production plan of respective IPP and the load power demand. Anyways, here we do not take into considerations the ramp rate factors as up ramp or down ramp, forbidden functioning area, minimum up and down time and the start-up shut down costs etc. The ith producer's cost function, $C_i(P_i)$, is presented by:

$$C_i(P_i) = e_i + f_i P_i^2 \tag{10}$$

Here, e_i and f_i are the cost cofactors of the ith IPP. The gain function, $F(a_i, b_i)$ of the ith producer is presented by:

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Maximize $F(a_i,b_i) = RP_i - C(P_i)$ (11)

Also, the jth costumer cost function is supposed as $B_j(L_j)$ and is denoted by:

$B_j(L_j) = g_j - h_j L_j^2$

(12)

Here, g_j and h_j are the cost cofactors of the jth huge costumer. The gain function, $B(c_j, d_j)$ for jth costumer is given as:

Maximize $B(c_j, d_j) = B_j(L_j) - RL_j$ (13)

Subject to: Equations. (3)- (6)

III. SOLUTION TECHNIQUE

A.Particle Swarm Optimization (PSO)

PSO, an effective algorithm, which is initiated via a group of arbitrary answers as population. Each answer is a particle. It has a velocity adaptable to the flying information of the self-search volume as well as its community. The ith particle position is denoted as Xi = (xi1, xi2…xiD). The best place of the ith particle is Pbesti. The best place among all of these particles is gbest and the associated value is gbestv. The velocity of ith particle is denoted as Vi= (vi1, vi2…viD). The place of individual particle is found by:

$X_r^{k+1} = X_r^k + V_r^{k+1}$

(14)

Where, k is the iteration count.

B. Fire Fly Algorithm (FFA)

FFA adopts an upheaval brilliance plan in which a specific firefly is altered by utilizing the past top information of other fireflies taking velocity into thought, which allows the variety preservation, not affecting untimely converging. For past years Optimization is a fascinating field of experimentation for a number of scholars. Crossover and mutation are major steps in advancement methods, but it's not there in PSO, in spite of the fact that this may contain many identical features, which is influenced from insect's herd conduct, where they collect food share. Each firefly learns from its environment and itself. The Global best is traced and this information is communicated to others and they got attracted to this place. The PSO technique factually performed much easily and finer as obvious from the literary study. Nevertheless, it might get trapped at the local extremes in complex problems. By FFA method the efficacy on complex problems could be improvised.

C. LUS-FFA Method

LUS–FFA algorithm: Different steps of the suggested optimization method are:

i. Initially, create the population matrix 'X'.

ii. Upgrade 'X' by the addition of a randomly created vector 'a' in the range 'd' as follows:

Xnew =X+a

iii. The fitness of 'Xnew' and 'X' is compared and 'Xnew' is accepted if performs better else 'X' with subsequent decrement of the range of 'd'.

iv. Now, 'Xnew' is taken as the beginning population matrix for LUS_FFA technique.

v. Evaluate 'mdif' from the mean solutions by taking the difference between them.

vi. Upgrade 'Xnew' by adding it with 'mdif'. Let the updated solution be X.

vii. If 'Xnew' performs better than 'X' then accept the former else the later.

viii. The new population matrix is formed by allowing the interaction of the fireflies among themselves.

ix. Lastly, the matrix of the solution set is formed either from 'Xnew' or 'X' on the basis of the better performance and then the steps ii to ix are repeated until the terminating condition is met.

IV. RESULT AND DISCUSSION

The LUS_FFA technique is performed with IEEE-30 bus system, which requires six generating firms and all are presumed as an independent Genco and major customers are contemplated as loading entities. The power producing units and the major cos-tumer's basic information are considered from article [24]. is 300 and K is 5 for the total demanded power. The bidding variables, i.e. bi and dj for the generators and massive costumers, according to the implemented and the earlier methods the optimized bidding pa-rameters are presented in Table 1. Table 2 shows that MCP based on LUS_FFA is estimated to be much better compared to earlier methods reported. Hence, the total benefit of the suggested way is greater than the Gencos in comparison to other pre-published works.

A. Case-1

Fig-1 describes the convergence curve. Fig-2 indicates that the attributes of the adopted LUS_FFA happens to be much better to the simple PSO algorithm under similar iteration counts. Gain of participators is higher than Monte Carlo, Genetic Algorithm and the conventional PSO technique, but those of the customers are comparably less to PSO [24]. The net gain is greater than obtained before as described in [24].

B. Case-2

The gain difference of each player, when an additional generating firm having identical constraints as unit-1 enters the market place, is quite remarkable. So, the

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energy transfer between multiple participators is altered, resulting in variation of benefit. Yet the whole gain increased multiple times (as obvious from Fig.3) i.e. the net collective prosperity has expanded because of the increased vying among the power producers in the market. Here, the results when compared with that discussed in ref [24] and LUS_FFA method provides far better under identical situations as reflected from Table 3.

C.Case-3

In this segment the condition of ramp extremes is included for a standard IEEE 30-Bus power network involving a 24-hour trading duration of the electric power market that practically reflects a day ahead power trading market. During the duration of trading every IPP is required to produce power satisfying its own ramp up and down extremes. It is an unique attempt to plan the bidding of indi-vidual IPP and for the whole

day. Here, the power demanded by the customers as load fluctuates every hour during the day of trading. This results in the variations in the MCP with time 't' (MCPt). Also, the individual benefit achieved by every IPP has been compared as discussed in Table 4-6.

Table 1:

BIDDING PARAMETERS

Generators (bi)	PROPOSED LUS_FFA	LUS-TLBO [27]	TLBO [26]	PSO [24]
1	0.0754	0.0874	0.0759	0.1064
2	0.1977	0.2167	0.2000	0.4967
3	0.6712	0.7207	0.4282	1.3009
4	0.1399	0.1418	0.1137	0.2395
5	0.3001	0.2735	0.1500	0.7096
6	0.2698	0.2514	0.1500	0.7096
Consumers	d_j	d_j	d_j	d_j
1	0.0800	0.0800	0.0800	0.3784
2	0.0600	0.0600	0.0600	0.2838

CASE-1

Table 2: Benefit of individual IPP and MCP

Generator	**PROPOSED LUS_FFA**		**LUS-TLBO [27]**		**TLBO [26]**		**PSO [24]**	
	Power	***Profit***	***Power***	***Profit***	***Power***	***Profit***	***Power***	***Profit***
1	151.1614	1899.3	160.00	1678.3	160.00	1678.3	160.00	1370.12
2	92.0248	867.3	85.1094	728.8	85.1094	728.8	105.8371	588.12
3	21.4863	333.2	36.1438	372.7	36.1438	372.7	48.5923	324.80
4	74.8135	591.5	62.0521	432.0	62.0521	432.0	120.00	428.90
5	31.6421	289.7	61.8753	287.1	61.8753	287.1	49.0859	180.71
6	43.7684	311.9	61.8753	287.1	61.8753	287.1	49.0859	180.71
Large consumer	***Load***	***Profit***	***Load***	***Profit***	***Load***	***Profit***	***Load***	***Profit***
1	119.3001	649.2	146.4839	858.3	146.4839	858.3	170.4639	1162.32
2	94.6360	224.6	111.9785	376.2	111.9785	376.2	143.9518	621.73
MCP	20.1071		19.9803		18.1492		16.4729	
Net Profit	5170.83		5144.10		5027.72		4857.41	

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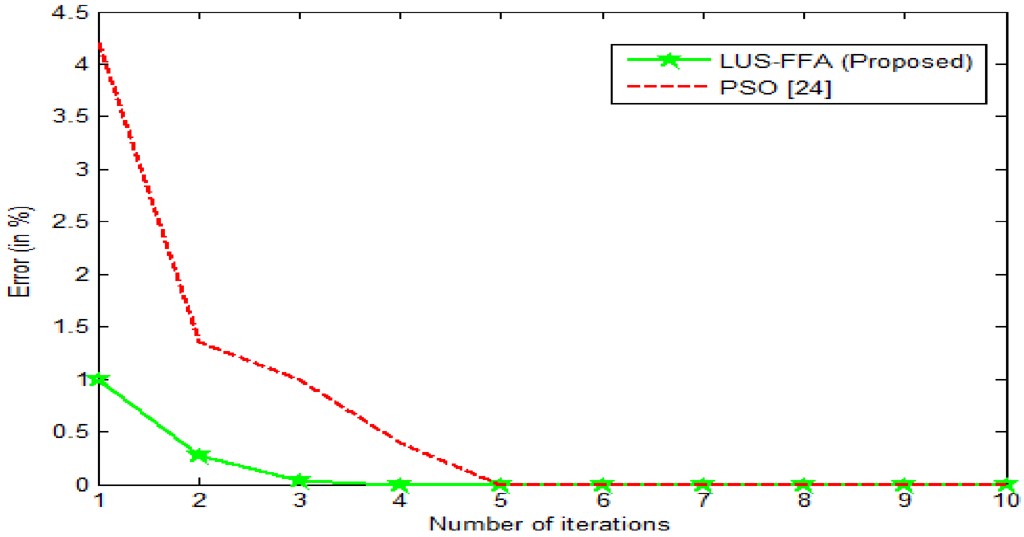

Fig. 1: The convergence curve of LUS_FFA method

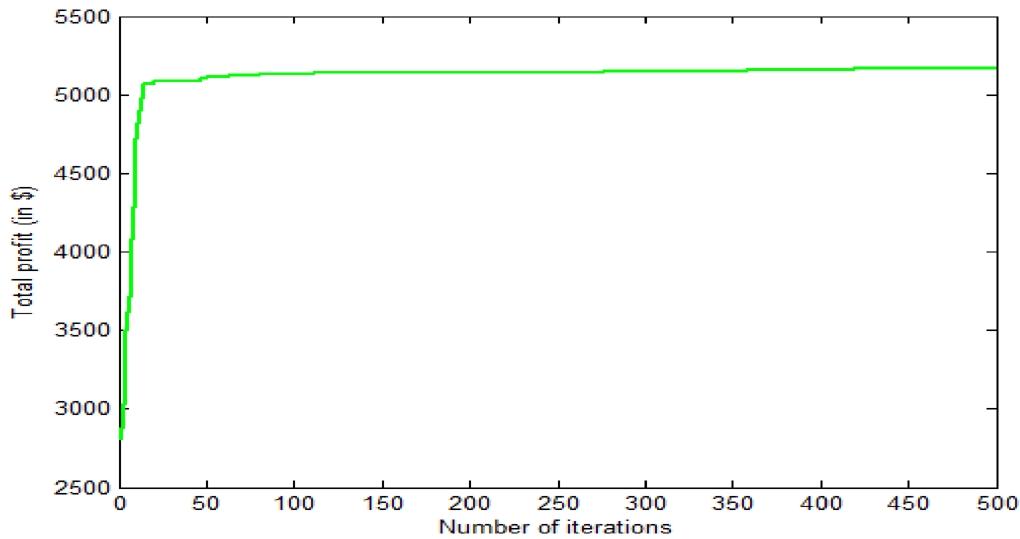

Fig. 2: Comparison of individual profit of IPPs

CASE-2

Table 3: Benefit of individual IPP and MCP

	SUGGESTED LUS_ FFA METHOD		LUS-TLBO [27]		PSO [24]	
Generator	**Power**	**Profit**	**Power**	**Profit**	**Power**	**Profit**
1	132.1251	1881.2	142.2056	1869.8	160.0000	948.5
2	38.1110	438.6	30.0000	420.1	80.7450	342.3
3	21.0000	280.3	20.0000	274.6	39.0117	209.3
4	22.1254	242.6	20.0000	184.5	78.5590	156.3
5	74.7642	186.65	69.8571	179.6	31.5215	74.5
6	74.7642	186.65	69.8571	179.6	31.5215	74.5
7	132.1251	1881.2	142.2056	1869.8	160.0000	948.5
Large consumer	**Load**	**Profit**	**Load**	**Profit**	**Load**	**Profit**
1	151.2101	628.3	160.0000	659.4	200	1654.42
2	138.7111	205.1	131.5180	207.3	150	1015.81
MCP	19.5942		19.4786		13.7282	
Total Profit	5941.58		5844.7		5424.00	

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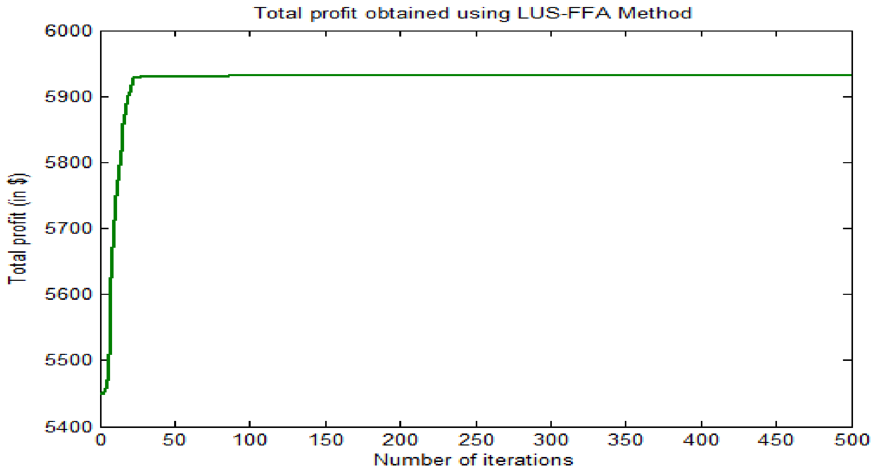

Fig. 3: Total profit maximization using LUS-FFA

CASE-3

Table 4: Power customer's net hourly load demand

Time in hours	**Demanded Power in MW**	**Time in hours**	**Demanded Power in MW**	**Time in hours**	**Demanded Power in MW**
1	1033	9	1300	17	1280
2	1000	10	1340	18	1433
3	1013	11	1313	19	1273
4	1027	12	1313	20	1580
5	1066	13	1273	21	1520
6	1120	14	1322	22	1420
7	1186	15	1233	23	1300
8	1253	16	1253	24	1193

Table 5: Power generated by each IPP to meet the dynamic load demand in each hour.

P in MW	1	2	3	4	5	6
1	172.0000	139.0000	341.0000	218.0000	82.0000	81.0000
2	206.9758	14.6177	326.6142	188.0000	112.5321	64.1245
3	291.9758	141.0000	285.2571	152.1027	91.2189	42.0000
4	211.9758	112.0000	292.9123	232.1027	123.1071	41.0000
5	193.2326	71.0000	237.3946	236.0000	205.1071	83.0000
6	278.2326	132.0000	274.1870	189.0000	151.5104	41.0000
7	323.1946	124.1725	255.1210	141.0000	234.5104	41.0000
8	243.1946	79.1725	252.5148	228.0000	298.0000	84.0000
9	289.2867	139.8284	317.5148	197.3611	258.3142	50.6741
10	356.1276	128.9651	358.0000	210.4858	200.2957	44.7141
11	404.423	135.214	353.102	167.314	203.2140	75.1451

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	8	7	6	7		
12	409.2517	122.0245	339.1397	225.1204	133.2140	83.7891
13	455.9571	144.0000	340.1120	215.4113	71.5042	86.4311
14	497.5142	120.3158	274.1120	170.4113	151.5042	58.2740
15	564.3204	98.0698	308.7501	173.2480	94.1324	82.4103
16	484.3204	53.0698	269.7501	128.2480	174.1324	122.4103
17	404.3204	43.4957	334.7501	208.2480	107.1155	157.0000
18	369.6745	77.1428	357.0000	166.2480	174.4775	134.3845
19	454.6745	137.1428	355.0000	243.6514	104.4775	137.1897
20	424.2145	112.9266	333.4163	207.1320	99.1584	95.1557
21	509.2145	143.0000	348.0000	238.0000	193.1584	142.1557
22	504.1560	114.0000	291.1495	208.1046	247.3417	154.2743
23	535.8357	64.4296	247.3599	177.0287	246.1355	148.6142
24	518.6197	41.0000	184.1472	205.2853	209.10024	141.2195

Table 6: Benefit of individual IPP and hourly MCP

IPP/PROFIT	1	2	3	4	5	6	MCPt (in $)
1	2199	1598	1697	995	1301	892	9.2145
2	1347	445	1398	1296	601	371	9.2899
3	1691	903	2290	1298	1096	612	10.8012
4	1902	1096	1799	1497	794	604	10.6004
5	1301	771	1508	1394	991	401	9.5914
6	1471	521	1800	1110	1500	699	10.0127
7	2097	905	2098	1401	1396	441	10.6902
8	2097	754	1591	1271	1651	399	10.1004
9	1251	702	1402	1003	1503	330	9.0012
10	2405	761	2397	1218	1804	597	10.9104
11	2802	1001	2541	1297	1794	602	11.0901
12	2629	602	1975	1104	1405	694	10.0071
13	3051	1099	2548	132	999	1201	11.1927
14	4047	1048	2890	1497	1503	521	12.0994
15	3298	631	2102	1004	898	881	9.9931
16	3699	399	2039	1041	959	554	9.9012
17	2894	351	1450	1098	598	1402	9.5017
18	2249	431	1692	1006	920	631	9.3124
19	2801	904	2502	1251	1151	1502	11.0131
20	3158	849	2229	1255	1052	951	10.6002
21	2653	958	2254	998	899	795	10.0102
22	2919	695	1117	1804	1280	797	9.5914
23	3538	459	1952	1307	1551	998	9.9941
24	2971	201	1261	1031	1101	905	9.0912

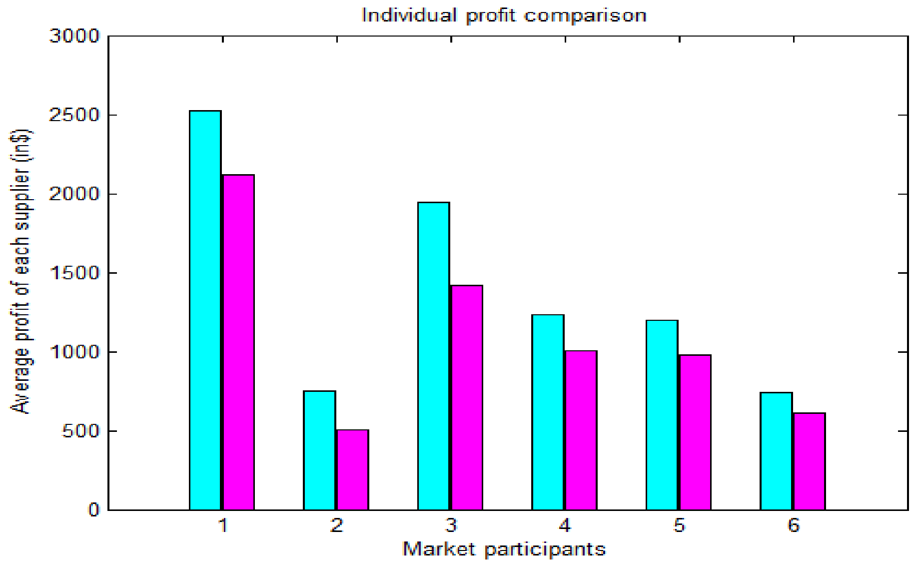

Fig. 4: Average individual profit comparison during the trading period

V.CONCLUSION

In focused power markets with fixed offered closeout instrument it is extremely exceptionally troublesome for the members to devise their individual benefit expansion procedures guaranteeing every one of them of winning the sale of the specific exchanging period. So, every one of them should be very much educated with respect to their opponents offering conduct else the benefit made by each will be influenced bringing about decrease of individual benefits. Moreover, if any new power maker goes into any current market then likewise the individual benefit share decreases which additionally has been considered in our work. From the test outcomes exhibited over, the uniqueness of the proposed strategy is plainly obvious. Be that as it may, the intricacy of the FFA calculation has been improved by consolidating the LUS technique, however the heartiness of the calculation is expanded a ton. The value request versatility of the customers is likewise thought to be non-zero (thought to be 5, in the current work) inferring purchasers request variety gets influenced by the MCP and portrays the truth. The age booking acquired is for a given exchanging period and can be stretched out for the whole exchanging day as required in the day-ahead power markets. Besides, the pragmatic working limitations of the partaking producing units will be considered alongside the impact of the transmission line blockages on MCP later on work.

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