A Prediction Based Bidding Strategy for Social Welfare Improvement in Uniform Pricing Mechanism

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Abstract

In the new competitive electricity market, bidding plays a significant role in the area of power trading. The participants are partaking in the trading procedure for a fixed amount of power. The price at which a single buyer bids a block of power influences both the net *volume* of power cleared and the market-clearing price of electricity traded in the entire network. In this paper, different *bidding* strategies are defined and simulated. The defined strategies show the dependency on the bid price for clearing a bid. The net earnings of the buyers and sellers depend on the bid price. The selection of bid price for each block of power is studied such that the total volume of power cleared is equal to the participating buyers' total power demand. The study focuses on determining the optimal bid to result in maximum societal benefit. In addition to the bid price effect on the volume of power cleared, the bid price prediction is also performed in this work using linear regression. The predicted Locational Marginal Price (LMP) of the buyers for different volumes of power cleared is estimated. The results are further compared with

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LMP obtained using an ordinary load flow problem through which a margin change in the net earnings is observed. An IEEE-30 bus system is simulated with different bidding strategies using MATLAB, and the predicted LMP shows a significant increase in net earnings.

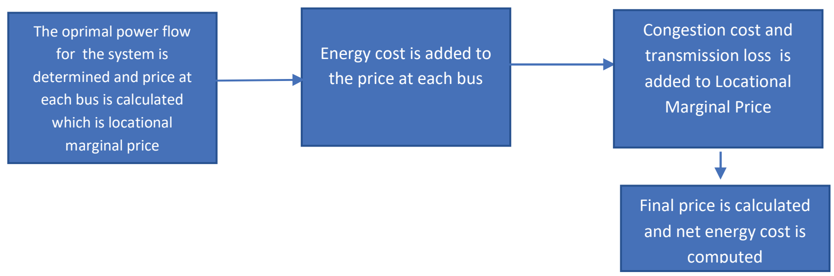
Keywords: .

1 Introduction

The participants in the electricity market trading process submit offers and bids based on availability and requirements. The buyer's role in deciding a bid price is crucial when the total volume of power cleared is supposed to meet the total demand. The electricity cost is purely depending on system constraints when bidding does not happen. Moreover, when the power consumption changes from time to time, there is no provision to submit a single bid. A single bid does not cater to the complex constraints of the generator. Hence block bid for a pre-defined time frame is formulated, which is generally 15 minutes duration and sometimes varies depending on the demand and market scenario. The bid for a particular interval, called a block, has chances of getting rejected based on real-time operating constraints and Market Clearing Price (MCP). The bids submitted by buyers participating in the trading process are fixed and cannot be modified further. Hence care should be taken while selecting the bid price. In this work, the net earnings are calculated by simulating different *bidding* strategies. The power is traded in blocks; hence the selection of bid price for each block of power should be such that the total block of power is cleared to meet the power demand. The volume of power cleared depends upon the bid price.

Power trading is the ability of units and generation companies (GENCO's) to make electricity prices profitably. As clear in the definition, locational marginal price (LMP) is the most important key factor in the market. Power pricing and evaluation [16]. The power trading day by day becoming complex and hence the knowledge of formulating a bid is essential for the traders participating in the bidding processes. This paper focuses on the price formulation from optimal power flow results taking all the constraints, such as line outages and congestion, and giving a price to the participant who is extracting power at a bus.

Price versus power is the major part of trading and bid rejections are done in the Indian power exchange because of the improper selection of price for the particular quantity of power. The research helps fill this gap by properly formulating the bid price for a particular megawatt of power at a particular period.



Linear regression algorithm is applied to optimize the net earnings by predicting the new values of Market Price. The IEEE 30 bus system is simulated for obtaining the values of Market Price. The new values of Market Price are predicted from the Optimal Power Flow (OPF) by choosing market price as an independent variable and net earnings as a dependent variable. For each defined strategy the regression algorithm is applied, and from the new Market Price, a significant increase in net earnings is observed.

2 Literature Review

In the day-ahead market, the MCP and clearing prices are not equal because of the strategical bidding made by generation companies and buyers participating in the trading [1]. In a competitive electricity market, the customer has the choice to select the price for the power they want to bid. Here, customer can either be DISCOMS, an industrial user, a corporate sector, a bulk consumer, or a retail consumer. The buyers need to track their load on an hourly basis and decide prices relevant to system conditions [2].

In the short-term energy market, generators sell a large amount of power to the buyer/trader. The price includes both the fixed charge component and the variable component of the generation. The fixed charge of the generator includes the locational marginal price components. The variable components of the generation include the generation company overheads [3].

The goal of the Central Electricity Regulatory Commission is to have a transition from a single buyer model to a multiple buyer model. In India, the power firms expect capacity-based procurement bids to enable the proposals to be submitted based on peak, medium, and baseload conditions.

According to Electricity Act, 2003 of National electrical policy part 5, "*The algorithm of the software application for price discovery and market splitting shall comply with the methodology mentioned in Byelaws, Rules and Business Rules of Power Exchange as approved by the Commission*" [8].

The MCP decided out of the bidding process is significantly lower than the estimated clearing price. The minimization of MCP leads to a successful bidding process [9]. Besides, a better communication architecture helps ISO during real-time scheduling of power. With appropriate communication technologies, real-time parameters are measured to predict the values for ensuring system security [13]. The provision for modifying the optimal power flow problem by including different constraints in the OPF equations has made it possible to predict the future values using different optimization techniques [11].

3 Background

In electricity trading, the independent system operator calculates the Locational Marginal Price (LMP) by formulating a load flow problem for pricing the electricity after receiving the bids and offers from the buyers and generating companies. The term locational refers to the price at the bus, and marginal refers to the cost of delivering one additional unit of power. Therefore, the LMP is the cost of providing one extra megawatt of power at a specific location on the grid. The LMP computation involves three components, the energy cost, the congestion cost, and the losses as specified in Equation (1). The energy cost is the cost incurred to generate one megawatt of power. The physical limitations of the grid cause congestion and the losses indicate the amount of power lost during transmission.

$$\begin{aligned}\text{LMP} = {} & \text{System Energy Price} + \text{Transmission Congestion Cost} \\ & + \text{Cost of Marginal Losses}\end{aligned} \tag{1}$$

Independent System Operators (ISO) require a prediction-based energy market for participants based on the available generation and load demand, comprising the day-ahead market and the real-time market [12]. The electricity-generating stations and load-serving entities or buyers submit their bids to ISO on the day-ahead based on each hour's varying costs for the next operating day. ISO decides and optimizes the generation dispatch schedule considering cost, security, and transmission constraints. The ISO balances the electricity supply and demand in each location on the bus considering the transmission constraints through an auction process as follows:

- ISO predicts demand on an hourly basis
- The generator places an offer based on the cost of generation, and the buyer submits bids based on predicted LMP.
- The responsibility of ISO is to sort the offers and bids in ascending and descending order, respectively, to determine the supply availability at different price points.
- ISO selects the least-priced combination of offers and bids required to meet the demand.

The marginal unit of generator offers and buyer bids decides the clearing price. Generators get paid at generation bus LMP and buyers pay for load bus LMP. The LMP calculated from basic load flow and LMP during the final settlement is different because of congestion and system constraints. The ISO settles this difference amount according to contracts and agreement policies. The linear regression algorithm helps to predict new MCPs, and hence the net revenues are improved.

4 Implementation

The cost of generation in a restructured power system is decided based on its fuel cost curves and operating cost to make an appropriate market decision. The buyers depend on LMP, which varies according to the bus number in the IEEE 30-bus system, to decide on the bid price. There is a need to coordinate the generating companies and buyers in the process of trading. The ISO takes the responsibility of coordinating between the sellers and the buyers. The ISO's role includes generation scheduling and rescheduling for an hourly period, analyzing and predicting power system security, allocating the generation reserve of the system under particular conditions like generation loss, and providing information to the dispatcher and market operation.

The buyer bids for each block of power by dividing the total demand into blocks. Each block contains information regarding the power required and the bid price. The sum of all blocks submitted by individual buyers is the total power needed to trade in a specific hour. The total volume cleared in a particular hour is dependent on auction rules and system constraints and this is not equal to the bid amount of power. In this paper, we study the effect of bid prices quoted by individual buyers on the net volume of power cleared. The bidding rule says that the bid price should be more than LMP.

In the IEEE 30-bus system chosen for the study, the buyers participate in the trading situated at bus numbers 8, 15, and 30. The initial OPF is performed on the system and the LMP is calculated at each bus. Eight different strategies are framed in this work and analyzed such that the buyer achieves maximum societal benefit.

In this analysis, the goal is to adjust the bids, thus clearing the next block of power demand. We use the term 'strategy', which refers to adjusting the bid. According to each strategy, the amount of power cleared varies. This variation ends when the amount of power cleared is equal to the maximum power demand quoted by the buyers.

5 Prediction Strategy

The LMP is the price paid by the buyers to the generating companies. The buyers have to strategically calculate their bid price for different volumes of power to increase the net earnings. In this work, linear regression is used to calculate the prediction-based LMP [10].

The strategies defined in this work establishes a linear relationship between the bid price and the net volume of power cleared. While using linear regression, the net earnings are chosen as a function of the total volume of power cleared. The new LMP is chosen as the independent variable, and the net earnings is chosen as the dependent variable for linear regression.

5.1 Algorithm

Step 1: Define the dependent and independent variables

$$LMP_{ij} = new\ LMP\ calculated\ for\ i^{th}\ buyer,$$
$$VC_{ij} = volume\ of\ power\ cleared,\ NE_{ij} = f(VC_{ij})$$

Step 2: For each strategy 1 to 7 and each buyer 1 to 3, compute the net earnings

$$LMP_{ij}, VC_{ij}\ \&\ NE_{ij}\ where\ i = 1\ to\ 3\ and\ j = 1\ to\ 7$$
$$NE_{ij} = LMP_{ij}\ x\ VC_{ij} + f(m_{ij}) \quad (1)$$

where $f(m_{ij})$ is function of fixed charges depends on load in MW

Step 3: Implement the regression by fitting the curve to the data and obtain coefficients β_o and β_1 using Equation (2)

$$NE_{ij} = \beta_o + LMP_{ij}\beta_1 \tag{2}$$

Step 4: Apply regression on the data, calculate the residual and check for the mean of residual standards if zero

$$Res = LMP_{ij} - LMP_{ijestim}$$

$$S_{Res} = \sqrt{\frac{(LMP_{ij} - LMP_{ijestim})^2}{n-2}} \tag{3}$$

Where $LMP_{ijestim}$ is the predicted LMP for ith buyer for jth strategy

Step 5: Calculate the new net earnings for predicting LMPs using Equation (4)

$$NE_{ijnew} = LMP_{ijestim}\ x\ \ VC_{ij} + f(m_{ij}) \tag{4}$$

6 Results and Discussion

In the IEEE 30 Bus system, three buyers at buses 8, 15, and 30 participate in the trading process. Initially, the buyers request a total of 60 MW of power. In this work, three buyers are participating and the bids are submitted by dividing the total 60 MW of power into three 20 MW blocks namely block 1, block 2 and block 3. Table 1 shows the initial bids submitted by the buyers with the LMP. Table 1(a) shows eight different strategies considered in this work. In each strategy, the buyer changes the bid value for clearing the next block of power. The letter ‘Y’ in the Table indicates the buyer’s choice to clear the volume of power in the corresponding block.

In strategy one, each buyer is bidding to clear the volume of power in block 1. In strategy 2, buyer B1 bids to clear the volume of power in both

Table 1 Bid Price and LMP to clear block 1 of power

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	60	50
B2	99.66	100	60	30
B3	99.64	100	40	20

Table 1(a) Bid Price and LMP to clear block 1 of power

	Buyer 1			Buyer 2			Buyer 3			Total
	Block 1 20 MW	Block 2 20 MW	Block 3 20 MW	Block 1 20 MW	Block 2 20 MW	Block 3 20 MW	Block 1 20 MW	Block 2 20 MW	Block 3 20MW	Power Targeted
Strategy 1	Y			Y			Y			60 MW
Strategy 2	Y	Y		Y			Y			80 MW
Strategy 3	Y	Y		Y	Y		Y			100 MW
Strategy 4	Y	Y	Y	Y	Y		Y			120 MW
Strategy 5	Y	Y	Y	Y	Y	Y	Y			140 MW
Strategy 6	Y	Y	Y	Y	Y	Y	Y	Y		160 MW
Strategy 7	Y	Y	Y	Y	Y	Y	Y	Y	Y	180 MW

Table 2 Strategy 1 – Buyers bidding with bids greater than LMP for clearing block-1 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	20	76.216	2000	1524.32	475.68
B2	20	77.76	2000	1555.20	444.80
B3	20	82.49	2000	1649.80	350.20
TVC	60		Total		1270.68

*TVC: Total Volume Cleared.

blocks 1 and 2, while buyers 2 and 3 bid to clear the volume of power in block 1. Likewise, in strategy seven, all buyers are bidding to clear the volume of power in all the blocks.

The buyer's bid amount based on the LMP obtained from optimal power flow is shown in Table 1. From Table 1 it is clear that each buyer is bidding for 100 $/MWH, which is more than the LMP obtained.

Table 2 shows the net earnings of the buyers when strategy one is applied. The buyer's bid price is 100$/MW, which is greater than the LMP shown in Table 1. It is observed that all the buyers can clear block 1 volume of power. Each buyer has cleared 20 MW of power respectively, and the total volume of power cleared equals 60 MW as targeted in strategy one (Table 1(a)).

Table 3 shows the effect of change in bid price on the volume of power cleared. The buyer B2 at bus 15 bids for 70 $/MWH which is less than 99.66$/MW. B2 was supposed to clear 20 MW, instead, B2 could clear only 8.9 MW, as shown in Table 4. If B2 further reduces the bid amount to 60 $/MWH, then the volume of power cleared may increase, but there is a chance of the bid getting rejected.

Table 5 shows the implementation of strategy two. It can be noted that the B1 block two bid price has been changed from 60 $/MW to 90 $/MW.

Table 3 Bid Price and LMP to clear block 1 of power

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	60	50
B2	**99.66**	**70**	**60**	**30**
B3	99.64	100	40	20

Table 4 Buyer 2 bidding less than LMP for clearing block-1 of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	20	72.41	2000	1448.20	551.80
B2	**8.9**	**70**	**890**	**623.00**	**267.00**
B3	20	77.85	2000	1557.00	443.00
TVC	48.9		Total		1261.80

Table 5 Bid Price and LMP to clear block 2 of power

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	**90**	50
B2	99.66	100	60	30
B3	99.64	100	40	20

Table 6 Strategy two – Buyer B1 bidding to clear block 2 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	40	85.36	4000	3414.40	585.60
B2	20	74.9	2000	1498.00	502.00
B3	20	90.5	2000	1810.00	190.00
	80				1277.60

Table 5 shows the net earnings when the B1 bids for clearing block 2 volume of power. It is observed that B1 can clear 40 MW of power by increasing the bid amount. The Market Price of buyer B1 is 85.36$/MWH and the bid price is 100$/MWH, the difference in market price and the bid price is due to auction rules and system constraints in the algorithms used by the ISO.

Table 7 shows strategy three, which aims to clear block 3 volume of power for buyer B1, without disturbing buyers B2 and B3. The bid price is increased from 50 $/MW to 90 $/MW.

Table 7 Bid Price and LMP to clear block 3 of power for buyer 1

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	90	**90**
B2	99.66	100	60	30
B3	99.64	100	40	20

Table 8 Strategy three – Buyer B1 bidding to clear block-3 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	43.2	90	4320	3888.00	432.00
B2	20	73.23	2000	1464.60	535.40
B3	20	94.64	2000	1892.80	107.20
	83.2				1074.60

Table 9 Bid Price and LMP to clear block 2 of power for buyer 2

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	90	90
B2	99.66	100	**90**	30
B3	99.64	100	40	20

Table 10 Strategy four – Buyer B2 bidding for clearing block-2 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	45	83.94	4500	3777.30	722.70
B2	31	83.94	3100	2602.14	497.86
B3	20	90.51	2000	1810.20	189.80
	96				1410.36

Table 8 shows the buyer's net earnings when the buyer B1 bids for clearing block 3 volume of power. Buyer B1 could clear 43.2 MW of power for the bid amount of $90 instead of 60 MW due to system security constraints.

Table 9 shows strategy four, which aims at clearing block 2 volume of power for buyer B2. To clear the 40MW of volume, buyer B2 has to increase the block 2 bid from 60$/MWH to 90$/MWH.

Buyer B2 could clear only 31 MW, as shown in Table 10. The transmission line connecting bus 15, where buyer two is drawing the power, has reached its maximum limit.

Table 11 Bid Price and LMP to clear block 2 of power for buyer 2

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	90	90
B2	99.66	100	90	**100**
B3	99.64	100	40	20

Table 12 Strategy five – Buyer B1 and B2 bidding for clearing block-3 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	36.3	83.4	3630	3027.42	602.58
B2	40	86.954	4000	3478.16	521.84
B3	20	90.381	2000	1807.62	192.38
	96.3				1316.80

Table 13 Bid Price and LMP to clear block 2 of power for buyer 2

Buyer	LMP ($/MWH)	Bid Amount for 20 MW	Bid Amount for 40 MW	Bid Amount for 60 MW
B1	96.084	100	90	90
B2	99.66	100	90	100
B3	99.64	100	**100**	20

Strategy five adopted in this work is shown in Table 11. To clear 60 MW of power, block 3 bid price by buyer B2 is increased from 30$/MW to 100$/MW.

The buyer could clear only 40 MW, as shown in Table 12. The generator and transmission constraints have limited the amount of power to be shared with buyer B2. A further increase in the bid price showed no change in the volume of power cleared.

Table 13 shows strategy 6, which aims to clear the block 2 volume of power for buyer B3. The bid price is increased from 40$/MW to 100 $/MW, As shown in Table 14 the buyer B3 cleared block 2 volume of power. The buyer bid price is 100$/MW which is more than the LMP 99.64$/MW.

Table 15 shows strategy seven, where the block 2 volume of power is cleared for buyer B3. The bid price is increased from 20$/MW to 120 $/MW. From Table 16, we observe that buyer B3 could not clear the block 3 volume of power. The transmission line constraints are limiting the buyer B3 to clear the block 3 volume of power.

Tables 1 to 16 shows the seven strategies applied in this work and the outcome of each strategy. Table 17 summarizes the total volume of power

Table 14 Strategy six – Buyer B3 bidding for clearing block 2 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	31	90	3100	2790.00	310.00
B2	40	90	4000	3600.00	400.00
B3	40	100	4000	4000.00	0.0543
	111				710.00

Table 15 Bid Price and LMP to clear block 2 of power for buyer 2

Buyer	LMP ($/MWH)	Bid Amount for 20 MW (Block 1)	Bid Amount for 40 MW (Block 2)	Bid Amount for 60 MW (Block 3)
B1	96.084	100	90	90
B2	99.66	100	90	100
B3	99.64	100	100	**120**

Table 16 Strategy seven – Buyer B3 bidding for clearing block-3 volume of power

	Cleared Volume (MW)	Market Price $/MWH	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
B1	40	90.82	4000	3632.80	367.20
B2	40	90	4000	3600.00	400.00
B3	38	100	3800	3800.00	1.054
	118				768.54

Table 17 Summary of strategies for net volume cleared and net earnings

Strategy	Total Volume of Power Cleared (MW)	Targeted Volume of Power Cleared (MW)	Net Earnings ($)
Strategy 1	60	60	1270.68
Strategy 2	80	80	1277.60
Strategy 3	83.2	100	1074.60
Strategy 4	96	120	1410.36
Strategy 5	96.3	140	1316.80
Strategy 6	111	160	710.00
Strategy 7	118	180	767.20

cleared against the targeted volume in each strategy. The difference between the actual volume of power cleared and the volume targeted is due to generation limits and transmission line limits.

Figures 1(a) and 1(b) show the variation of volume of power cleared and net earnings against the strategies. It is observed that as the volume of power

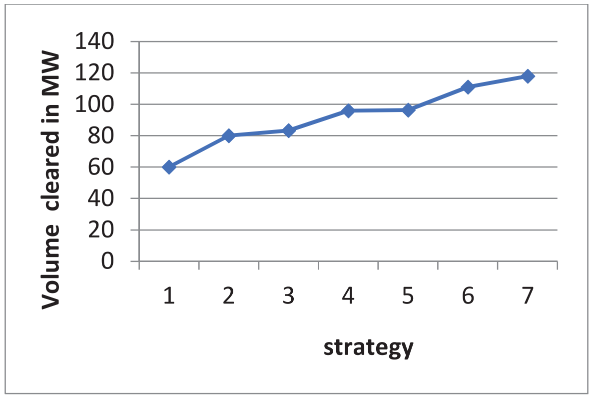


Figure 1(a) Variation of volume cleared against strategies.

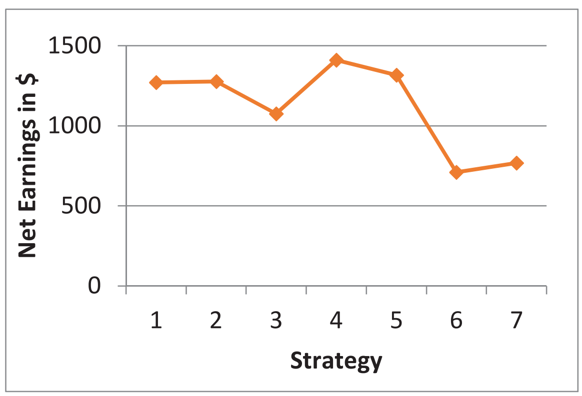


Figure 1(b) Variation of net earnings against strategies.

cleared increases, the net earnings also increase. A further effort to increase the volume of power cleared resulted in decreased net earnings.

Table 18 compares the volume of power cleared with the implementation of OPF and bidding strategy 7. Strategy 7 shows a significant increase in the net earnings of the buyers in total compared to the net earnings with OPF. It is observed that there is a 33% increase in net earnings. In this case, the three buyers are bidding more than the LMP, hence a significant reduction in market price is observed for buyer 1 and buyer 2.

Table 19 shows a bidding pattern adapted to clear each block of the volume of 20 MW. In strategy one, the bid aims to clear 20 MW of volume. The buyer can clear only 40 MW of volume even when targeted for 60 MW.

Table 18 Summary of strategy seven and OPF for net cleared volume and net earnings

	Cleared Volume (MW)	Bid Price LMP ($/MW)	Market Price ($/MW)	Fixed Charges ($)	Revenue ($)	Net Earnings ($)
OPF						
B1	60	96.084	96.084	6000	5765.04	234.96
B2	42.31	99.66	99.66	4231	4216.61	14.39
B3	17.56	99.64	99.64	1756	1749.68	6.32
Total	119.87					255.67
Strategy 7						
B1	40	100	90.82	4000	3632.80	367.20
B2	40	100	90	4000	3600.00	400.00
B3	38	100	100	3800	3800.00	1.054
Total	118					768.74

Table 19 Summary of strategies for MCV and net earnings for buyer B1

Bidder 1	Block 1 Bid Price ($/MWH)	Block 2 Bid Price ($/MWH)	Block 3 Bid Price ($/MWH)	Total Cleared Volume (MW)	Required Total Cleared Volume (MW)	Net Earnings ($)
Strategy 1	100	60	50	20	20	475.68
Strategy 2	100	90	50	40	40	585.60
Strategy 3	100	90	90	43.2	60	432.00
Strategy 4	100	90	90	45	60	722.70
Strategy 5	100	90	90	36	60	602.58
Strategy 6	100	90	90	31	60	310.00
Strategy 7	100	90	90	40	60	367.20

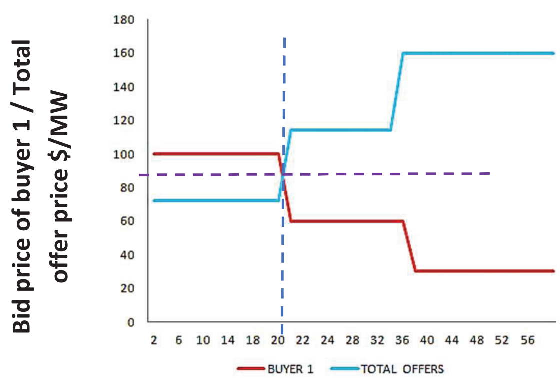


Figure 2 Total offers versus buyer one bids to clear block 2 volume of power.

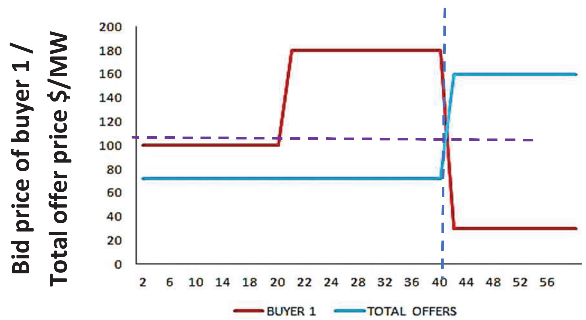


Figure 3 Total offers versus buyer one bids to clear block 2 volume of power.

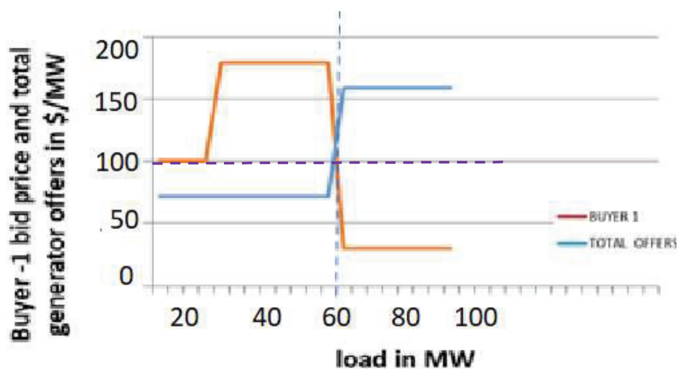


Figure 4 Total offers versus buyer one bids to clear block 3 volume of power.

Figure 2 shows the buyer B1 bidding strategy for clearing the net volume of 20 MW. The intersection of offers and the bids are observed at 20 MW. The corresponding bid amount is 90$/MW. To clear block 1 (20 MW) of the volume of power, the buyer has to bid for more than 90$/MW. Table 19 shows that the buyer B1 bidding at 100$/MW could clear the volume of 20 MW.

Figure 3 shows the buyer B1 bidding strategy 2, for clearing the block two-volume of power. The intersection of offers and the bids is observed at 40 MW. The corresponding bid amount is 120$/MW for clearing block 1 and block 2 volume of power (20 MW), and the buyer must bid more than or equal to 120$/MW.

Figure 4 shows the buyer B1 bidding strategy for clearing block 3 volume of power. The offers and the bids intersect at 60 MW. The corresponding bid amount is 130$/MW. To clear block 3 (20 MW) of volume, the buyer must bid more than or equal to 130$/MW. From Table 11, the buyer bidding at

Table 20 Summary of strategies for MCV and net earnings for buyer B2

Bidder 1	Block 1 Bid Price ($/MWH)	Block 2 Bid Price ($/MWH)	Block 3 Bid Price ($/MWH)	Total Cleared Volume (MW)	Required Total Cleared Volume (MW)	Net Earnings ($)
Strategy 1	100	60	30	20	20	444.8
Strategy 2	100	60	30	20	20	502
Strategy 3	100	60	30	20	20	535.4
Strategy 4	100	90	30	31	40	497.86
Strategy 5	100	90	100	40	60	521.84
Strategy 6	100	90	100	40	60	400
Strategy 7	100	90	100	40	60	400

Table 21 Summary of strategies for MCV and net earnings for buyer B3

Bidder 1	Block 1 Bid Price ($/MWH)	Block 2 Bid Price ($/MWH)	Block 3 Bid Price ($/MWH)	Total Cleared Volume (MW)	Required Total Cleared Volume (MW)	Net Earnings ($)
Strategy 1	100	40	20	20	20	350.2
Strategy 2	100	40	20	40	20	190
Strategy 3	100	40	20	40	20	107.2
Strategy 4	100	40	20	40	20	189.8
Strategy 5	100	40	20	40	20	192.38
Strategy 6	100	100	20	36	40	286.09
Strategy 7	100	100	120	36	60	294.2

130$/MW in strategy six could clear only the volume of 40 MW. The reason is that the transmission line carrying the power to the buyer has already reached its maximum KVA.

Table 20 shows the bidding strategy and net profits earned by buyer B2. It is noted that the maximum net earning is obtained when strategy four is applied. Table 1(a) shows a bidding pattern adopted to clear the volume of power of each block. Each block mentioned in the table is 20 MW. In strategy one, the buyer successfully clears the targeted volume of 20 MW. After applying all strategies, because of line constraints and generator limits the buyer is able to clear only 40 MW of volume even when targeted for 60 MW.

Table 21 shows the bidding strategy of buyer B3 and net profits earned. From strategy one to strategy five the buyer three could clear the first block volume of power as targeted. In strategy six, the buyer could clear 36 MW of power out of 40 MW targeted. In strategy seven, the buyer has cleared 36 MW out of the targeted 60 MW. It is observed from the seven strategies that the Buyer B3 could not clear the third block of power.

6.1 Linear Regression Applied to Strategical Bidding

Linear regression algorithm optimizes the net earnings by predicting the new values for the LMP. The regression algorithm shown in Section 5.1 takes two variables, Market price, and net earnings as input and predicts new market price. The market price has a linear relationship with the net earnings of the buyers.

Table 22 shows the difference in net earnings and Market Price with and without prediction. In strategy four, the Market Price obtained from OPF for clearing 45 MW of power is 83.94$/MW, giving buyer B1 the net earnings of 722$/MW. After applying the regression algorithm, the predicted Market Price for clearing 45 MW of power is 79.27$/MW, which increases net earnings from 722$/MW to 933$/MW.

Table 22 Summary of Net earnings for buyer 1 with and without prediction

Cleared Volume (MW)	Market Price ($/MW)	Predicted Market Price ($/MW)	Net Earnings Without Prediction ($)	Net Earnings With Prediction ($)
20	76.216	84.68	475.68	306.3627
40	85.36	82.27	585.60	709.1333
43.2	90	85.64	432.00	620.368
45	**83.94**	**79.27**	**722.70**	**933.0526**
36.3	83.4	81.90	602.58	657.0536
31	90	88.31	310.00	362.2442
40	90.82	87.06	367.20	517.5804

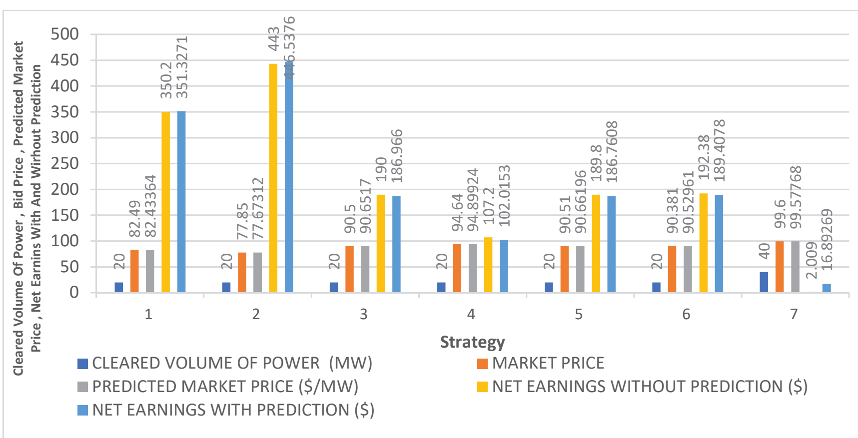


Figure 5 Comparison of predicted and actual values of buyer 1.

Table 23 Summary of Net earnings, LMP, and predicted LMP for buyer 2 with and without prediction

Cleared Volume (MW)	Market Price ($/MW)	Predicted Market Price ($/MW)	Net Earnings Without Prediction ($)	Net Earnings With Prediction ($)
20	77.76	75.88331	444.8	482.3338
8.9	70	69.69138	267	269.7468
20	74.9	75.50337	502	489.9326
20	73.23	75.28152	535.4	494.3696
31	**83.94**	**82.83738**	**497.86**	**532.0412**
40	86.954	88.65615	521.84	453.754
40	90	89.46545	400	421.3821
40	90	89.46545	400	421.3821

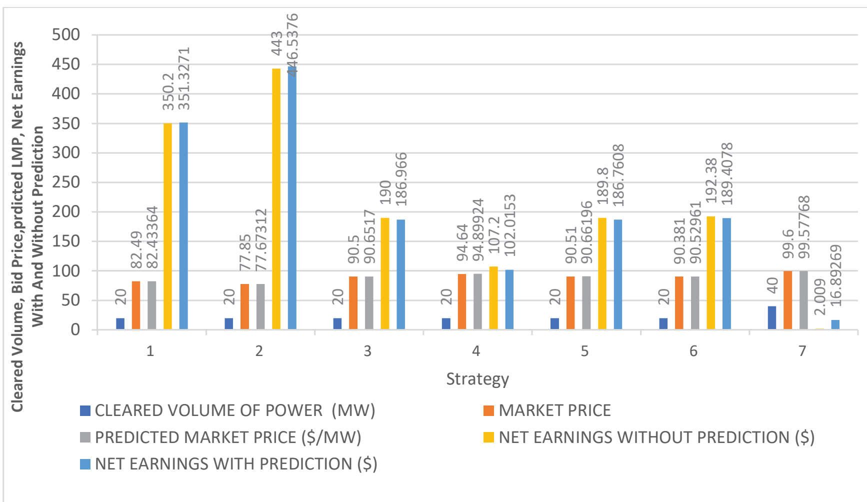


Figure 6 Comparison of predicted and actual values of buyer 2.

Figure 5 shows a comparison of LMP, net earnings, and cleared volume with and without prediction, the strategy applied.

Table 23 shows a comparison of the net earnings of buyer 2 with and without prediction. When strategy five is applied, the Market Price obtained from OPF is 83.94$/MW for clearing 31 MW of power, giving the buyer net earnings of 432$/MW. After applying the regression algorithm, the predicted Market Price for clearing the same volume of power is 82.83$/MW, which increases net earnings from 497$/MW to 532$/MW.

Table 24 Summary of Net earnings for buyer 3 with and without prediction

Cleared Volume (MW)	Market Price ($/MW)	Predicted Market Price ($/MW)	Net Earnings Without Prediction ($)	Net Earnings With Prediction ($)
20	82.49	82.43364	350.2	351.3271
20	77.85	77.67312	443	446.5376
20	90.5	90.6517	190	186.966
20	94.64	94.89924	107.2	102.0153
20	90.51	90.66196	189.8	186.7608
20	90.381	90.52961	192.38	189.4078
40	99.6	99.57768	2.009	16.89269
38	99.1	98.64405	34.2	51.52627

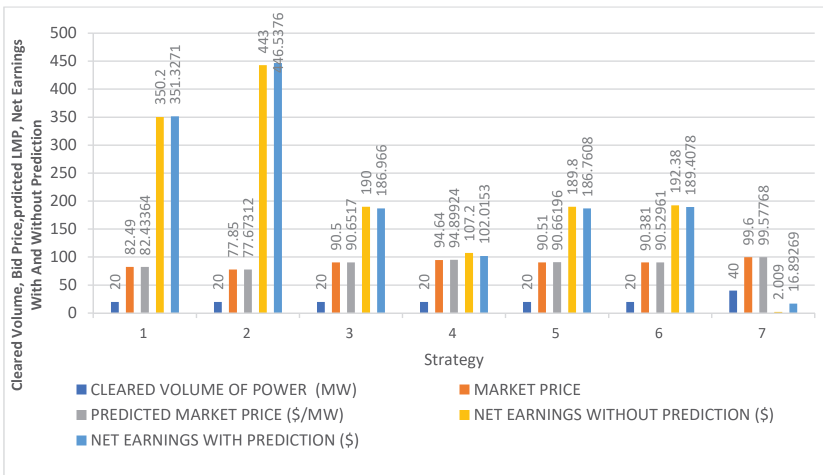


Figure 7 Comparison of predicted and actual values of buyer 3.

Figure 6 shows a comparison of LMP, net earnings, and cleared volume with and without prediction, the strategy applied.

Table 24 shows a comparison of the net earnings of buyer 3 with and without prediction. When strategy four is applied, the Market Price obtained from OPF is 90.51$/MW, giving the buyer net earnings of 189.8$/MW. After applying regression algorithm, the predicted Market Price is 90.661$/MW, decreasing net earnings to 186.7$/MW. When strategy six is applied the net earnings are increased from 2$ to 16$.

Figure 7 shows a comparison of LMP, net earnings, and cleared volume with and without prediction, the strategy applied.

7 Conclusion

A typical bidding strategy and its effect on net volume cleared was studied in this paper. Strategies from one to seven defined in this paper are to study the bid price effect on the market-clearing price and the net volume of volume. Strategy one, when applied, could able to clear the target volume of power. The buyer at bus 15 bidding for an amount less than its LMP could not clear the volume of power targeted as shown in Table 4. Strategy two and three targeted clearing the second and third block of power for buyer B1. Strategies four to seven, when implemented, could not clear the targeted volume but could get some fraction of it because of transmission line constraints and generator limits. If the participant is unaware of the LMP when purchasing power, there is a mere chance of bid rejection. In this paper, the bidding strategy aims to clear the net volume of power and improve net earnings. As the volume of power cleared is increased the net earnings increases and reaches the maximum, a further increase in volume of power has shown a reduction in net earnings.

The Linear regression-based prediction strategy was adopted in this paper to predict new values of LMP which resulted in an increase in net earnings by 17 % for buyer B1 and 1.5% for buyer B3. There is no significant increase in net earnings for buyer B2. the impact of bidding strategy on the volume of power cleared is studied, hence providing societal benefits.

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