# Wind Power Trading Options in Competitive Electricity Market

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*Abstract:* **Integration of wind power into the competitive electricity market presents challenges to power system planners and operators. It is not possible for wind generators to bid into the competitive electricity market due to high cost and intermittent nature of available power. This paper analyses and proposes the pricing mechanism for wind power in the competitive electricity market. The both demand and supply side bidding scenarios with case studies are presented in the paper. The impact of wind power in market mechanism such as market collusion, ancillary series and market power are also discussed. This paper could be guide line for the policy makers and market operators to promote the wind power with system reliability and security.**

*Index terms:* **Wind power, Competitive power market, bidding, market clearing price.**

## I. Introduction

DUE to decreasing oil and coal reserve, environmental concerns and fear of nuclear disasters, it is believed that future power generation will not be limited to the conventional power plants. Despite rapidly climbing prices for natural gas and oil, the simple fact is, alternative energy in all its forms is not yet competitive on the price front for everyday users. Alternative energy is generally defined as any power source that is not based on fossil fuels or nuclear reactions. That includes electricity generated from wind, solar, geothermal, biomass or plant matter, and hydro power. Alternative fuels also can include ethanol from corn, bio-diesel made from vegetable crops and methane made from waste or other sources. Wind power is a potential candidate in non-conventional power generation family.

Wind farms are becoming an increasingly common sight on off-shore and on-shore. Their large scale integration in the electricity system presents some planning and operational difficulties due to mainly the intermittent and difficult to predict nature of wind which is considered at unreliable energy sources. However, the percentage of energy provided by wind is increasing due to technology and efficiency improvements, government financial support and energy policies. Wind turbines have become more efficient and their costs have dropped about 80 percent since 1980 to about four to eight cents per kilowatt-hour today, vs. about 38 cents to 40 cents 25 years ago.

An economic analysis often reveals that wind power is competitive with conventional power. But such an analysis strips out distortions such as input fuel subsidies, taxes and cross-subsidies between different class of consumers and uses the opportunity cost of capital as the discount rate. It also includes valuations for environmental externalities associated with burning fossil fuels. The wind power without government subsidy is still not competitive to the conventional energy sources. The energy production cost issue becomes more challenging due to ongoing restructuring process motivated to provide competition wherever possible for the cheap and choice of energy to the customers.

Competitive power market opens the room for playing the generators and retailers/consumers in their bid prices. The price formation is an internal decision of sellers and buyers. Bidding at both sides (supply and demand) are equally important from the market point of view. Competition in supply is concerned with how generators price their commodities so as to be commercially successful in the supply-demand market. The plural term commodities is used to emphasize that a supplier may have several types of plants (thermal, hydro, combine cycle etc.) and the pricing, and consequently the dispatch strategies, will reflect numerous technical and commercial particularities.

In the competitive electricity market, wind power is assumed as non-competitive as it has higher cost and uncertainty of availability of power [1]-[3]. To fit the non-conventional energy sources into liberalized electricity market, these generators are taken into the market differently than the dispatchable generators [5]-[6]. In some countries [7], wind generation is accommodated in day-ahead and hour-ahead energy markets without imbalance penalties. Imbalance (scheduled generation minus actual production) penalties are imposed to prevent gaming and to secure better system operation. In some electricity market, wind generators are not allowed to bid and they are taken into the system as and when these powers are available. Normally, wind generators are paid at the actual energy market price plus a fixed premium [1]. Even at these prices, wind generators can only recover the cost if they get some subsidy from the governments. With the removal of subsidies from these generators, it would be very difficult for them to survive in the emerging electricity market unless a suitable market mechanism is devised to take care of their output powers as and when available.

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With rising environmental concerns, the wind energy is a better choice. But wind might run into competitive trouble against emerging clean coal technologies. Moreover the impacts of wind's variability on the system operating costs are not negligible [8]. In most cases, the costs are less than 10% of wholesale energy value and in some cases substantially less. For power systems with a substantial natural gas component, wind actually provides a hedge against fluctuations and spikes in gas costs. It can be a hedging tool of system operators against the gamming and market power in the electricity market.

Due to oligopoly nature of market and electricity as a special commodity, there are fair chances of having the market power and market abuse. A good trading mechanism is a basic need which may reduce the market inefficiency. The assessment of cost associated with wind generation prediction errors in an electricity market is presented in [1]. A case of Spanish electricity market has been considered to show the effect of forecasting error. Trading of wind generation in short term market for UK with different window blocks have been considered in [4].

This paper analyses and proposes the pricing mechanism for wind power integrated into the electricity market. The both demand and supply side bidding scenarios are illustrated with examples. Several other considerations in market mechanism such as market collusion, ancillary series and market power are also highlighted. This paper could be guide line for the policy makers and market operators to promote the wind power with system reliability and security.

## II. Bidding Strategies

In genuinely competitive conditions, several producers compete to win a share of the market and bid against each other to supply electricity to the grid. The prices bid by suppliers for the blocks of generation offered to the grid would reflect what portions of the load curve a supplier hopes to win for each type of plant in its possession. This, in turn, depends on production cost estimates, temporal considerations of system demand variation, unit commitment costs and commercial considerations such as profit or economic utility maximization and expectations of competitors' behavior.

The sealed bid auction is widely used in the pool type electricity market. Each supplier submits a sealed bid to the pool to compete for the supply of the forecasted load that is broadcasted by the pool. Theoretically, in perfectly competitive market, suppliers should bid at, or very close to, their marginal production costs to maximize returns. However, the electricity market is not perfectly competitive, and power suppliers may seek to benefit by bidding a price higher than marginal production cost. Each supplier's objective is to maximize benefit, therefore, given its own costs and constraints and its anticipation of rival and market behavior by constructing its offer (bid) price. On the other side, the pool operator will use a dispatch strategy that minimizes customers' payments given the supply costs represented in the suppliers' bids.

There are two type of market exists based on the bidding mechanism. If bidding is done by only suppliers, it is termed as single-sided bidding whereas if both suppliers and costumers are allowed to bid into the market, it is known as double-sided bidding mechanism.

## III. Market Clearing Process

Each generator bids to sell its available supplies at some offer price and each utility (or other load serving entity) bids to purchase electricity at some offer price**.** Once the market-clearing price is determined, all bids to sell with offer prices lower than or equal to the market clearing price and all bids to purchase with offer prices greater than or equal to the market-clearing price is accepted. All sales bids with higher offer prices or purchase bids with lower offer prices would be rejected.

### *A. Single Price Market Clearing Process*

In uniform market clearing price mechanism, all the sellers would receive the market-clearing price for their electricity, even if they bid less than that price and all buyers would pay the market-clearing price, even if they bid more than that price. The theory behind such a bidding system is that all bids to sell electricity would be priced at the marginal cost of that electricity. Bidding at a lower price than marginal cost would also not change the revenues if the bid were lower than the market-clearing price. However, such a bid could result in the firm selling electricity at a price lower than its marginal cost and thus losing money. Therefore, for a firm operating competitively, bidding a price equal to its marginal cost would lead to the greatest profit. In theory, such a competitive market would be desirable for the wholesale electricity markets and would result in the lowest total cost to generate a given amount of electricity.

### *B. Pay-as-Bid Market Clearing Process*

A second alternative would be to design the system to pay bidders just what they bid, rather than to pay them the market-clearing price. The total cost of all purchases would be averaged, and each buyer would pay the average bid price. Many have argued that a system of paying on pay- as-bid basis, rather than on a market-clearing basis, would result in smaller total payments by the buyers of electricity. Under pay-as-bid system, each firm makes the most profit by guessing the cut-off price and bidding at or just below that price, as long as the cut-off price is at least as high as its marginal cost. Thus, even in a competitive market, suppliers would not bid at their marginal costs. If all firms could guess the cut-off price perfectly, each firm whose marginal cost was no larger than the cut-off would bid the cut-off price and each would be paid the cut-off price. The cutoff price would be the same as the market-clearing price.

The advantage often postulated for such a system would disappear under the best circumstance: perfect guessing. Although each firm would learn much from observing the results of the hourly bids, twenty-four a day, there would undoubtedly be mistakes, and to compensate, firms would bid somewhat below their estimate of the cut-off price. Some lower-cost firms would guess incorrectly and bid above the cut-off price, thereby leading to increases in the cut-off price. Thus, some higher-cost firms would generate electricity and some lower-cost firms would remain idle. The total cost of generating the given quantity of electricity would, therefore, be increased above the cost in a market-clearing system. The net result would be some variability in the prices paid for electricity at any hour, with some prices higher than what would have been the market-clearing price and some possibly lower. Whether such a system would increase or decrease the total payments for obtaining a given quantity of electricity would depend on the precise bidding strategies of the various market participants. However, pay-as-bid system could be expected to increase the total cost of generating electricity and would therefore be less efficient than a one-price market-clearing system.

There is another difficulty with the auction system, arising because the system is based on hourly or half-hourly bidding and market clearing. Some generating plants, typically operating as base-load plants, have very long and very costly periods for ramping up from no production to full capacity. These plants might be profitable to operate if they received at least a particular price for a large fraction of the day or for all of the peak period of a day. However, if they were operating only a few hours, even at a higher price, they might not be profitable to operate, since the fixed costs of ramping up could be greater than the profit earned during those more limited hours. For such plants, their offer price at any hour must depend on whether they would be generating electricity at the other hours of the day.

## IV. Determination of Market Clearing Price

The market-clearing price is the lowest price that would provide enough electricity from accepted sales bids to satisfy all the accepted purchase bids. This market-clearing price setting can also be understood in other way. The sales bids would be ranked from the lowest offer price to the highest offer price i.e., in their merit order. The purchase bids would be ranked from their highest offer price to the lowest offer price, in their merit order. Equivalently, for purchasers that simply offered to buy a fixed quantity, the quantities would just be added up. At some price, the total of sales bids up to that point in their merit order would be equal to the total of purchase bids down to that point in their merit order. That price would be the market-clearing price.

The bidders can be allowed to bid their outputs or demands either in the blocks or as linear form as shown in Fig. 1. In a market, both the supply and demand bids are of the same type i.e. either block or linear bids. The detail analysis of wind energy payment in the liberalized market is presented for linear bid cases.

### A. Single Side Bid Market

In a linear bid model, a supply curve which is a function of market price ($p$) of any bidder-$i$ can be expressed as

$$q_i(p) = p / m_{si} \quad (1)$$

where $m_{si}$ is the slope of the supply curve as shown in Fig. 1. If there are $Ng$ suppliers who bid into the market, the combined supply curve will be

$$q(p) = p \sum_{i=1}^{Ng} \frac{1}{m_{si}} \quad (2)$$

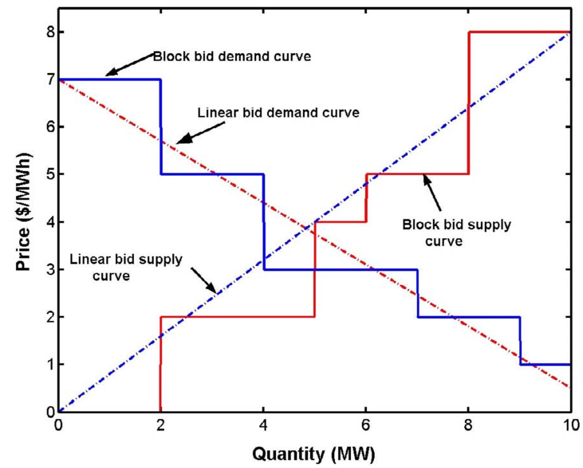


Fig. 1: Demand and supply bid curves

For the fixed demand $D$, the market clearing price ($p^*$) will be obtained by solving following equation.

$$p^* \sum_{i=1}^{Ng} \frac{1}{m_{si}} = D \quad (3)$$

In this, it is assumed that bidders have enough capacity. With limited capacity of any individual supplier can be included accordingly. If the $i^{th}$ generator has the minimum ($q_i^{\min}$) and maximum ($q_i^{\max}$) power output limits, the supply curve defined in equation (1) will become

$$q_i(p) = \left(\frac{p}{m_{si}}\right)\left[u(q_i, q_i^{\min}) - u(q_i, q_i^{\max})\right] \quad (4)$$

where $u(q, q_0)$ is the unit function defined as

$$u(q, q_0) = \begin{cases} 1 & \text{if } q \geq q_0 \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

The combined supply curve would be

$$q(p) = \sum_{i=1}^{Ng} \left(\frac{p}{m_{si}}\right)\left[u(q_i, q_i^{\min}) - u(q_i, q_i^{\max})\right] \quad (6)$$

Thus the market clearing price can be determined by equating equation (6) with total demand.

### B. Double Side Bid Market

In single side bidding, the demand is assumed to be fixed irrespective of the market price. Also single side bidding is a special case, where demand bidder is inelastic to the price. Demand curve for any individual in linear bid mode can be expressed as,

$$d_i(p) = (p_{i0} - p) / m_{di} \quad (7)$$

where $m_{di}$ is the slope of the demand curve and $p_{i0}$ is the intercept on price axis as shown in Fig. 1. If there are $Nd$ consumers who bid into the market, the combined demand curve will be

$$d(p) = \sum_{i=1}^{Nd} \frac{p_{i0}}{m_{di}} - p \sum_{i=1}^{Nd} \frac{1}{m_{di}} \quad (8)$$

The market clearing price ($p^*$) can be obtained by solving the following equation.

$$p^* \sum_{i=1}^{Ng} \frac{1}{m_{si}} = \sum_{i=1}^{Nd} \frac{p_{i0}}{m_{di}} - p^* \sum_{i=1}^{Nd} \frac{1}{m_{di}} \quad (9)$$

or

$$p^* = \frac{\sum_{i=1}^{Nd} \frac{p_{i0}}{m_{di}}}{\left( \sum_{i=1}^{Ng} \frac{1}{m_{si}} + \sum_{i=1}^{Nd} \frac{1}{m_{di}} \right)} \quad (10)$$

The effect of generator output and consumption limits can be taken appropriately.

### *C. Market Clearing Price with Wind Generators*

There are two possibilities for integration of wind generators in the competitive electricity market. In option one, they will be allowed to bid into the market and take the market clearing price with some premium. Moreover, they must not be charged the output variability penalty as other dispatchable generators are charged for the same. The risk of getting dispatched in the pay-as bid market is more. Due to government's commitments for green energy this option is not suitable. Moreover, wind generators are not competitive without the government subsidy and in future government would like to remove the subsidies.

Another option, which is more appealing, is that the outputs of wind generators can be taken into the system whenever and wherever, they are available. In this condition the market clearing price (MCP) is to be determined to take care of wind generation output and the variability of wind power as well. With the different types of biding options, the MCP is to be effectively determined which is discussed in the case studies.

The effect of non-availability of wind power is the same as the non-availability of conventional power plant which have less probability of the same and they are penalized with huge revenue. Since the wind power depends on the availability of wind, the forecasting error is higher and therefore its effect on the market price and system operation is to be minimized. With proper pricing mechanism, the efficiency of market can be improved.

## V. Other Aspects of Wind Power Trading

### *A. Mitigation of Market Power*

With introduction of competition in electricity market, there are several situations where market does not operate in a fair and transparent manner by the network constraints and also due to gaming by the market participants. Market power, in economics aspect, is the ability to profit by moving the market price away from the competitive level. In regulatory aspects, market power to a seller is the ability profitably to maintain price above competitive levels for a significant period of time. According to economics, any ability to do this, no matter how fleeting or minimal, is still market power. Most firms have some market power and this causes no significant problems provided the amount is small. Market power is harmful to the competition and it is necessary to identify the potential for its abuse, and to take steps to mitigate the market power.

Market power can be exercised by withholdings the output of generators. Withholding can be accomplished financially by bidding a high price, or physically by not bidding at all. If a high bid does not result in withholding, it is not an exercise of market power, even though it profitably raises the market price. In most markets, other than power markets, it is impossible to raise the market price without withholding, so this anomaly never occurs.

The most obvious effect of market power is the transfer of wealth from consumers to all the suppliers in the market, not just to the supplier who is exercising the power. This is not a major concern of economist which usually ignores the problem of wealth transfer. Economists are more concerned with efficiency, and in this case, are concerned with that high monopoly prices will lead to inefficiently low levels of consumption. The resulting loss of benefit to the consumers will be greater than the increase in profits. Strictly speaking, market power in electric power industry is due to following.

- Large share of generation or market dominance
- Network constraints
- Additional opportunity to create intentional congestion.

Wind power outputs can be used by market operators (MOs) for mitigating the market power exercised by the dispatchable generators. In normal cases, MOs are mitigating the market power abuse by using the dispatchable loads which is more expensive than the wind power because the cost of non-served energy is more than the cost of energy to be supplied. Since the wind power is intermittent and other generators do not know the exact amount of output from the wind power, their market power capability will be reduced.

### *B. Market Collusion*

Collusion or horizontal merger of potential competitors can create or strengthen the market power. For collusion of suppliers to be successful, suppliers must be able to reach terms that are mutually profitable. Factors that tend to facilitate collusion are:

- A frequently repeated action for a homogeneous product under similar demand and supply conditions,
- Intimate knowledge of rival's operating costs and behavior, and
- Almost immediate knowledge of a rival's actions.

Generally, several aspects of electricity markets discourage collusive behavior. First, demand conditions vary considerably throughout the day and the actual demand levels experienced can vary significantly associated with these variables compounded by the uncertainty associated with predicting the amount and prices offered by all rivals with given forced outages and system operating constraints. Second, while information regarding power suppliers' operating cost in the past has been publicly available, this historical information is not necessarily indicative of suppliers' likely bid prices, since these operating cost do not reflect startup cost and are in many instances, average costs for an entire power plant.

Wind power with pump storage hydro power plant can have much effect on the market price setting. To recover the cost, wind power may try to get associated with other types of generators and may create the market power. Any such type of merger/collusion should be avoided by allowing the wind power to generate power as and when available.

*C. Ancillary Service Provisions*

Ancillary services such as reactive power support, spinning reserve, load frequency control (AGC), black start capability, energy imbalance etc. can be procured through auction based competitive markets similar to energy market. These ancillary services required for maintaining the quality and security/reliability of supply. Due to intermittent output of wind power coupled with uncertainty of wind, there is a possibility of higher cost of market due to greater imbalance of power, if wind generators are allowed to bid into the market. On the other hand, if wind power is with MOs, it can be used to provide the real power either in ancillary service or primary energy market to reduce the cost of electricity.

## VI. Study Cases

Different biding scenarios of wind power in the electricity market are illustrated. In this study, the uniform pricing approach is considered. For sake of simplicity, only three generators other than a wind generator have been considered to bid into the market. For more bidding generators, the combined supply curved is to be obtained as explained in section IV. The output of wind generator is assumed to be 5 MW. Following cases are studied:

Case-A: Linear supply bid with fixed demand
Case-B: Linear supply bid with linear demand bid

Table I shows linear bidding parameters, at any unit time, of three supply bidders as defined in (1). The lower and upper limits of these generators are also given in the Table I. The cumulative supply curve is obtained using (2) and shown in Fig. 2.

TABLE I: LINEAR BID DATA

| | $m_{si}$ (\$/MW$^2$) | $q_g^{max}$ (MW) | $q_g^{min}$ (MW) |
|---|---|---|---|
| Bidder-1 | 0.10 | 20 | 100 |
| Bidder-2 | 0.25 | 10 | 50 |
| Bidder-3 | 0.20 | 10 | 100 |

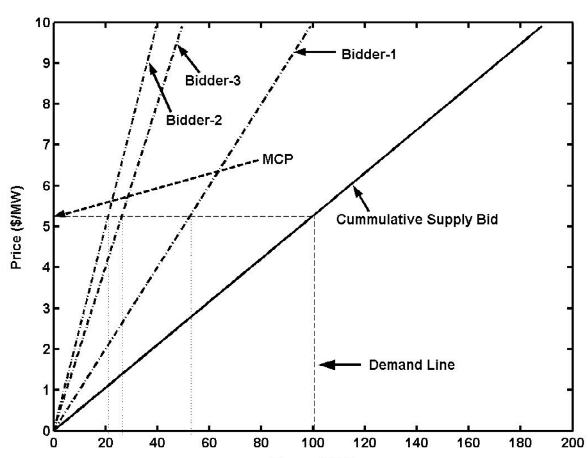


Fig.2: Linear supply bid with fixed demand

**Case-A**: In this case, a constant demand of 100 MW is considered. If wind power would not be available, the total demand would have been met by the three supply bidders 1, 2, and 3. The market clearing price (MCP), which is the intersection of demand curve and total supply curve, is \$5.26/MWh. The scheduled output powers of the supply bidders is obtained by intersection of MCP line to the individual supply bid lines as shown in Fig. 2. The bidders 1, 2 and 3 must generate 52.63 MW, 21.05 MW and 26.32 MW, respectively.

Consider wind power is available. Now it must be absorbed without knowing its actual price of output. With the availability of wind power (5 MW), the bidders can share the total dispatch of 95 MW (=100-5 MW). The corresponding MCP is now \$5.0/MWh. Since the MCP is reduced, it may not possible to recover the cost of wind power and also the excess cost during the non-availability of wind power. Thus the market price is to be fixed to the value obtained without considering the wind generation which is \$5.26/MWh. The output of bidders will be reduced according to the bidding characteristics which can be obtained by reducing the output by ($\Delta q_i$) as

$$\Delta q_i = \frac{\Delta p}{m_{si}} \tag{11}$$

where $\Delta p$ is the change in MCP with and without wind power.

To see the bidding impact of wind generators, let wind generator be allowed to bid into the electricity market. The variations of wind output and the MCP with the different bidding rates are shown in Fig. 3. From Fig. 3, it can be seen that for its complete dispatch, wind power can bid any value less than \$5.0/MWh which is the market clearing price obtained by the total demand minus the wind power. It also shows that if wind power bids at zero, it will be completely dispatched and the MCP will be \$5.00/MWh. At zero bid of wind power, the cumulative supply curve will be parallel line below the total supply curve (without the wind power bidding).

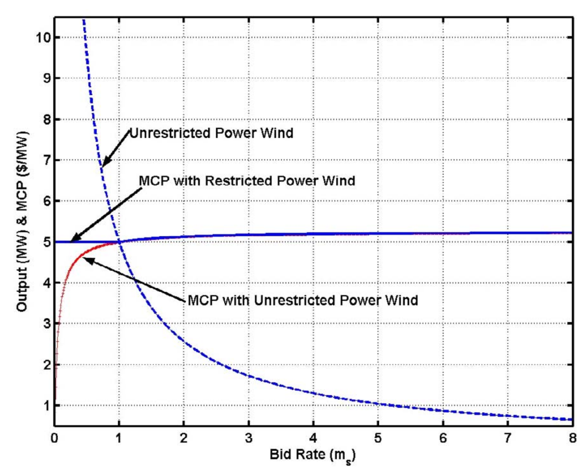


Fig. 3: Market clearing price with different bidding rate of wind power

The MCP with unrestricted wind power (having large wind power output) is the same as MCP at the restricted wind power (5MW in this case) at bidding rate of 1.0. It can be mathematically proved. For the maximum market clearing price $p$, the $m_s$ for wind would be infinite and for minimum MCP, the $m_s$ should be zero which can be obtained solving following equation.

$$\frac{\partial p}{\partial m_s} = \frac{\partial}{\partial m_s}\left( \frac{D}{\sum_{i=1}^{Ng} \frac{1}{m_{si}}} \right) = 0 \quad (12)$$

There are two options available with market operator to decide the market clearing price. In option-I, the MCP can be calculated with reduced load (demand minus wind power availability during that period). It is $5/MW in this example. Since the wind power has reduced the MCP, a premium can be given to the wind power over and above MCP. To benefit wind power, and of course other generators, in option-II, MCP can be calculated without considering the wind power for total demand and the output of the bidding generators are adjusted using (11). The revenue collected from the market is $526.32 (=MCP*Demand) which can be seen from Table II. Bidding rate ($m_s$) from 1 to 10 will be reduced the wind power dispatch. In option II, even in the case of non-availability of wind power due to absence of wind, the market operator is not going to have deficit of money. And also wind power, if available, gets more revenue compared to bidding into the market without any risk.

TABLE II: OUTPUT POWER AND PAYMENTS (CASE-A)

| | Output (MW) | | Payments ($) | | Payment in |
|---|---|---|---|---|---|
| | $m_s$>10 | $m_s$ <1 | $m_s$>10 | $m_s$<1 | Option II |
| Bidder-1 | 52.63 | 50.0 | 277.01 | 250.00 | 263.16 |
| Bidder-2 | 21.05 | 20.0 | 110.80 | 100.00 | 105.26 |
| Bidder-3 | 26.32 | 25.0 | 138.51 | 125.00 | 138.58 |
| Wind Power | 0.00 | 5.0 | 0.00 | 25.00 | 26.32 |
| Total | 100.0 | 100.0 | 526.32 | 500.00 | 526.32 |

**Case-B:** In most of the electricity market, instead taking the constant forecasted demand, the demand side participants are also allowed to bid into the market with their demand elasticity. Two different demand bidders are considered in this work for simplicity. Their bid data are given in Table III. The Total demand curve of the two demand bids along with a cumulative supply curve of three bidders as given in Table I are shown in Fig. 4.

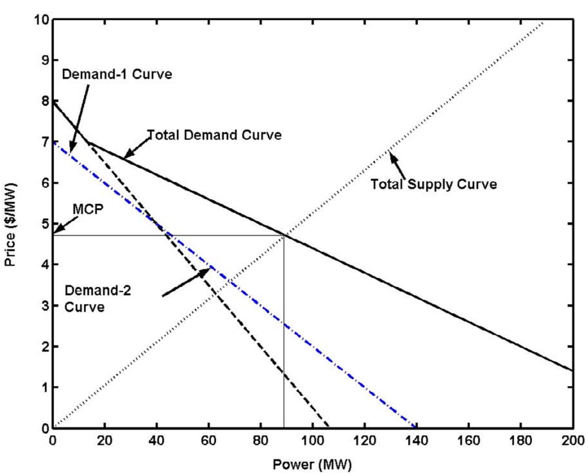


Fig. 4: Linear supply and demand bid curves

The MCP, which is the intersection of cumulative supply and total demand curves as shown in Fig. 4, is found to be $4.713 /MWh. The demand requirements of both bidders would be 45.73 MW and 43.82 MW, respectively. If wind generator bids at zero (Option-I), the MCP will be the intersection of a new supply curve parallel below (5 MW in x-axis) to the cumulative supply curve of three supply bidders. It is similar to the intersection of a parallel line below the demand curve to the total supply curve without the wind power. The MCP is found to be $4.618/MWh. Mathematically, it can also be obtained as

$$p^* = \frac{\sum_{i=1}^{Nd} \frac{p_{i0}}{m_{di}} - 5}{\left( \sum_{i=1}^{Ng} \frac{1}{m_{si}} + \sum_{i=1}^{Nd} \frac{1}{m_{di}} \right)} \quad (13)$$

TABLE III: LINEAR DEMAND BID DATA

| Data | $m_{di}$ ($/MW/MW) | $p_{i0}$ ($/MW) |
|---|---|---|
| Demand-1 | 0.050 | 7.0 |
| Demand-2 | 0.075 | 8.0 |

Due to the elasticity of demand bidders, there is reduction in the spot price which causes the increased in the consumption of demand bidders and it is 47.64 MW and 45.09 MW, respectively. The effect on the variation of bidding of wind generator on wind output and the MCP is shown in Fig. 5. It can be noted that bidding rate less than 1.0 will have no impact on the MCP with restricted wind power of 5 MW (considered maximum output). However, with higher bidding rate, the MCP increases but the power dispatched from the wind power is less.

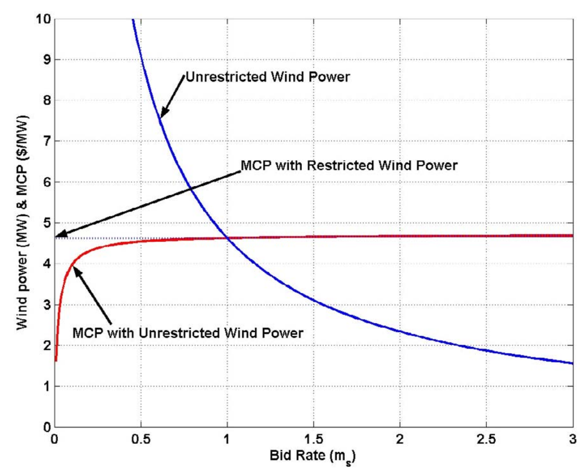


Fig. 5: MCP with restricted and unrestricted wind power bids

Table IV shows the payments made/received from the bidders at different MCP. Negative sign shows the payment received from the demand bidders. It can be seen from Table IV that the money given to the wind generation is higher with MCP calculated at zero wind power. If market provision has the imbalance penalties for down loading, the generators can be paid at actual MCP (i.e. $4.618/MWh) with zero bid of wind power whereas wind power can be paid at maximum MCP. The payment to be collected from the demand bidder will be at the maximum MCP rate (column 6). In the event of non-availability of wind power, the suppliers will be asked to increase their output and the wind power money will be given to them.

TABLE IV: OUTPUT POWER AND PAYMENTS (CASE-B)

| | Without wind power | | With wind power | | |
|---|---|---|---|---|---|
| | Power (MW) | Payment (at 4.713) | Power (MW) | Payment (at 4.618) | Payment (at 4.713) |
| Bidder-1 | 47.13 | 222.14 | 46.18 | 213.26 | 217.64 |
| Bidder-2 | 18.85 | 88.86 | 18.47 | 85.32 | 87.05 |
| Bidder-3 | 23.57 | 111.10 | 23.08 | 106.63 | 108.81 |
| Wind | 0.00 | 0.00 | 5.00 | 23.09 | 23.56 |
| Demand-1 | 45.73 | -215.56 | 47.64 | -220.00 | -224.53 |
| Demand-2 | 43.82 | -206.54 | 45.09 | -208.20 | -212.53 |

## VII. CONCLUSION

A suitable market mechanism is required to accommodate the non-conventional energy sources due to several technical and non-technical reasons. Having intermittent nature of availability, a proper trading option must be used for these sources to recover their costs in competitive power market. This paper presents the various market strategies in competitive power market having wind generators.

A proper use of these sources can also avoid the abuse of competitive power market by which the efficiency of the market can be increased. Wind power can play a vital role in mitigating the market power, ancillary services but their costs must be recovered for successful promotion of wind power energy. The trading with wind power must be transparent for free and fair trade of electricity. This paper could be guide line for the policy makers and market operators to promote the wind power with system reliability and security.

## VIII. REFERENCES


[1] A. Fabbri, T. G. S. Roman, J. R. Abbad and V. H. M. Quezada, 'Assessment of the cost associated with wind generation prediction errors in a liberalized electricity market', *IEEE Trans on Power Systems*, Vol. 20, No. 3, pp. 1440-1446, August 2005.

[2] Wind Energy Manual, Iowa Energy Center, USA, [on-line], http://www.energy.iastate.edu/renewable/wind/wem/wem-02_toc.html

[3] R. Spencer, 'Untapped Potential of Wind Power', IEEE Power Engineering Review, pp. 10-11, September 2002.

[4] G.N. Bathurst, J. Weatherill and G. Strbac, 'Trading Wind Generation in Short Term Energy Market', IEEE Trans. On Power Systems, Vol. 17, No. 3, pp. 782-789, August 2002.

[5] J. Kabouris and C.D. Vournas, 'Application of Interruptible Contracts to Increase Wind Power Penetration in Congested Area', IEEE Trans on Power Systems, Vol. 19, No. 3, pp- 1642-1649, August 2004.

[6] C. Chompoo-inwai, W.J. Lee, P Fuangfoo, M. Williams and J.R. Liao, 'System Impact Study for the interconnection of Wind Generation and Utility System', IEEE Trans on Industry Application, Vol. 41, No. 1, pp. 163-168, January/February 2005.

[7] R. Piwko, D Osborn, R Gramlich, G Jordan, D Hawkins and K Porter, 'Wind energy delivery issues', IEEE Power & Energy Magazine, Vol.3, No.6, pp.47-56, November/December 2005.

[8] E. A. DeMeo, W Grant, MR. Milligan and M.J. Schuerger, 'Wind plant intergration: Cost, Status & Issues', IEEE Power & Energy Magazine, Vol.3, No.6, pp.38-46, November/December 2005.


## IX. BIOGRAPHIES

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