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Research Paper



Optimal bidding of market players in competitive electricity markets based on a novel hybrid PSO-IGWO method

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Abstract

Strategic bidding is an important issue in the restructured electric marketplace. In an hour ahead actual power market having sealed bid auc-tion policy involving incomplete information of symmetrical and unsymmetrical nature have been addressed separately in the present work. Various constraints either equality type or inequality type have been properly analysed to model a market very close to a real one. Social welfare, where all the players individually benefitted is the prime objective. Hence, the bidding coefficients are to be selected very carefully. At present, the digital advancement supports each participant to optimize its desired objective through the optimization methods available so far. But, the proposed Particle Swarm Optimization-Improved Grey Wolf Optimization (PSO-IGWO) is a very novel hybrid method. Its supremacy compared to the other methods has been clearly evidenced by implementing in the present work. The standard IEEE-30 bus sys-tem and a practical 75 Bus Indian system have been considered to validate the effectiveness of the novel technique suggested and the excel-lent outputs evidence this fact on comparison with the results, of a very recently published article, found adopting GA optimization tech-nique [28].

Keywords: *Competitive Electricity Market; Bidding; Optimal Bidding Issues; PSO; GWO; IGWO and HYBRID PSO-IGWO Method.*

1. Introduction

1.1. Background and motivation

The power market modelling fundamentally was initiated by A. k. David [1] and acts as a backbone for the current research work henceforth. Then, David with F. wen advanced the work to a differ-ent level as described in [2, 3]. Here, different bidding models have been proposed to find the MCP. Strategic bidding with aim of mak-ing more profit out of the market imperfections and partial compe-tition, where, the price bided is more than the marginal cost have been dealt in details. Electrical power markets underwent a major reform around the globe enhancing competition in the market from traditional monopolies to competitive power markets by virtue of liberalization of the electric market from early 1980's in many countries in terms of services, free access of the network, open com-petition in power markets etc. [4]. Adequate operation of electric utilities results in the overall growth of any nation. With innovation of new optimisation methods to exercise the market power causes the reform of the competitive electricity market [5]. Around 1985 different countries across the globe have initiated energy market re-forms in the form of privatization, deregulation or liberalization etc. where Chile is the first among them [6].

1.2. Literature review

Optimal bidding strategies govern the risk reduction and the profit maximization of the market players in a competitive electricity mar-ket, where the market players are the participants either from power producer side (the generating companies selling power to the mar-ket) or from the consumer side (buying power from this market). Here, both the generation side suppliers and large load demand side consumers have been considered to be bidding into the forward marketplace which operates on the hour-ahead basis. To achieve this suitable bidding structure is to be devised. In a forward electric market with sealed auction mechanism, the information of oppo-nent's behaviour may be identical to all or non-identical i.e. sym-metrical or unsymmetrical knowledge respectively. Initially, around 1989, as per [7], for power production expansion issues in future of an existing plant dynamic programming method were adopted. Optimization involves different models with various mathematical methods like LR, MIP, NLP, DP and MDP etc. Saleh suggested the LR method for optimising the objective function [8], whereas, an MIP method to find out the real power, ancillary ser-vices and the MCP has been used in [9]. A MCP determination through different auction processes has been discussed in [10]. In [11], it has been shown that the risk management by the market players while bidding optimally, especially, by a Genco in the mar-ket so that the unsold energy penalty is avoided.
Single auction mechanism cases of bidding are reported by many researchers, but among the recent cases, the model implementing FACLPSO method in [12] is quite informative.

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As per Kian, R.C. Agrawal and R.K. Mallick in [13], [14] and [15] respectively, both the supplier and the large consumers have to be involved in the auction process and is known as double-sided auction mechanism. A novel of Bertrant game approach with inelastic demand has been considered in [16]. For complex bidding problems models based on agents or brokers replace the equilibrium models where the suppliers interact intelligently with each other. GA, based on artificial intelligence, has been adopted by Richter in [17] to optimize the total profit out of the market. This method of Genetic Algorithm was again used by Azadeh, Ghaderi, Pourvalikhan Nokhandan and Sheikhalishahi in [18], where, the market mechanism incorporated pay-as-bid MCP along with a hidden auction. In electric markets with an auction mechanism where a market player doesn't know its opponent's bidding strategy has to predict the same from the previous data to maximise its own profit by governing the existing market power in its own favour during the specific trading period.

So, individual player of the market needs to be informed adequately about the rival's strategic behaviour otherwise its profit will reduce whereas that of the others will increase. A simple PSO technique has been applied in [19] for determining strategic variables of an independent power supplier. In [20], network constrained profit maximization using PSO has been proposed. Pravabathi in [21] has elaborated the stepwise and linear bidding issues in the form of the dead weight loss, a loss in the social welfare in disguise, in a very lucid manner. Hybrid series and parallel optimisation methods have been adopted by many researchers as far as for strategic bidding issues are concerned, e.g. an ANN-LM hybrid optimisation method and a PSO-SA hybrid method were suggested in [22] and [23] respectively.

As per different electric market models and pricing methods involved in bidding process, the optimal bidding parameters to be selected is very much complicated and are reported by Mathur in [24]. Hence, keeping the enhanced advantages of the hybrid methods proposed earlier in view, the present work also considers a hybrid optimisation method based on PSO proposed in [25] and a most recent method IGWO [26], an improved version of GWO [27] and the performance of the new combination is significantly identified on comparison with a very recently pre-published paper [28] from the test result discussion portion of this paper.

1.3. Contribution

The novelty of the present work lies in the following highlights:

- A novel hybrid PSO-IGWO method has been proposed which has not been used by any researcher so far whose efficiency will be evident in the result and analysis portion.
- Both the IEEE-30 Bus and 75-Bus Indian system has been considered in the present work.
- In a DAEM with sealed bid auction along with the consideration of the incomplete information as in the real market classified as symmetrical and unsymmetrical information are carried out separately.
- Equality and inequality constraints have been suitably considered to depict a more realistic market.
- The output obtained by implementing the PSO-IGWO method outperforms than that reported by a very recently published paper [28].

1.4. Structure of paper

The paper has been organized as follows, Section 2 describes the electrical market model. Section 3 deals with the probabilistic models to account for the symmetrical and the unsymmetrical informations of the rival participants. Section 4 deals with the new developed hybrid PSO-IGWO technique. Section 5 discusses the comparative factors by implementing the suggested technique to justify the importance of the present work. Lastly, the concluding statements and the possible modifications or improvements for further research are covered in Section 6

2. Mathematical market model formulation

In an oligopolistic market, let 'm' generating utilities, each with a single generator, along with 'n' large load demanding buyers as the market players. A player bids a linearly increasing or decreasing supply or demand function to the power exchange depending on the player category i.e. whether the player is a power supplier or consumer respectively.

For the ith power producer the linear curve representing the supply function is denoted by equation (1)

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

Where, Pi is the real power produced by the ith power producer and ai and bi are the constants of bidding for the ith power producer and are always non-negative with i within the range as specified below.

i = 1, 2, 3…...m.

Also the large power buyers bid as per the function stated below.

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

Where, L_j is the load demanded by the j^{th} large buyer in the competitive market and c_j, d_j are the corresponding non negative bidding constants with j varying in the range as given below.

j = 1, 2, 3…...n.

Now, the power market mediator having the bidding data of all the market players will estimate the net power to be supplied and the total demanded power as a result MCP can be evaluated graphically, denoted by R along with the net amount of power to be dispatched in the hour ahead market in the specific period and the generation of level of each supplier and the demand level of individual large consumer of the market. Hence, the eqn.2 and 3 can be represented involving MCP as follows:

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

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

From equations 3 and 4 we can get the power to be generated to meet the demand of the market during the period under consideration so as to satisfy the following equality and inequality constraints

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

Where, $P_{\min,i} \le P_i \le P_{\max,i}$ (6)

i = 1, 2, 3….m

$L_{\min,j} \le L_j \le L_{\max,j}$ (7) j = 1, 2, 3…….n

And Q(R) is the net power demand of all the small customers which is related to R, the elasticity factor (K) and Q_0 . This is explained in the following equation:

$$Q(R) = Q_0 - KR \tag{8}$$

After constraints are omitted temporarily the solution of the Equations. (1) - (3) can be represented as shown

$$\left[R = \frac{Q_O + \sum_{i=1}^{m} \frac{a_i}{b_i} + \sum_{j=1}^{n} \frac{c_j}{d_j}}{K + \sum_{i=1}^{m} \frac{1}{b_i} + \sum_{j=1}^{n} \frac{1}{d_j}} \right] \quad (9)$$

$$\left(P_i = \frac{R - a_i}{b_i} \right) \quad (10)$$

Where I =1, 2, 3…….m

$$\left(L_j = \frac{c_j - R}{d_j} \right) \quad (11)$$

Where j=1, 2, 3…….n

After solving equations (9), (10) and (11) we obtained the power to be generated to meet the demand of the market. Now, the extreme limits of power to be generated are deviating from the values provided in the input data table as shown symbolically in (6) and (7) and each of them must be kept un-deviated from the pre-specified limits. but, it has been assumed that the quantity of power found out of equation (10) are dispatchable via the corresponding power producing company due to non-consideration of the inter temporal constraints like minimum up and down time, the start-up shut down costs and ramp rate limits like up ramp and down ramp limits etc.

The i^{th} power producer is presumed to have a quadratic cost relation and is given as

$$C_i(P_i) = e_i + f_i P_i^2 \quad (12)$$

The profit maximization bidding strategy for i^{th} power producer is given as:

$$\text{Maximize } F(a_i, b_i) = RP_i - C(P_i) \quad (13)$$

Subject to: Equations (5) - (8)

So, we need to determine a_i and b_i values to maximize F (a_i, b_i) subjected to the constraints mentioned in equations (1) - (5).

Likewise the j^{th} large consumer is assumed to have quadratic cost function and is given

$$B_j(L_j) = g_j - h_j L_j^2 \quad (14)$$

The profit maximization bidding strategy for j^{th} consumer is shown as:

$$\text{Maximize } B(c_j, d_j) = B_j(L_j) - RL_j \quad (15)$$

Subject to: Equations (5) - (8)

Hence, we required to get c_j and d_j to maximize B (c_j, d_j) subjected to the constraints Equations (5) - (8).

Hence, the paper proposes a novel hybrid PSO-IGWO method to solve the bidding issues of each type of the market player by providing an optimal solution thereof. Hence, a_i and c_j are presumed to same as the input data while b_i and d_j are found using the suggested robust method (PSO-IGWO) and our results are found to be much more excellent on comparison to that reported by adopting the simple fundamental GA method in [28].

3. Probabilistic model

If the power producers were aware of the strategic behaviour of one another in that case they could change the MCP to obtain a higher share of the total profit which is impossible as the bidding mechanism is a sealed one and has been assumed in the market under consideration. The proposed method of the present work can easily be implemented to find out the bidding parameters with a number of power producers and power demanding customers of different net effective loads and in various competitive markets as different markets around the globe is non-uniform.

However, from the past market data of a year or even more a market player can use the probability distribution function (pdf) as detailed with all the mathematical formula in [3] to predict the rival player's activity in the market. One of the most important relations is presented below for the j^{th} power supplier competing in the market for illustration purpose. A similar equation can be written for the large consumer of the market also.

$$\text{pdf}_p(\alpha_j, \beta_j) = \frac{1}{2\pi\sigma_j^{(\alpha)}\sigma_j^{(\beta)}\sqrt{1-\rho_j^2}} \times \exp\left\{ -\frac{1}{2(1-\rho_j^2)} \left[\left(\frac{\alpha_j - \mu_j^{(\alpha)}}{\sigma_j^{(\alpha)}} \right)^2 - \frac{2\rho_j(\alpha_j - \mu_j^{(\alpha)})(\beta_j - \mu_j^{(\beta)})}{\sigma_j^{(\alpha)}\sigma_j^{(\beta)}} + \left(\frac{\beta_j - \mu_j^{(\beta)}}{\sigma_j^{(\beta)}} \right)^2 \right] \right\} \quad (16)$$

Where, ρ_j is the coefficient of correlation between α_j and β_j. $\mu_j^{(\alpha)}, \mu_j^{(\beta)}, \sigma_j^{(\alpha)}$ and $\sigma_j^{(\beta)}$ are the joint probability distribution parameters.

Solution Algorithm

a) About PSO

The social learning issues in the fundamental PSO results in faster convergence compared to Monte Carlo and GA methods, where, each particle learns from own best and the global best position to modify its position. PSO method is quite easy to implement and performs far better. But it may be trapped in the local optima in case of very complex multimodal functions. As the fitness value of any particle is found by all the variables on which the objective function depends and the particle which has found the position of the global maximum or minimum in some variables or dimensions may possess a low value of fitness due to poor values in other variables or dimensions. Though there exist different modified PSOs still the biggest advantage is achieved by the present proposed method, where, it is being cascaded with the IGWO method.

b) About IGWO

For last three decades optimization is continued to be an interesting area for research work progress and before discussing about IGWO, which is an improvement of the basic GWO method, must be elaborated. GWO is a recent approach known as Grey Wolf Optimizer (GWO). By imitating the sequence of hunting of the prey by a group wolves the algorithm has been developed. Alpha, beta, delta, and omega are four ($\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\delta}$, $\boldsymbol{\omega}$) types of grey wolves, who simulate the hierarchy followed in the nature. Searching, encircling and attacking the prey is the sequence of hunting. For multimodal non-linear cases with numerous local optima, a novel way to overcome the difficulties the IGWO technique were proposed and has been developed very recently, where the diversity is maintained while discouraging any type of premature convergence and the fitness value is obtained with comparatively less no of iterations. So, GWO's efficiency on complex multimodal functions were found to be enhanced by IGWO. In [26], the vectors D Dc &, E Dc &, and G Dc have been calculated and the exploration capability has been enhanced without getting trapped in the local optima. The Pseudocode of the IGWO algorithm is presented below.

c) About Hybrid PSO-IGWO

Here, the series optimisation using PSO [25] and IGWO [26] in cascade has been carried out to make use of the efficacy of both the methods. The best population of PSO method is used as the initial population of the IGWO method. The IGWO method properly balances the parameters a (governing the exploration factor) and A (controlling the exploitation factor), but trapping may still occur at the local optima as is governed by vector C only, but to enhance the diversity of the search agents the hybrid PSO-IGWO method is proposed, where, an agent updates its position according to the alpha, beta, delta, or randomly chosen search agents.

Now, the hybrid PSO-IGWO method is used to evaluate the bidding variables of the market players to optimize the self-profit and the

profit as a whole and as a result the best outcomes are obtained as evidenced by the following section. The highest profit achieved by any market player is considered as the alpha wolf and is continuously updated with the iterations as per the flow chart given below. The current positions of the parameters, Xα, Xβ, and Xδ are evaluated and prior to the next iteration a, A, and C are changed to calculate the best values of all the parameters. Now the loop is continued till we mark significant change in the profit. The logical steps of the hybrid PSO-IGWO method are presented below.

i). Generate the initial population 'x' (PSO algorithm starts here).
ii). Update the population by adding 'x' with Vnew.
iii). Compare the fitness of 'x ' and ' X_{new} '. Accept 'x ' if performs better otherwise accept ' X_{new} ' . (PSO algorithm ends here and IGWO algorithm starts here).
iv). Take ' X_{new} ' as initial population for IGWO algorithm and Initialize a, A, and C.
v). Calculate the fitness of the search agents and name Xa, Xb and Xc as the best, the second best and the third best search agent respectively.
vi). While (t < Max number of iterations)

for each search agent
if |A|<1 then, Calculate Da & , Db & , and Dc &
else Calculate D'a &c , D'b &c , and D'c &c
end if
Update the position of the current search agent
end for
Update a, and C, and A
Calculate the fitness of all search agents
Update Xa , Xb , and Xc

Update ' X_{new} ' by X'_{new}

vii). Accept if it performs better. Otherwise accept X_{new}.
viii). Finally select the solution from X'_{new} or X''_{new} whichever performs better, which is the input of PSO.
ix). Repeat steps ii to ix until the stopping criteria is met.

4. Results and discussions

The tables below show the comparison of the method adopted in this present work with the output obtained using GA and MC [28] methods. Evidently, the results got in the present case of PSO-IGWO hybrid optimisation are much better indicating the new technique to be very much efficient in finding the optimized outcomes of any non-linear and complex functions. The IEEE-30 bus bench mark system data is obtained from [3] where, six generating companies and two large electrical power consumers are taken up as the loads. The input data is provided in Table.1and Table.2. Qo and K are assumed to be 300 and 5 respectively as the net sum of the small loads of the network. The decision parameters also known as the strategic coefficients of bidding are bi and dj of the market players in general. The current and the previous ways of optimisation used are put in Table.3. Table.4 representing that the PSO-IGWO hybrid optimisation obtains a net profit far better compared to that which has been reported in [28].

5. Case-I (IEEE 30 bus case)

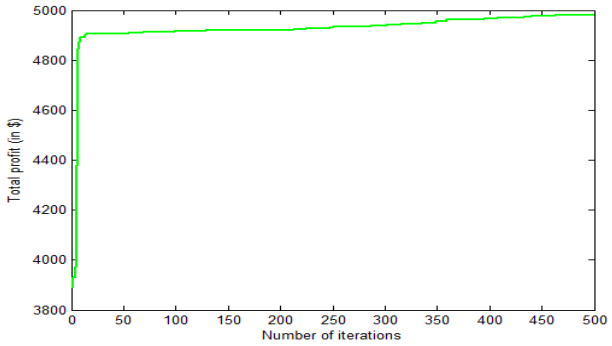


Fig. 1: Total Profit Maximisation Using PSO-IGWO Method (Symmetrical Case).

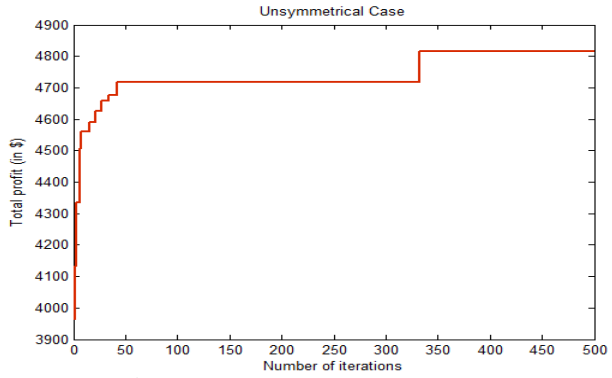


Fig. 2: Total Profit Maximisation Using PSO-IGWO Method (Unsymmetrical Case)

Fig-1 and Fig.2 show the total profit maximisation curves obtained using the proposed method and are comparatively more than the pre published recent paper [28] results. Comparison of PSO-IGWO with the GA and MC methods of [28] which clearly evidences the superiority of the proposed method are shown in Fig.3 and Fig-4 for symmetrical and unsymmetrical cases respectively.

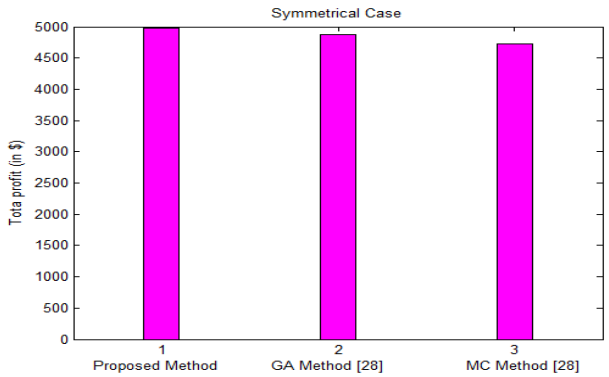


Fig. 3: Total profit Comparison (Symmetrical Case).

Table 1: Generators and Large Consumers Data

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
Large consumer	g	h	Lmin(MW)	Lmax(MW)
1	30	0.04	0	200
2	25	0.03	0	150

Table 2: Rival's Bidding Coefficients Estimation

Incomplete information cases	μ_i^{α}	μ_i^{β}	σ_i^{α}	σ_i^{β}	ς_i
With symmetrical information	$1.2 \times b_i$	$1.2 \times c_i$	$0.0375 \times b_i$	$0.0375 \times c_i$	−0.1
With unsymmetrical information	$1.1 \times b_i$	$1.1 \times c_i$	$0.0375 \times b_i$	$0.0375 \times c_i$	−0.1

Table 3: Bidding Strategies for Generators and Large Consumers

Information type	Market Players	PSO-IGWO (Proposed)	GA [28]	MC [28]
With symmetrical information	Generator	Bi	bi	bi
	1	0.0875	0.0647	0.02927
	2	0.4367	0.1052	0.12420
	3	0.7676	0.2753	0.29231
	4	0.1092	0.0554	0.07433
	5	0.1500	0.1508	0.17058
	6	0.1500	0.1508	0.17058
	Large consumer	Dj	dj	dj
	1	0.0800	0.0806	0.09771
	2	0.0600	0.0596	0.07719
With unsymmetrical information	Generator	Bi	bi	bi
	1	0.0921	0.0647	0.02927
	2	0.4285	0.1642	0.15366
	3	0.8095	0.2753	0.29231
	4	0.4720	0.0554	0.07433
	5	0.1500	0.1508	0.17058
	6	0.1500	0.1508	0.17058
	Large consumer	Dj	dj	{dj
	1	0.0800	0.0806	0.09771
	2	0.0650	0.0596	0.07719

Table 4: MCP ($/MWH) and Profit (IN $) Of Generators and Large Consumers

Information type	Market Players	PSO-IGWO (Proposed)		GA [28]		MC [28]	
With symmetrical information	Generators	Power (in MW)	Profit (in $)	Power (in MW)	Profit (in $)	Power (in MW)	Profit (in $)
	1	160.00	1409.6	160.00	1,372	160.00	1,368.0
	2	81.16	617.5	105.91	592.6	89.40	572.7
	3	20.00	252.0	49.23	326.4	45.70	322.9
	4	78.79	520.7	120.00	429	88.80	386.4
	5	62.34	391.5	50.11	181	43.10	177.5
	6	62.34	391.5	50.11	181	43.10	177.5
	Large consumers	LOAD (in MW)	Profit (in $)	LOAD (in MW)	Profit (in $)	LOAD (in MW)	Profit (in $)
	1	136.60	948.0	171.23	1,165	139.7	1,126.3
	2	110.80	448.4	145.86	623	112.1	592.6
	MCP (in $)	16.51		16.37		16.35	
	Total Profit (in $)	4979.2		4870		4723.9	
With unsymmetrical information	Generators	Power (in MW)	Profit (in $)	Power (in MW)	Profit (in $)	Power (in MW)	Profit (in $)
	1	160.00	1672.1	160	1,592.5	160.00	1,420
	2	76.98	659.3	36.2	184.2	74.21	585.6
	3	47.48	308.2	55.4	396.4	47.45	342.2
	4	50.24	382.7	120.0	596.5	93.50	420.5
	5	66.59	326.5	59.5	256.4	45.8	192
	6	66.59	326.5	59.5	256.4	45.8	192
	Large consumers	LOAD (in MW)	Profit (in $)	LOAD (in MW)	Profit (in $)	LOAD (in MW)	Profit (in $)
	1	137.64	735.3	155.2	942.6	137.5	1,125.5
	2	114.19	403.8	122.5	442.4	109.2	564.4
	MCP (in $)	17.94		17.85		16.72	
	Total Profit (in $)	4814.4		4667.4		4299.8	

Table 5: Competing Fifteen Generators Data

Generator	e	f	Pmax (MW)	Pmin(MW)
1	0.8140	0.0008	1500	100
2	1.3804	0.0014	300	100
3	1.5662	0.0016	200	40
4	1.6069	0.0016	170	40
5	1.5662	0.0016	240	2
6	1.7422	0.0018	120	1
7	1.7755	0.0018	100	1
8	1.7422	0.0018	100	20
9	1.1792	0.0012	570	60

10	1.6947	0.0017	250	30
11	1.6208	0.0016	200	40
12	0.4091	0.0004	1300	80
13	0.6770	0.0007	900	50
14	1.4910	0.0015	150	10
15	1.0025	0.0010	454	20

Table 6: MCP ($/MWH) and Profit (in $) of Generators

Market Players	PSO-IGWO (Proposed)		GA []	
Generators	Power (in MW)	Profit (in $)	Power (in MW)	Profit (in $)
1	100.00	132.26	171.7	119.7
2	100.00	69.62	56.6	23
3	40.00	23.45	62.6	23
4	40.00	21.83	100	100
5	2.00	2.74	3.4	3.5
6	1.00	14.83	52.7	22.5
7	1.00	6.49	80	150
8	20.00	15.06	73.5	40.2
9	110.54	121.63	74.3	34.5
10	30.00	14.13	90	57
11	40.00	21.27	104.5	73
12	431.40	594.36	225.4	233
13	172.36	225.93	202.6	182
14	109.93	61.57	125	189
15	101.76	103.26	77.0	33
MCP (in $)	7.97		7.56	
Total Profit (in $)	1428.4		1284	

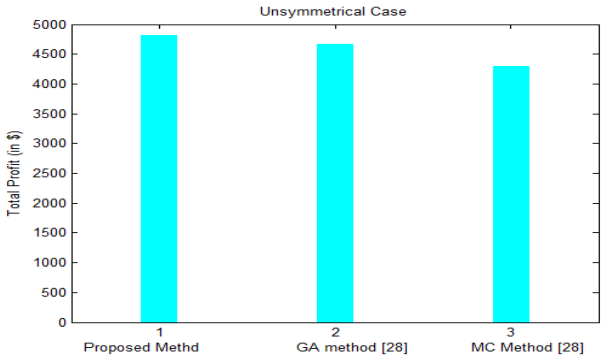


Fig. 4: Total Profit Comparison (Unsymmetrical Case).

The information about the rival matters a lot to any competitor in the market as evident from the above outcomes for maximising one's own profit while taking care of the allied constraints like own power generation maximum and minimum limits and bidding coefficients limits etc.

Case-II (Indian 75 bus Practical Case)

Here, the Indian 75 Bus practical system has been analysed involving 15 power producing units and Table.4 depicts the details of the input data from the paper [28]. Table.5 compares the profits made by the new proposed method with those as reported in [28] and are quite superior outcomes.

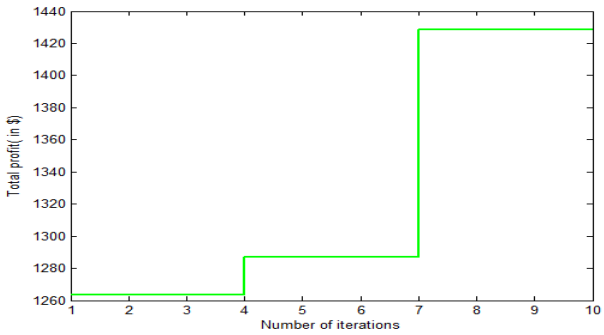


Fig. 5: Total Profit Maximisation Using PSO-IGWO.

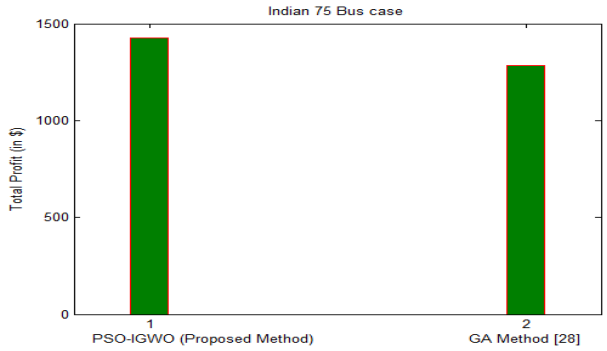


Fig. 6: Comparison of Total Profits.

Fig.5 and Fig.6 show the total profit maximisation and comparison curve respectively. Profit5 maximisation of the whole market in totality is our sole concern.

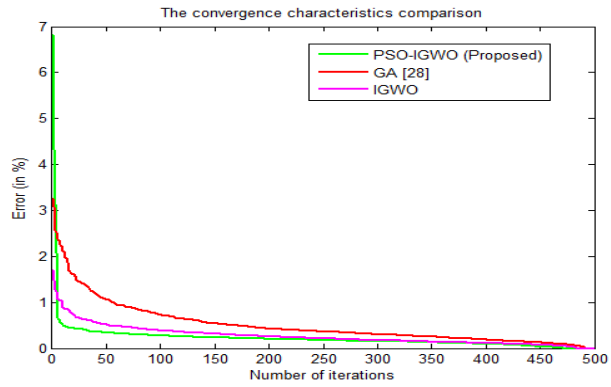


Fig. 7: Comparison of Convergence Characteristics.

6. Conclusion and future scope

As the information is based on the probabilistic prediction, it is incomplete in nature resulting in two distinct cases, discussed above in detail, as symmetrical and unsymmetrical information respectively. The results shown justifies the strength of the method implemented in the current work. The figures provided validates the total profit obtained by adopting the proposed method and the comparison of the total profits in each case. Clearly, the total profit obtained per hour in IEEE-30 bus case and 75-bus Indian case are 4979.2, 4814.4 and 1428.4 and are significantly higher in comparison to

4870, 4667.4 and 1284 respectively as reported in a very recently published paper [28] using simply a GA method. This shows the supremacy of the adopted hybrid PSO-IGWO method as the IGWO algorithm efficacy and the robustness have been improved by cascading with the PSO method. The price and the demand are not independent and an elasticity factor of 5 has been considered which affects MCP and reflects the real market. The power generation during a specific trading period may be repeated for the whole day for a DAEM. Practical power producing constraints of the players in addition to the transmission line capacity, its maximum value and line congestions etc. will be taken up in further work.

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