Bidding Strategies For GENCOS In Pool Based DAEM Using GWO Method

Ramachandra Agrawal, Ranjan Kumar Mallick, Anasuya Roy Choudhury

Abstract: In a Day Ahead Electricity Market (DAEM) the power suppliers need to adopt adequate bidding procedures to maximize their individual profits. So each Genco participating in the market has to bid strategically i.e. choose its own bidding coefficients so as to win the auction at any particular hour among the rival Gencos of the market. In this paper a very recent and robust bio inspired technique named Grey Wolf Optimization (GWO) is used to determine the optimal bidding parameters. The strength of GWO lies in the fact that it converges very fast compared to all such methods developed so far and also found to be very efficient in providing a better optimal bidding strategy as evidenced by the statistical analysis report provided. This method is applied to IEEE 30 Bus system with 6 no of Gencos and an Indian 75-bus practical system with 15 no of Gencos and is verified by mathematical modeling through MATLAB simulation. It was evidenced by the output that the proposed method results in much higher profits compared to Shuffled Frog Leap Algorithm (SFLA), Fuzzy adaptive GSA (FAGSA) and PSO.

Index Terms: MCP, DAEM, GWO, Optimal Bidding Strategy, Oligopolistic

1. INTRODUCTION

Power industry restructuring helped a lot in introducing healthy competition at various possible levels of the existing electricity market structure thereby nullifying or reducing the scope of market power misuse i.e. to wipe out the existing monopoly at generation and trading sectors. But the electricity markets are always associated with sudden changes making it more oligopolistic in nature than a perfect competitive market for which there exists always a scope of misusing the market power i.e. a Genco may bid more than the Market Clearing Price (MCP) which otherwise would have been either less than or equal to the MCP. Another important issue of the oligopolistic market is price demand elasticity. In this environment a supplier needs to find an optimal bid with the technical constraints, prediction of the rivals bidding coefficients, market behavior, price elasticity and past history, which is known as strategic bidding problem (SBP)

While modeling the SBP we can have three different approaches as stated below. In the first method using game theory approach and assuming the oligopolistic models has been reported. The second method is the bidding nature of the evaluation and the way it behaves of the participants who are in the rivalry form. A power producer may enhance its profit margins owing to the fact that the electricity trading market is not completely competitive which is called strategic bidding. For maximization of the profit the power generating company have to adopt an efficient way of bidding depending on the past market bidding data analysis, which is the third method. In the new restructured power market, out of the major competitive structures poolco is the one with a central auction system bringing the local consumers and power traders together. Meta heuristic approaches such as PSO, SA, GA and a hybrid of such methods were used by many researchers to solve strategic bidding problem. A double auctions method along with GA has been implemented to find out the bidding strategies for the power producers where the market model resembles to any commodity exchange marketplace. With the bid data from all the market players, the system operator independently prepares the resultant power supply and demand curves for generating companies and the buyers. The MCP is the intersection point of the above mentioned two curves, which is a point of equilibrium where trading between the participants will occur. Electricity market liberalization had begun in Europe in the era of 1990's and continuing till now. Electricity market reforms were initiated by U.K., European Energy Exchange serving the bidding regions namely Switzerland, France and Germany recognized three main services the primary, secondary Control and minute reserve have been identified as important services by the European association of transmission operators as discussed in. Market oriented modifications were carried out by several countries like Chile, Argentina, Peru, Bolivia, Colombia, Brazil and the Central American countries in between 1982 to 1997 at different point of times. Bids get changed once in six months in Argentina. Brazil followed the day ahead market whereas the market of Colombia followed the British way. California electricity market had begun in 1998, which deals with an energy market for the following day. In 1997, PJM electricity market started operating. The wholesale electricity market trading occurs by mutual agreements, in Texas. In 1990, China and Japan initiated the market reforms. The electricity market of Iran which is 3-days-ahead market. The Electricity act-2003, In India, assumes the state level regulators of electricity to completely govern the activities among the states, where as CERC looks into the activities among the states. Currently it is functioning on a market of the following day with sealed auctions mechanism having bidding from both the suppliers and the consumer side and the market is cleared at the MCP. Around 1985, in UK and Chile the revolution of market reforms began and then were spread to many other countries. Through the analysis of market rules between different countries, understanding of the structure and patterns of the market price were much better. An analytical technique in hybrid with a graphical method of two dimensions is employed to analyze the apprehension involved more meticulously. Nash equilibrium method for a bidding structure reflecting the power market dynamics has been reported in. The generating company bidding strategies are affected by varying the segment number of bidding and were examined thoroughly. The power demand and the associated sensitivity factor to the price affect the bidding strategy to be adopted and has been accounted in. The PSO and SA are combined, by Soleymani, for predicting the bid, for the ISO, by the power producer with inadequate rival's bidding information where the payment mechanism is to pay as per the bid submitted by the company. Additionally, a novel method to define strategic bidding as a problem which is multiobjective to be dealt providing the optimal result by firefly algorithm. With linear bid curve, emission constraints and using PSO technique a bidding strategy for a power producer is reported in. Based
on LMP and congestion of the tie power lines of different areas, in DAEM pool marketplace, the effect of price-demand elasticity on bidding has been dealt by Singh et. al. In\textsuperscript{14}. While maximizing profit the amount of power would decreased to Qmand price would enhanced to Prm causing dead weight loss as a result the benefit of the society is reduced and is undesirable, a new way of considering the social welfare is reported in\textsuperscript{15}. Optimization model of bidding for generating companies in DAEM has been analyzed in detail in\textsuperscript{16}. The Supply Function Equilibrium (SFE) is about modeling the rivals behavior to maximize profits with the uncertain demand that prevails in the market which was applied in England and Wales reformed electricity pool market as per the publication by Green et al\textsuperscript{17,18}. A precise method of finding the SFE with advantage of considering the generator's capacity limits which can be applied practical large scale power systems was proposed by Bompad et al\textsuperscript{19}. D.M. Vinod kumar et. al showed how the bidding strategy problem can be modeled as an optimization problem using P.S.O technique\textsuperscript{20,21}. Decomposition based PSO method for strategic bidding by A.D. Yucekaya et.al has been reported in\textsuperscript{22}. Here, the MCP was assumed to be exogenous to the bidding models. Further David et. al used imperfect information modeling method to ensure higher profits of the Gencos as reported in\textsuperscript{23}. An efficient method called shuffled Frog Leap Algorithm (SFLA) has been used to optimize the bidding parameters and profit maximization with further increase of the profits incurred by the Gencos compared to the PSO method in a recently published work\textsuperscript{24}. Y.GAO et.al efficiently used these valuable information and fuzzy to model the decision making in any type of market depending on bi-level relationship\textsuperscript{25}. The 75-bus data has been taken from\textsuperscript{26}. Also Fuzzy Adaptive PSO was proposed by S.N. Singh et.al., i.e. a new strategy to improve the performance of the original PSO\textsuperscript{27}. Fuzzy Adaptive GSA was proposed by Vinod Kumar et.al., where diversity being preserved avoiding premature or undesired convergence\textsuperscript{28}. However the proposed GWO method was first developed by S. Mirjalili et al\textsuperscript{29}., 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 GWO technique outperforms even under the presence of price demand elasticity in the market providing still better profits.

The major contribution of this paper is as mentioned below:

- Only power supplier bidding strategy optimization case with IEEE-30 bus system and 75- bus Indian practical system has been mathematically modeled in MATLAB based on a very recent technique GWO and the superiority is evidenced by the output comparison.
- In case of 75 bus system due to the erroneous results provided by D.M. Vinod kumar et al., the profit obtained (using the exact data mentioned in their papers) can not be compared, but in case of IEEE-30 bus system the results obtained are quite consistent with that reported by the same authors in that same paper.
- However, in the proposed work the results obtained confined to the inequality and equality constraints of the generating units unlike the violations found in the pre-published papers in Applied soft computing journal of Elsevier during 2013 and 2014 by the afore mentioned Authors.
- Additionally, the statistical analysis made in conjunction with both of the pre-published papers is quite appealing and describes the robustness of the proposed GWO algorithm in terms of faster convergence, Percentage Deviation (PD) and CPU run time etc.

Justification of the results reported by GWO method in 75-bus case against the erroneous pre-published work has been adequately explained in the test result discussion portion. The remainder portion of this thesis is in the following sequence. The Section II is based on the modelling which is mathematical in nature of the problem bidding. The algorithm which is based on the GWO technique is shown in section III. For solving the problem of bidding which is depicted in section II and the utilization of the GWO Algorithm is presented in the section IV. The results which are obtained related to the optimal problem of bidding is in section V for IEEE -30 and 75 bus Indian practical systems without considering the elasticity price. Section VI concludes that paper output with the future scope of extending the present work whereby it can be applied to the real time practical electricity markets.

2 PROBLEM STATEMENT

A number of ‘m’ Gencos is assumed as present in the market of trading power with an aggregated demand i.e. a single buyer via bidding. A supplier bids as per an increasing supply curve varying linearly to the power exchange or Independent System Operator (ISO) where auction mechanism of sealed bid with uniform MCP is being adopted.

Let for the ith supplier, generating real power (\(P_i\)), supply curve of linear supply denoted by, \(G_i(P_i)\), is and is represented by equation (1).

\[
G_i(P) = (a_i + b_i P_i) \quad (1)
\]

Where, \(a_i\) and \(b_i\) are always positive and also known as the linear bidding coefficients of ith supplier and \(i = 1, 2, 3, \ldots \ldots \ldots \ldots \ldots m\).

The work of ISO is to determine a practical generation schedule which maximizes the total profit of the system as a whole along with the constraints of security and reliability using adequate dispatch procedures. In order to determine the outputs of generation ISO or PX imposes the constraints of load flow generation and limits of demand to meet the aggregate demand by solving the equations as given below:

\[
a_i + b_i P_i = R \quad (2)
\]

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

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

Where, \(Q(R)\) is the pool load forecasted by ISO for Gencos as follows, if \(Q_o\) is a constant number and \(K\) is the price elasticity of the consumers demand present in aggregate form, which is
zero since no consumer has been considered in this paper (i.e., K=0 will be used in the further mathematical analysis).

$$Q(R) = Q_o - KR$$  \hspace{1cm} (4)

and

$$P_{\min,i} \leq P_i \leq P_{\max,i}$$

Where, $P_{\min,i}$ and $P_{\max,i}$ are the limits of output power of the ith supplier and $i=1,2,3,\ldots,m$.

When constraints are not paid attention for the time being then the solution to Eqs. (1) - (3) will be given in empirical form as follows:

$$R = \frac{Q_o + \sum_{i=1}^{m} \frac{a_i}{b_i}}{K + \sum_{i=1}^{m} \frac{1}{b_i}}$$  \hspace{1cm} (5)

$$P_i = \frac{R - a_i}{b_i}$$  \hspace{1cm} (6)

Where, $i=1, 2, 3,\ldots,m$.

The levels of the generation of the individual power producer or genco are got by solving the equations (5) and equation (6). But when the generation limits are diverted from the specific values then within the values they are kept. The power outcomes produced however we assume that these power outputs obtained are physically feasible to be dispatched by the concerned generating company as we are not considering any inter temporal constraints like ramp rate limits like up ramp and down ramp, minimum up and down time and the startup shut down costs etc.

The cost function, $C_i(P_i)$, of the ith supplier is assumed to be quadratic and is given as

$$C_i(P_i) = e_i P_i + f_i P_i^2$$  \hspace{1cm} (7)

Where, $e_i$ and $f_i$ are the quadratic cost coefficients of the ith supplier.

The profit maximization bidding strategy for ith supplier is given as:

Maximize $F(a_i, b_i) = RP_i - C(P_i)$  \hspace{1cm} (8)

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

In order to make higher maximization of the profit then it would be better for the suppliers who could know the characteristics nature of bidding so that they could be able to uplift the market clearing the price but as we have assumed sealed auction mechanism of the market it is not feasible as we have assumed sealed bid auction mechanism of the market. Hence this paper proposes GWO method to solve the bidding problem of the power suppliers or Gencos optimally. Here ai is assumed to be fixed i.e. as per standard IEEE-30 Bus with 6 no of Gencos and an Indian 75-bus practical system with 15 no of Gencos bidding coefficient data 'bi' is got through the proposed robust search technique GWO. Our outputs are found to provide better outcomes when the SFLA, FAGSA and conventional Particle Swarm Optimization technique are compared with the outputs. For searching the methods of optimal bidding for different number of consumers and the sellers loads and the markets of electricity do not remain the same. The method suggested in this paper may also be used easily for finding the optimal techniques of bidding for different no of sellers and consumers, different aggregate loads and different electricity markets as the rules of all the markets around the world don’t remain the same.

3 SOLUTION ALGORITHM

3.1 Fundamentals of GWO [25]

GWO is a novel approach called Grey Wolf Optimizer (GWO) where the algorithm is developed which imitates the leadership sequence of hunting mechanism of the prey by the grey wolves of the real world. Alpha ($\alpha$), beta ($\beta$), delta ($\delta$) and omega ($\omega$) are four types of wolves simulating the hierarchy of leadership. Hunting is through searching, encircling and attacking the prey. It was found that the GWO algorithm is providing much better results and is applicable to challenging problems with unknown search spaces. They prefer to be in groups with 5-12 members on an average. They follow a strict social decreasing dominance from the top to the bottom. A male and a female, called alphas, are the leaders. They are mainly the decision makers of hunting, sleeping place, wake up time etc. Which are bounded to the pack. Sometimes it was observed that the other wolves in the group were followed by an alpha wolf. Entire pack hold their tails down to acknowledge the alpha implying that he /she is the dominant wolf as his/her orders are to be followed by the pack. Mating in the pack is allowed to the alpha wolves only not because of the strongest, but the excellent one in managing the members of the group, implying that due importance should be given to the discipline of the organization instead of its strength. The betas are in the second level in the grey wolves helping in decision-making process of the alpha or any other works of the pack. The beta like the alpha wolf may be of either gender and is perhaps the best to act as a successor to alpha when any alpha wolf ages very old or dies. The alpha is respected by the beta, but the beta governs the subsequent level wolves in the pack. So, basically the beta advises the alpha, but at the same time maintains discipline in the pack. Alpha’s commands are get implemented among the members of the group by the beta and acknowledges about the detailed happenings to the alpha. The lowest grey wolf in the hierarchy is omega, who is always submissive to all the other dominant wolves. They may be eaten by the dominant wolves as they are the last which may make one feel that why then they are included or present in the pack but internal fighting is observed among the dominant wolves as they are sometimes the babysitters of the group and also the media for venting of their violence and frustration. In this way the entire pack maintains the structure of dominance. A subordinate (or delta ($\delta$) as per some references) is never an alpha, beta, or omega. Delta wolves dominate the omega but are submissive to alphas and betas. Caretakers belong to this category. The most important social activity of grey wolves in group hunting, which can be subdivided as following steps, 1. the prey is tracked chased and approached.
2. until the prey stops to move the prey is pursued encircled and harassed.
3. The prey is finally attacked.
b) Solution Algorithm using GWO
GWO 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 iteration as will be evident from the outcome of the test and discussion portion of this paper. However, performance of particle swarm optimization on complex multimodal problems has been improved by GWO, a new strategy, the proposed method of this paper. This hunting method and the social hierarchy of grey wolves are modelled mathematically in order to perform optimization named as GWO and the algorithm is given below along with the corresponding mathematical model formulated with the following set of equations:

\[ D = |\mathbf{C} \mathbf{X}_p(t) - \mathbf{X}(t)| \]  

(9)

\[ \mathbf{X}(t + 1) = |\mathbf{X}_p(t) - \mathbf{A.D}| \]  

(10)

Where, present iteration is \( t \) and \( \mathbf{X}_p \) is the position vector of a grey wolf denoted as \( \mathbf{X} \). The coefficient vectors \( \mathbf{C} \) and \( \mathbf{A} \) are evaluated as per the formula given below:

\[ \mathbf{A} = 2.\mathbf{a}.\mathbf{r}_1 - \mathbf{a} \]  

(11)

\[ \mathbf{C} = 2.\mathbf{r}_2 \]  

(12)

Where, \( \mathbf{a} \) is decreasing from 2 to 0 linearly as the iteration proceeds and \( \mathbf{r}_1 \) and \( \mathbf{r}_2 \) are the random vectors belonging to [0, 1] range. Now, the position of alpha, beta and delta is normally updated using the best position of the alpha wolf as per the formula shown below:

\[ \mathbf{D}_a = |\mathbf{C}_1 \mathbf{X}_a - \mathbf{X}|, \mathbf{D}_b = |\mathbf{C}_2 \mathbf{X}_b - \mathbf{X}|, \mathbf{D}_\delta = |\mathbf{C}_3 \mathbf{X}_\delta - \mathbf{X}| \]  

(13)

\[ \mathbf{X}_1 = \mathbf{X}_a - \mathbf{A}_1 \mathbf{D}_a, \mathbf{X}_2 = \mathbf{X}_b - \mathbf{A}_2 \mathbf{D}_b, \mathbf{X}_3 = \mathbf{X}_\delta - \mathbf{A}_3 \mathbf{D}_\delta \]  

(14)

Where, \( \mathbf{X}_a \), \( \mathbf{X}_b \), \( \mathbf{X}_\delta \) are the best fitness value, the second best fitness value and the third best fitness value obtained respectively. So, the next iteration value of the alpha wolf is evaluated as follows.

\[ \mathbf{X}(t + 1) = \frac{\mathbf{X}_1 + \mathbf{X}_2 + \mathbf{X}_3}{3} \]  

(15)

Where, \( \mathbf{X}(t+1) \) and \( \mathbf{X}(t) \) are the population matrices in \( (t+1)^{th} \) and \( t^{th} \) iterations respectively.

GWO general Algorithm:
1. Initialize the grey wolf population \( \mathbf{X}_i \) \( (i = 1, 2, \ldots, n) \)
2. Initialize a, A, and C
3. Calculate the fitness of each search agent
4. \( \mathbf{X}_a \) = the best search agent
5. \( \mathbf{X}_b \) = the second best search agent
6. \( \mathbf{X}_\delta \) = the third best search agent
7. while \( (t < \text{Max number of iterations}) \)
8. for each search agent
9. Update the position of the current search agent
10. end for
11. Update a, A, and C
12. Calculate the fitness of all search agents
13. Update \( \mathbf{X}_a \), \( \mathbf{X}_b \) and \( \mathbf{X}_\delta \).
14. \( t = t + 1 \)
15. end while
16. return \( \mathbf{X}_a \)

4 APPLICATION OF GWO TO BIDDING PROBLEMS
For using GWO techniques for solving the parameters of bidding of the participating Gencos to maximize the individual profits and the overall profit in general. The maximum profit made by any Genco is chosen to be the alpha wolf. Its value is continuously updated in each iteration according to the flow chart shown above.

Present position of the search agents, \( \mathbf{X}_a \), \( \mathbf{X}_b \), and \( \mathbf{X}_\delta \) are estimated by using the empirical formula provided in the fundamental paper [29]. Before next iteration a, A, and C are updated to calculate the fitness values of all the search agents. The updated values of \( \mathbf{X}_a \), \( \mathbf{X}_b \), and \( \mathbf{X}_\delta \) are estimated and loop is then continued until we fail to observe any further improvement in the profit made by Gencos. The algorithm of bidding based on GWO method is given below.

Algorithm (For power producer’s profit maximization)
1. The grey wolf population is initialized \( \mathbf{X}_i \) \( (i = 1, 2, \ldots, n) \) randomly within the constraints of the parameters as specified in the data table.
2. Initialize a, A, and C as mentioned in the fundamental paper.
3. Calculate the fitness using the equation (8) provided in the problem section statement above.
4. \( \mathbf{X}_a \) = the best fitness value obtained above.
5. \( \mathbf{X}_b \) = the second best fitness value.
6. \( \mathbf{X}_\delta \) = the third best fitness value.
7. Set the value of \( T \) as the maximum number of iterations.
8. while \( (t < T) \)
9. for each candidate solution
10. Update the position of the current candidate solution using the equations (9) to (12) written in sub-section (b) of the solution section above.
11. end for
12. Update a, A, and C as done earlier.
13. Now find the fitness of all candidate solutions as found in step-3.
14. Update \( \mathbf{X}_a \), \( \mathbf{X}_b \) and \( \mathbf{X}_\delta \) with the best fitness value saved in \( \mathbf{X}_a \).
15. Increase the iteration count by increasing \( t \) by 1.
16. End while loop.
17. Output the value of \( \mathbf{X}_a \)

5 TEST RESULTS AND DISCUSSIONS
The utilization of GWO, and it is the algorithm which is proposed and the IEEE bus system and an Indian 75-bus practical system are used from [20] and [22] respectively, which involves six and fifteen generators respectively, consumers are taken into the consideration as the large and
each is taken to be gencos a single buyer. The generating unit’s data of IEEE-30 bus system and Indian-75 Bus practical system data are given in Table number- I and Table number- V (in case-ii) respectively. Qo and K are taken to be (500, 0) for IEEE-30 bus system without (zero) demand price elasticity, (1000, 10) from SFLA case for 75-bus Indian practical system with demand price elasticity value as 10 for the load demand which is aggregate in nature for the producers of the power of the previous techniques shown in Table II. The MCP is shown by the table III which is more better than SFLA technique which is further more good than FAGSA in [24] and PSO in [20].The gain of the gencos in GWO when compared when in high position and that is taken out from the SFLA and the outcomes found out utilizing the algorithm which is proposed from SFLA[20],FAGSA[24] and PSO[20] methods. The simulations are carried on a 2.10GHz, Intel Core(TM) i3 Processor and 4GB RAM using MATLAB (R2010a) version and table-IV provides the statistical analysis of the results obtained using the algorithm which is determined in terms of the best,worst,average,percentage deviation (PD (in %)) and most importantly the CPU run time in seconds which is 0.120 s, the least among the other methods compared with, which has the utmost practical significance pertaining to any electrical power system operation.

Case-I (IEEE-30 Bus system)

**TABLE-I. Competing six Generators data**

<table>
<thead>
<tr>
<th>Generator</th>
<th>E</th>
<th>f</th>
<th>Pmin(MW)</th>
<th>Pmax(MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>0.00375</td>
<td>20</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>1.75</td>
<td>0.0175</td>
<td>15</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>0.0625</td>
<td>10</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>3.25</td>
<td>0.00834</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
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</tr>
<tr>
<td>6</td>
<td>3.0</td>
<td>0.025</td>
<td>10</td>
<td>130</td>
</tr>
</tbody>
</table>

**TABLE-II. Bidding Strategies for Generators**

<table>
<thead>
<tr>
<th></th>
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</thead>
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<tr>
<td>Sl.No</td>
<td>Bi</td>
<td>bi</td>
<td>bi</td>
<td>bi</td>
</tr>
<tr>
<td>1</td>
<td>0.0484</td>
<td>0.021004</td>
<td>0.021437</td>
<td>0.001092</td>
</tr>
<tr>
<td>2</td>
<td>0.2324</td>
<td>0.090472</td>
<td>0.121787</td>
<td>0.050953</td>
</tr>
<tr>
<td>3</td>
<td>0.1873</td>
<td>0.263450</td>
<td>0.337380</td>
<td>0.181976</td>
</tr>
<tr>
<td>4</td>
<td>0.0428</td>
<td>0.054320</td>
<td>0.23806</td>
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<tr>
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<td>0.063465</td>
<td>0.072791</td>
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**TABLE-III. MCP (in $/MWH) and Profit (in $) of six Generators**

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Sl NO</td>
<td>PROF</td>
<td>PROF</td>
<td>PROF</td>
<td>PROF</td>
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<tr>
<td>1</td>
<td>160.0</td>
<td>122</td>
<td>160.0</td>
<td>1097</td>
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<td>000</td>
<td>3.3</td>
<td>0</td>
<td>0</td>
<td>.16</td>
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<tr>
<td>2</td>
<td>139.1</td>
<td>843</td>
<td>95.76</td>
<td>581.</td>
</tr>
<tr>
<td>912</td>
<td>5</td>
<td>19</td>
<td>19</td>
<td>157.</td>
</tr>
<tr>
<td>3</td>
<td>46.65</td>
<td>251.5</td>
<td>29.73</td>
<td>196.</td>
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<td>03</td>
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<td>6</td>
<td>6</td>
<td>22</td>
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<td>4</td>
<td>100.0</td>
<td>616</td>
<td>100.0</td>
<td>537.</td>
</tr>
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<td>00</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>22.21</td>
<td>163</td>
<td>56.75</td>
<td>285.</td>
</tr>
<tr>
<td>43</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>38</td>
</tr>
<tr>
<td>6</td>
<td>31.94</td>
<td>250</td>
<td>56.75</td>
<td>285.</td>
</tr>
<tr>
<td>M CP</td>
<td>9.74</td>
<td>9.45</td>
<td>9.06</td>
<td>6.88</td>
</tr>
<tr>
<td>Total Profit</td>
<td>3348.90</td>
<td>2984.50</td>
<td>2617.73</td>
<td>1790.57</td>
</tr>
</tbody>
</table>

**TABLE-IV. Statistical Analysis**

<table>
<thead>
<tr>
<th>Method</th>
<th>Best profit (in $)</th>
<th>Worst profit (in $)</th>
<th>Average profit (in $)</th>
<th>PD (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWO</td>
<td>3348.90</td>
<td>2888.40</td>
<td>3285.25</td>
<td>6.4</td>
</tr>
<tr>
<td>FAGSA</td>
<td>2984.50</td>
<td>2591.1</td>
<td>2604.4</td>
<td>5</td>
</tr>
<tr>
<td>PSO</td>
<td>1790.50</td>
<td>1574.8</td>
<td>1662.7</td>
<td>1</td>
</tr>
</tbody>
</table>

**FIGURE-1. Convergence Characteristics of GWO**

**FIGURE-2. Convergence Characteristics Comparison**

**FIGURE-3. Comparison of individual profit of Gencos**
The following errors have been detected:

1. The power generation maximum limit for generators numbering 3, 8 and 14 are 200,100 and 150 MW respectively (from table-V), but the power generated by these generators as reported in the pre-published paper in 2014 (in SFLA, the proposed method) are 280,170,15 and 250 MW respectively, each unit exceeds its maximum limit.

2. Similarly, the power generation maximum limit for generators numbering 4, 7 and 14 are 170,100 and 100 MW respectively (from table-V), but the power generated by these generators as reported in the pre-published paper in 2014 (in PSO, one of the compared methods are 172,6,160 and 250 MW respectively, each unit exceeds its maximum limit.

3. In that same journal the values of $Q_0$ and K are 1,000 and 10 respectively, but the total power generated is 2499.86 MW, which should be less than 1000 MW as $K=10$.

4. Also, the MCP (denoted by ‘R’) is given to be 8.6 $ (in SFLA case), but as per the equality constraint the total power generated should be equal to the value obtained from $(Q_0 \cdot K^2)$, which is evidently violated.

5. The total power generated in PSO case, reported in the same table is 2,999 MW and hence the comparison made is also vague as the data should be same for comparison.

6. In the statistical analysis part the PD (in %) reported should be multiplied by 100 as per the formulae provided i.e. the value of the PD (in %) for SFLA and PSO cases would have been 6.4 and 12 respectively.

Hence, under such an erroneous scenario the comparison of the results obtained implementing our proposed algorithm is not feasible. However, the simulation results are provided in the table-VI with out any intention of comparison.

**TABLE-V. Competing Fifteen Generatorsdata**

<table>
<thead>
<tr>
<th>Generator</th>
<th>E</th>
<th>F</th>
<th>Pmax (MW)</th>
<th>Pmin(MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8140</td>
<td>0.0008</td>
<td>1500</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>1.3804</td>
<td>0.0014</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>1.5662</td>
<td>0.0016</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>1.6069</td>
<td>0.0016</td>
<td>170</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>1.5662</td>
<td>0.0016</td>
<td>240</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1.7422</td>
<td>0.0018</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1.7755</td>
<td>0.0018</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1.7422</td>
<td>0.0018</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>1.1792</td>
<td>0.0012</td>
<td>570</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>1.6947</td>
<td>0.0017</td>
<td>250</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>1.6208</td>
<td>0.0016</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>0.4091</td>
<td>0.0004</td>
<td>1300</td>
<td>80</td>
</tr>
<tr>
<td>13</td>
<td>0.6770</td>
<td>0.0007</td>
<td>900</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>1.4910</td>
<td>0.0015</td>
<td>150</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>1.0025</td>
<td>0.0010</td>
<td>454</td>
<td>20</td>
</tr>
</tbody>
</table>

**TABLE-VI. Bidding Strategies for Generators**

<table>
<thead>
<tr>
<th>Generator</th>
<th>GWO</th>
<th>SFLA[20]</th>
<th>PSO[20]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si.No</td>
<td>bi</td>
<td>bi</td>
<td>bi</td>
</tr>
<tr>
<td>1</td>
<td>0.0179</td>
<td>0.0029</td>
<td>0.0022</td>
</tr>
<tr>
<td>2</td>
<td>0.0123</td>
<td>0.0040</td>
<td>0.0028</td>
</tr>
<tr>
<td>3</td>
<td>0.0260</td>
<td>0.0024</td>
<td>0.0070</td>
</tr>
<tr>
<td>4</td>
<td>0.0250</td>
<td>0.0063</td>
<td>0.0067</td>
</tr>
<tr>
<td>5</td>
<td>0.5200</td>
<td>0.1347</td>
<td>0.0028</td>
</tr>
<tr>
<td>6</td>
<td>0.8640</td>
<td>0.0115</td>
<td>0.0062</td>
</tr>
<tr>
<td>7</td>
<td>0.0346</td>
<td>0.0191</td>
<td>0.0062</td>
</tr>
<tr>
<td>8</td>
<td>0.0353</td>
<td>0.0049</td>
<td>0.0098</td>
</tr>
<tr>
<td>9</td>
<td>0.0240</td>
<td>0.0104</td>
<td>0.0083</td>
</tr>
<tr>
<td>10</td>
<td>0.0339</td>
<td>0.0062</td>
<td>0.0034</td>
</tr>
<tr>
<td>11</td>
<td>0.0318</td>
<td>0.0055</td>
<td>0.0029</td>
</tr>
<tr>
<td>12</td>
<td>0.0080</td>
<td>0.0074</td>
<td>0.0056</td>
</tr>
<tr>
<td>13</td>
<td>0.0140</td>
<td>0.0047</td>
<td>0.0020</td>
</tr>
<tr>
<td>14</td>
<td>0.0300</td>
<td>0.0024</td>
<td>0.0056</td>
</tr>
<tr>
<td>15</td>
<td>0.0200</td>
<td>0.0061</td>
<td>0.0025</td>
</tr>
</tbody>
</table>
er methods compared with,

ion line congestion effect on

Electricity Pool

in this case is 10 (since, K=10), with increased power demand

The total power demand reported in SFLA case is 2499.86

increased from 2984.50 $ to 4196.80 $.

$ to 1517.50 $ unlike them where it has been

reduce which is evident in our case i.e. from 3348.90

proportionately then to a value of 9.7/(15/6)=3.88) i.e.

The logic that with the maximization of the market

participants from 6 to 15 the MCP will also reduce (if proportionately then to a value of 9.7/(15/6)=3.88) i.e.

from 9.70 to 2.61 which is our result (by

maximization process and using the empirical formulae

evaluating the MCP .On IEEE 30 bus system the eligibility as well as the efficiency of the GWO is tested. . The GWO

which is proposed provides higher profits for the Gencos and further can be used on the basis of repeated
generation utilized for the entire trading period together with

on continuous generation basis along with different inter
temporal constraints so that the result so obtained will be

practically implementable

6 CONCLUSION

For bidding for six and fifteen gencos this paper effectively
implemented the GWO technique for a day of trading in the
electricity market of a day ahead.The statistical analysis of the outcomes which are obtained using the algorithm which is proposed on the basis of best,worst,average,percentage deviation (PD (in %)) and most importantly the CPU run time, the least among the other methods compared with,
evidences the strength of the adopted method and is of very much real time significance in connection to any electrical power system operation. The emergence of whole sale commodity market of electric power involves a competitive market among the competing generators to offer their electricity output to retailers. Now-a-days a new innovative idea of consumer purchasing electricity directly from generators is emerging. Moreover the constraints which are intertertemporal like transmission line congestion effect on MCP, minimum up and down times, ramp limits of ups and downs are not being taken into consideration .Every participant of the market think about its own benefit and the maximization process and using the empirical formulæ evaluating three MCP .On IEEE 30 bus system the eligibility as well as the efficiency of the GWO is tested. . The GWO

which is proposed provides higher profits for the Gencos and further can be used on the basis of repeated
generation utilized for the entire trading period together with

on continuous generation basis along with different inter
temporal constraints so that the result so obtained will be

practically implementable

REFERENCES


