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Research paper

Optimal Bidding by IPP in a Restructured Dynamic Competitive Electricity Market Adopting IGWO Method

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Abstract

In a restructured Electricity Marketplace the Independent Power Producer (IPP) has to bid adequately to optimize their profits for each self independently. So each IPP of the electric power market should bid to adopt a proper strategy enabling it to win the maximum share of the total power demanded at any specific trading period from its rivals participating in the competitive market. In this present work, a very latest and efficient bio-inspired method known as Improved Grey Wolf Optimization (IGWO) has been considered to find out the optimal values of the bidding coefficients. The implementation of IGWO evidenced much better output in terms of higher profits in comparison to the earlier methods reported recently by the eminent researchers. Additionally, a new case study involving an entire trading day with the ramp rate constraints for the IPPs along with the consumer demand variation, both on an hourly basis, is presented, which has not been proposed by anyone so far. The Market Clearing Price (MCP) variation is also kept within the specified extreme boundaries during each hour of the entire trading duration of the day depicting a dynamic market environment. The proposed technique along with the simple GWO method when tested on IEEE 30 Bus standard configuration incorporating 6 IPPs in the MATLAB environment resulted in much-improved outcomes compared to the latter case.

Keywords: *Market Clearing Price; Grey Wolf Optimization; Optimal Bidding Strategy; Restructured and forward electricity markets.*

1. Introduction

Electric Power sector restructuring has introduced desirable competition at major levels of the old electricity power market to reduce the gaming of market power by eliminating the existing monopolies at power production and marketing sectors [1]. However, electricity power markets are often susceptible to the sudden large disturbances causing it to be an imperfect competitive, unlike other commodity markets. So, it is possible to misuse the market power via gaming by the market players. As a result, the Market Clearing Price (MCP) goes up [2-3]. Another issue of concern for such markets is the price demand elasticity. A generating firm should consider various constraints of operation before predicting the opponent's bidding coefficients from the past market data and is assumed to be a strategic bidding problem (SBP) [4] for the generating company. To set up a competitive electricity market based on bidding by the participants of the market is need to be modelled as found in the forward electric power markets of Australia, Singapore and New Zealand etc. [5]. The market clearing price is calculated by comparing the offers from suppliers to bids from large buyers at each nodal point of the network for creating a supply and load demand equivalent price normally on an hourly time interval [6]. Across the globe, the electrical power sector restructuring is a major concern over the last few decades. The advancement in the digital arena has provided a much easier way to each market participant to look into the strategy of bidding to maximize its own profit out of the market under consideration [7]. Due to geographical, territorial or political reasons, independent power systems were evolved, but technical and economic reasons necessitated interconnections among these power producers which form the basis of the building blocks of an interconnected power system [8]. Colombian market follows British approach [9]. California deregulated wholesale electric power market opened in 1998. In Texas, wholesale electric markets and bilateral consent based agreements for power trading are discussed in [10]. CERC governs the inter-state activities and are at present operating on a DAEM based on the closed auction mechanism using bidding involving both the category of participants [11, 12]. A dynamic model of bidding of the electricity market implementing Nash equilibrium is reported by Lai et al in [13]. Optimization of generating companies and the ways of modelling in the DAEM have been analyzed in detail in [14]. The Supply Function Equilibrium (SFE) in [15] is about modelling the rivals behavior to maximize profits where uncertain demand prevails in the market which was applied in England and Wales reformed electricity pool market as per the publication by Green et al [16].A precise method of finding the SFE with the advantage of considering the generator's capacity limits which can be applied practical large-scale power systems was proposed by Bompard et al [17].

To bid optimally using PSO in an electric power market, D.M. Vinod Kumar et al. showed the bidding technique modeling [18,19]. However the proposed IGWO method is the improvement implemented over the GWO technique, first proposed by S. Mirjalili et al [20], has been applied to the strategic bidding problem and found to be an efficient method with faster convergence characteristics compared to above-mentioned methods and the IGWO technique outperforms even with the presence of price demand elasticity in the market providing still better profits.

The remaining portions are in the following sequence. Section II deals with the modelling of the strategic bidding issues in the mathematical form. Section III deals the proposed IGWO technique. Section IV describes the implementation of IGWO Algorithm in solving the formulated problem in section II. Section V is about the outcomes obtained corresponding to the bidding problem for IEEE-30 bus network neglecting the elasticity of price effects on MCP. Section VI concludes the paper with the further scope of extension of the present work.

2. Problem Formulation

Let 'm' IPPs are participating in a pool type day ahead electricity market via bidding. A generating firm bids a supply price and quantity of power to the Independent System Operator (ISO) with sealed bid and uniform MCP are followed. So the ith power producer's supply function is linearly related to the power produced as per the equation is given below.

$$G_i(P_i) = (a_i + b_i P_i) \quad (1)$$

Where i = 1, 2, 3…………………..m.

Here Pi is the active power and ai, bi are the bidding constants of the ith IPP. ISO will find the generation volume and the corresponding scheduling so as to maximize the net profit of the entire system while satisfying the criteria of security, stability and reliability using appropriate dispatch methods as given below:

$$(a_i + b_i P_i) = R \quad (2)$$

$$\sum_{i=1}^{m} P_i = Q(R) \quad (3)$$

Where, Pmin,i≤ Pi ≤ Pmax,ii=1,2,3…….m and R is the MCP of the competitive electricity market. Q(R) is the aggregate load estimated by ISO for the generating firms as follows.

$$Q(R) = Q_0 - KR \quad (4)$$

Qo is a constant number and K is the price demand elasticity and K=0 is assumed.
The solution to Eqs. (1) - (3) in the empirical form is shown below:

$$R = \frac{Q_0 + \sum_{i=1}^{m} \frac{a_i}{b_i}}{K + \sum_{i=1}^{m} \frac{1}{b_i}} \quad (5)$$

$$P_i = \frac{Ri - a_i}{b_i} \quad (6)$$

Where I =1, 2, 3……………….m

Equations (5) and (6) are solved to find each IPP's schedule of the power generation and the trading power quantity should not exceed the specified limits. However, Ramp up and down rate constraints, unit up and down time limits, POZs, shut down and the start-up costs are not considered here.

The cost of the power generated as a function of the i^{th} IPP is given below:

$$C_i(P_i) = e_i + f_i P_i^2 \quad (7)$$

The profit optimization of the i^{th} IPP is given by the following:
Maximize

$$F(a_i, b_i) = RP_i - C(P_i) \quad (8)$$

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

3. Solution Algorithm

3.1. Grey Wolf Optimization (GWO)

GWO is a new meta-heuristic approach called Grey Wolf Optimizer (GWO) where the algorithm is developed imitates the leadership sequence of hunting mechanism of the prey by the grey wolves in nature. Alpha, beta, delta, and omega are four types of grey wolves simulating the hierarchy of leadership. Hunting is through searching, encircling and attacking the prey. Hunting in groups is an interesting social activity of grey wolves, which can be subdivided as following steps:

- Tracking, chasing and approaching the prey.
- Pursuing, encircling, and harassing the prey until it stops moving.
- Attack towards the prey.

The above steps are put in the following algorithm

i. Set the GWO population Xi (i = 1, 2, ..., n)
ii. Set the values of a, A, and C
iii. Evaluate the fitness of each search entity
  Xα=the best search entity
  Xβ=the second best search entity
  Xδ=the third best search entity
iv. while (t < Max no. of iterations)
    for each search entity
  Upgrade the position of the present search entity
    end for
  Upgrade a, A, and C
  Evaluate the fitness of all search entity
  Upgrade Xα, Xβ, and Xδ
  t=t+1
  end while
v. return Xα

3.2. Improved GWO (IGWO)

For the past few decades Optimization has been an interesting area of research for many researchers. Crossover and mutation are major steps in evolutionary techniques. Though GWO was recently developed but there exists the modification called as IGWO. The biggest limitation of the GWO was for multimodal problems where the search space possesses a large number of local optima. A new strategy to eliminate the difficulties of the original GWO is the IGWO method. But IWO is the most recently developed method which preserves the diversity of the search space discouraging premature convergence while converging to the global optima within a very less no of iterations. However GWO's performance on complex multimodal objective functions has been enhanced by IGWO.

3.3. IGWO algorithm applied to bidding problem

The GWO method properly balances the parameters a (governing the exploration of the search space) and A (controlling the exploitation), but then it may be trapped in the local optima as it stresses upon the ability of exploration which is controlled by the vector C only. However, the aim is the enhancement of the diversity of the search agents. In the IGWO method, an agent modifies its position as per the alpha, beta, delta, or randomly chosen search agents. In [21], the authors calculated the vectors D Dc &, E Dc &, and G Dc & for an agent to increase the exploration capability without being trapped in the local optima. IGWO method has been used to evaluate the bidding variables of the participants to optimize their own profits and the total profit. The maximum profit achieved by any supplier is presumed to be the alpha wolf and is continuously modified with iteration according to the flowchart presented above. The present positions of the agents, Xα, Xβ, and Xδ are calculated and prior to the next iteration a, A, and C are modified to evaluate the fitness values of all the agents. Now the loop is iterated until we observe the appreciable change in the profit. The Pseudo-code of the IGWO algorithm is presented below.

i. Set the grey wolf population (Xi,i=1,2,3 ,...,n)
ii. Set a, A, and C.
iii. Evaluate the fitness of each search entity
Xa =the best search entity
Xb =the second best search entity
Xc =the third best search entity
iv. While (t < Max number of iterations)
for each search entity
if |A|<1 then, Evaluate Da & , Db & , and Dc &
else Evaluate D'a &c , D'b &c , and D'c &c
end if
Upgrade the position of the present search entity
end for
Upgrade a, and C, and A
Evaluate the fitness of all search entities
Upgrade Xa , Xb , and Xc
t=t+1
end while
v. Return Xa

4. Test Result and Discussion

The IGWO method is implemented on the IEEE-30 bus network using six power generators from [18]. The generating unit's data of the standard IEEE-30 bus system data is presented in Table 1. Qo and K are taken as (500,0) without (zero) demand price elasticity of aggregate power demand. The decision parameters i.e. the strategic optimal bidding coefficients bi of the IPPs, presented for comparison in Table 2. The MCP as per IGWO is proved better than SFLA [22], FAGSA [23] and PSO [22] as detailed in Table 3. So the gross profit of the power suppliers in IGWO is compared to that reported in SFLA [22], FAGSA [23] and PSO [22] and shown better by a higher margin.

Table 1: SIX GENERATORS (IPPs) DATA (IEEE-30 BUS SYSTEM)

Generator	e	f	Pmin (MW)	Pmax(MW)
1	6.0	0.0112	40	160
2	5.25	0.0525	30	130
3	3.0	0.1375	20	90
4	9.75	0.0253	20	120
5	9.0	0.075	20	100
6	9.0	0.075	20	100

Table 2: BIDDING STRATEGIES FOR IPPs

Generator	*IGWO*	*SFLA[22]*	*FAGSA[23]*	*PSO[22]*
Si.No	bi	Bi	bi	bi
1	0.0511	0.021004	0.021437	0.001092
2	0.1396	0.090472	0.121787	0.050953
3	0.7224	0.263450	0.337380	0.181976
4	0.0800	0.054320	0.023806	0.024283
5	0.2522	0.108594	0.0100457	0.072791
6	0.1020	0.108594	0.063465	0.072791

Table 3: MCP ($/MWH) AND PROFIT ($) OF SIX IPPs

Generator	IGWO		SLFA[22]		FAGSA[23]		PSO[22]	
SI NO	POWER	Profit	POWER	Profit	POWER	Profit	POWER	Profit
1	160.000	1211.5	160.00	1097.16	160.00	1034.9	160.00	772.41
2	142.0771	843.3	96.76	581.93	60.04	376.38	100.83	340.10
3	12.6970	106.4	29.73	196.19	58.91	157.22	32.35	125.06
4	86.4955	536.3	100.00	537.32	100	498.47	100.00	280.36
5	28.4396	183.7	56.75	285.94	60.41	275.38	53.40	136.32
6	70.2908	380.6	56.75	285.94	60.41	275.38	53.40	136.32
MCP	10.1720		9.45		9.06		6.88	
Total Profit	3460.70		2984.50		2617.73		1790.57	

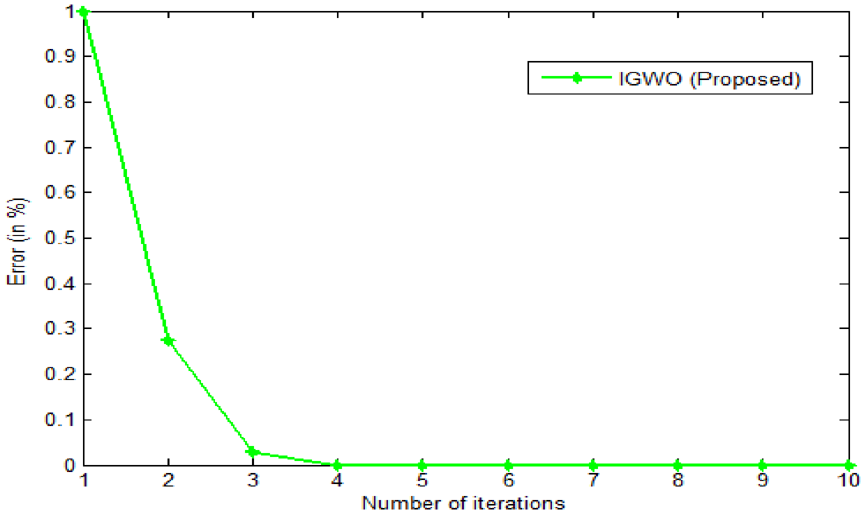

Fig. 1: Convergence Characteristics of IGWO

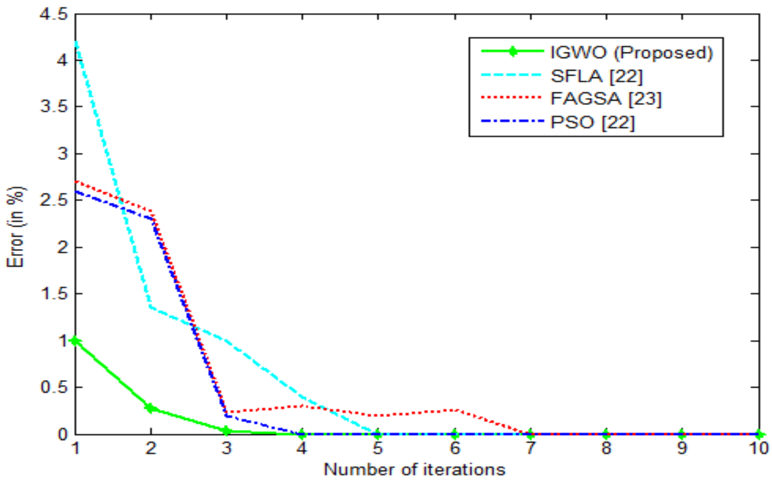

Fig. 2: Convergence Characteristics Comparison

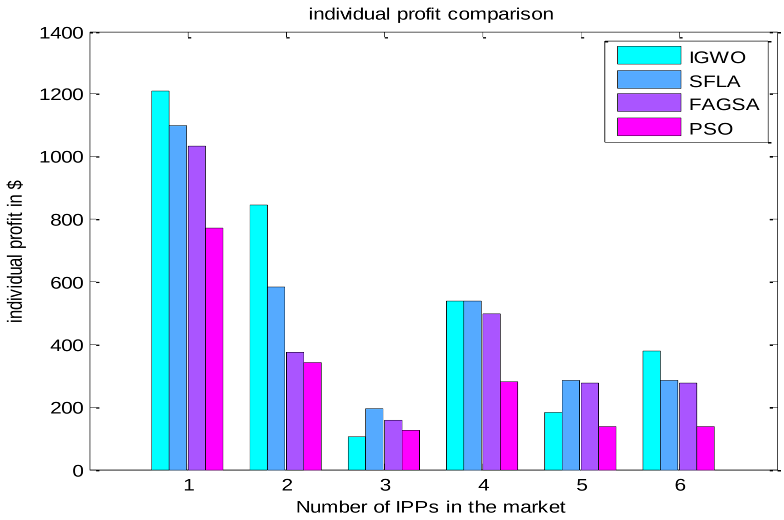

Fig. 3: Comparison of individual profit of IPPs

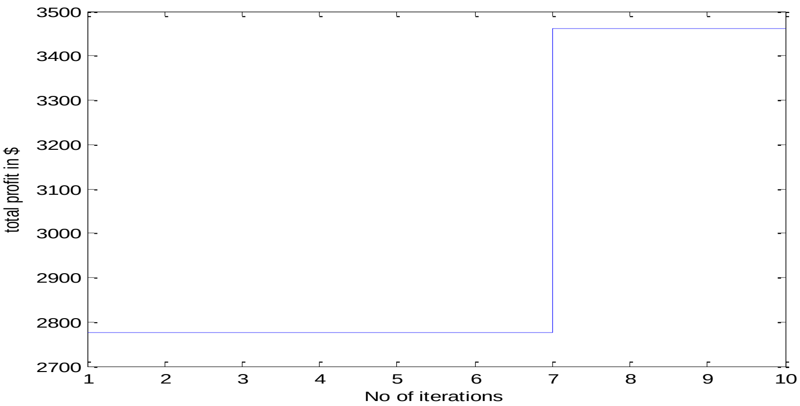

Fig. 4: Total profit maximization using IGWO

4.1. Case-1

Fig.1. shows the convergence characteristics of IGWO method alone and Fig.2. for all the earlier methods where the suggested one (IGWO method) convergences faster for an equal number of iterations. Profits of six IPPs are higher than SFLA [22], FAGSA [23] and PSO [22] methods as per Fig.3, but those of Genco no 3 and 5 are relatively lesser. But as per Fig-4, the overall profit is 3460.70$ which is substantially higher than each of those obtained earlier adopting SFLA [22], FAGSA [23] and PSO [22] methods respectively.

4.2. Case-2

Here, an inter-temporal criterion is considered such as ramp rate extremes in an IEEE standard 30-Bus power network system with a 24-hour trading period of the electricity market, which practically depicts a day ahead electricity market. During this entire trading period, each IPP has to generate power being subjected to its corresponding up and down-ramp extremes. No attempt has been made for the planning of the bidding techniques of individual IPP in addition to the afore-discussed constraint and also, for an entire day with the hourly load demand variations of the day. So, now the MCPt. denotes the MCP variations on hourly basis with the allowed extreme limits of -15% to +15% envelopes.

The generating unit's data of the standard IEEE-30 bus system data are given in Table 4. Hourly consumer aggregate load demands of a trading day are listed in Table 5. The power generated by each IPP to meet the demand in each hour has been presented in Table 6. Also, the benefits gained by individual IPP are compared following the optimization using GWO and IGWO methods. Self- profit of individual IPP and the MCP, both on each hour are shown in Table 7.

Fig.5.Shows the variation of the MCP during the trading period on an hourly basis while Fig.6. evidences the average individual profit comparison during that period. It was found the suggested IGWO method outperforms to the simple GWO method.er for an equal number of iterations.

Table 4: Input Data for Dynamic Trading

Unit no.	aj	bj	cj	P0min (in MW)	P0max (in MW)	Ur (MW/h)	Dr (MW/h)
1	0.00028	4.10	150	50	680	80	85
2	0.00312	4.50	80	30	150	45	60
3	0.00048	4.10	109	50	360	60	65
4	0.00324	3.74	125	60	240	45	80
5	0.00056	3.82	130	60	300	70	80
6	0.00334	3.78	100	40	160	55	40

Table 5: Hourly load demand of consumers of a trading day in aggregate form

Time in hours	Hourly Power demand in MW	Time in hours	Hourly Power demand in MW	Time in hours	Hourly Power demand 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 6: Power produced by individual IPP to satisfy the hourly demand

Time in Hours	Power Output in MW					
	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5	Gen 6
1	322.1589	150.0000	146.0402	130.9950	205.2750	78.5308
2	367.1989	141.1535	211.0402	125.0994	144.0924	44.4155
3	287.1989	96.1535	151.0402	200.7603	224.0924	40.7546
4	343.6874	83.6347	131.0052	226.3628	154.0924	74.2174
5	307.6874	143.6347	196.0052	181.3628	84.0924	114.2174
6	364.3372	150.0000	197.7414	136.3628	158.3412	59.2174
7	382.5787	150.0000	181.3190	91.3628	238.3412	76.3983
8	431.4769	134.4938	210.1906	60.0000	300.0000	49.8387
9	351.4769	96.4938	275.1906	140.0000	300.0000	89.8387
10	365.3617	96.2537	289.3437	209.0409	300.0000	40.0000
11	328.8316	132.3626	344.5198	199.8690	294.4170	40.0000
12	308.1310	150.0000	360.0000	154.8690	300.0000	40.0000
13	358.4424	140.3414	351.1169	161.7686	230.0000	71.3308
14	301.5809	133.8691	359.2962	240.0000	160.0000	78.2538
15	386.5809	150.0000	360.0000	240.0000	132.6199	52.7992
16	406.3677	105.0000	360.0000	240.0000	81.6323	40.0000
17	458.7757	88.1492	300.0000	211.2505	148.6616	48.1631
18	378.7757	116.6389	360.0000	240.0000	144.5854	40.0000
19	463.7757	150.0000	360.0000	240.0000	155.7116	63.5127
20	383.7757	105.0000	304.7308	220.0946	202.2983	57.1006
21	468.7757	150.0000	360.0000	240.0000	282.2983	78.9260
22	509.5401	119.8862	330.2066	220.3789	283.9204	56.0677
23	555.9252	91.9767	318.8574	181.1772	221.0933	50.9703
24	578.9376	46.9767	258.8574	183.7700	187.7239	43.7344

Table 7: Individual profit of each IPP and MCP, both on hourly basis

Time in Hours	Power Output in MW						MCPt (in $)
	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5	Gen 6	
1	2752	1240	1603	1240	1680	573	9.4991
2	2060	910	1214	1020	1653	590	10.1612
3	2192	773	1000	1369	1240	300	9.7161
4	2342	542	1105	1405	1501	700	10.3860

5	1837	862	1010	1000	806	880	9.5197
6	1374	612	935	904	570	602	8.5034
7	1921	704	1450	640	1110	407	9.1745
8	1997	645	1950	502	2120	416	10.6802
9	2843	587	1514	610	1546	520	9.8989
10	2715	617	1711	1500	2134	400	10.4870
11	2522	915	2021	1400	1827	420	10.5191
12	2486	1014	2760	1003	2136	306	11.0318
13	2055	545	2040	860	1602	307	9.6307
14	2057	960	1870	1204	1447	730	9.8845
15	1415	868	1600	1006	1180	409	9.1048
16	2409	540	1740	1118	1022	440	9.5240
17	3154	605	2210	1310	922	460	10.6280
18	2672	792	1909	1080	1280	315	9.7425
19	2227	936	1876	1230	1137	457	9.9378
20	2981	923	2030	1308	1475	438	10.3234
21	2839	916	2314	1340	1960	405	10.8502
22	3448	844	2201	1442	2165	450	10.8319
23	2910	505	1700	1025	1550	314	9.3029
24	3520	301	1960	903	1559	370	9.5318

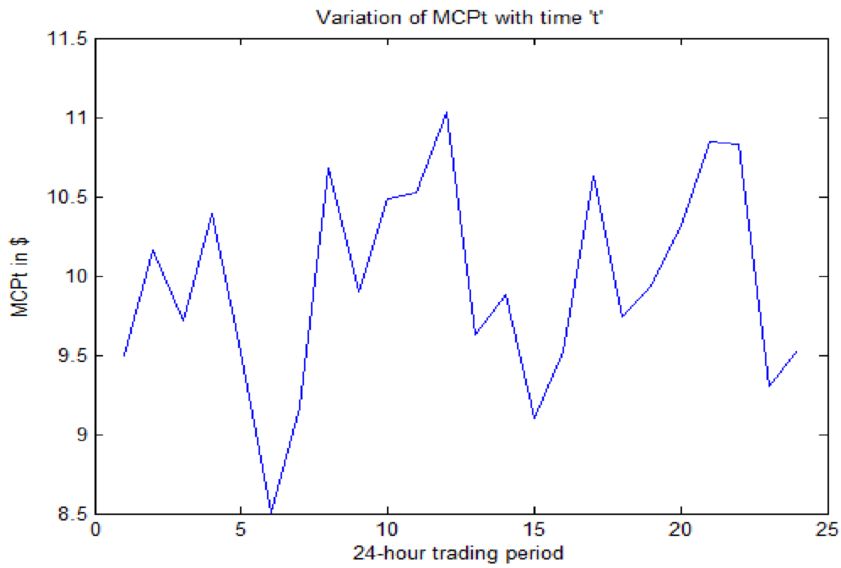

Fig. 5: MCP Variation with time of the trading duration

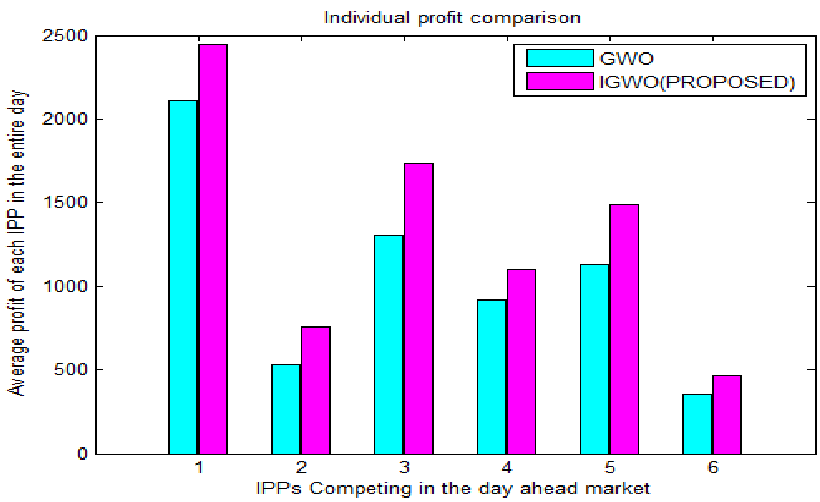

Fig. 6: Individual average benefit comparison of the trading duration

5. Conclusion

This work has implemented the IGWO method to bid strategically by each of the six IPP in a competitive electricity market during a specific period of an energy trading day. The wholesale market of power provides a competitive marketplace among the competing IPPs to sell their electric power output to retail consumers. However, at present days an innovative way for consumers to purchase electric energy directly from generating firms is evolving. Additionally, the MCP is affected by the condition of ramp rate extremes and has been considered in the current work for an entire day trading period on an hourly basis which is graphically evident that the variation of MCP during the entire day doesn't deviate from the prescribed limits. Here an IPP bids for maximizing its self-profit after evaluating the MCP in each hour, where each of the profits from the competitive marketplace by adopting a proper strategy with the help of GWO and IGWO method separately and it was found that the second method is more efficient than the simple GWO method. The efficacy of IGWO is verified on the standard IEEE 30-bus power network system evidenced by the higher profits found in both cases. In future, constraints such as capacity of the existing transmission network lines transferring power, the effect of line congestions and the peak load deviation by demand side variations etc. as well as the constraints mentioned above will be dealt to realize more practical need based results

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