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Wind Power Trading with Variable Demand in Deregulated Electricity Market

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Abstract— In the emerging electricity markets, a suitable trading mechanism is required to accommodate the wind power generations to recover their costs. This paper presents various market strategies in a competitive power market having wind generators. Till now, wind power trading studies has been done on the basis of fixed demand. In real life scenario fixed demand doesn't exist. In this paper a practical approach is proposed by taking variable demand. Market clearing price has been analyzed in both supply side and demand side bidding scenarios for bid trading models. Wind power can also play a vital role in ancillary services and mitigating the market power, but their costs must be recovered for successful promotion. Trading with wind power must be transparent for free and fair trade of electricity. An MCP index has been modeled to give indication of the MCP variations. This paper can be a guideline for the policy makers and Market Operators to promote the wind power with system transparency. Calculations have been done with the help of MATRIX LABORATORY.

KeyTerms—Competitive power market, Bidding, Market clearing price (MCP), MCP Index

I. Introduction

Deregulation in the power industry has changed the monopoly into oligopoly in the generation and trading sectors. Generating companies may enter into contract to supply the generated power to power dealers/distributors or bulk consumer or sell the power in a pool in which the power traders and customer also participate. In a power exchange, bidders can place their buy and sell bids [1]. Electricity sector restructuring, also commonly known as deregulation is expected to draw private investment, increase efficiency, promote technical growth and improve customer satisfaction as different parties compete with each other to win their market share and remain in business [2]. Short-term generation of wind farms cannot be predicted with a high degree of accuracy [3]. In a market situation, these forecasting errors lead to commercial risk through imbalance costs. In the presence of imbalance prices and uncertain generation, a method is required to determine the optimum level of contract energy to be sold on the advance markets [4]. It is obviously important for merchant wind generation to apply scheduling and trading strategies that reflect the uncertainty in wind power & prices and the corresponding trade-off between risk & return [5].Wind power penetration in many cases faces significant barriers due to limited transmission capability [6]. Wind generation is one of the most mature and cost-effective resources among different renewable energy technologies. Due to the utility deregulation, more generators from independent power producers (IPPs) have been proposed in recent years [7]. 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 [2]. However, it can support the secure operation of the system as an ancillary service. Improving economic, environmental benefits, supportive state policies, and the rising costs of competing fuels are all contributing factors towards greater market interest in wind energy [8].A key question is how the variations in wind plant outputs affect the operation of the power system on a daily basis with variable demand and what the associated costs are [9].

Electricity has several unique features that are different from other commodities. It cannot be stored and a constant monitoring system is required to stabilize a balance between supply and demand; both are often expressed by a nonlinear relationship [10]. Due to the variability and limited predictability of wind power, wind producers participating in most electricity markets are subject to significant deviation penalties during market settlements, and system operators need to schedule additional reserve to balance the unpredicted wind power variations [11]. Wind power penetration levels are increasing rapidly around the world. There has been a rapid expansion of wind energy in recent years and the global installed capacity of wind power approaching 200 GW [12]. The integration of wind is qualitatively different from other types of generations as its output depends on weather, at what time and how firm the wind blows. As compared to conventional generators, wind generator's output is relatively wild, uncontrollable, unpredictable, impulsive, volatile and variable [13]. Most of the works for wind power trading has been done on the basis of fixed demand. In real life scenario fixed demand doesn't exist. In this paper a practical approach is proposed by taking variable demand. Market clearing price has been analyzed in both supply side and demand side bidding scenarios for bid trading models.

II. Competitive Power Trading Market

Restructuring of the power industry aim at abolishing the monopoly in the generation and trading sectors, thereby, introducing competition at various levels wherever it is possible [14]. Restructured electricity markets may provide opportunities for producers to exercise market power, maintaining prices in excess of competitive levels [15]. In electric industry restructuring process, the main issue is to run the system in free and fair manner ensuring the desired quality of power to the consumers at most economical price through safe, secure and reliable operation of the power system. With the enactment of Electricity Act 2003, along with other recent initiatives, Government of India has outlined the counters of a suitable enabling framework for the overall development of wholesale electricity market by introducing competition at various sectors [16]. Two types of markets exist based on the bidding mechanism. If bidding is done only by the suppliers, it is termed as a single-sided bidding, whereas, if both suppliers and customers are allowed to bid into the market, it is known as a double-sided bidding mechanism. A typical competitive power trading market with its stake holders is shown in fig. 1.

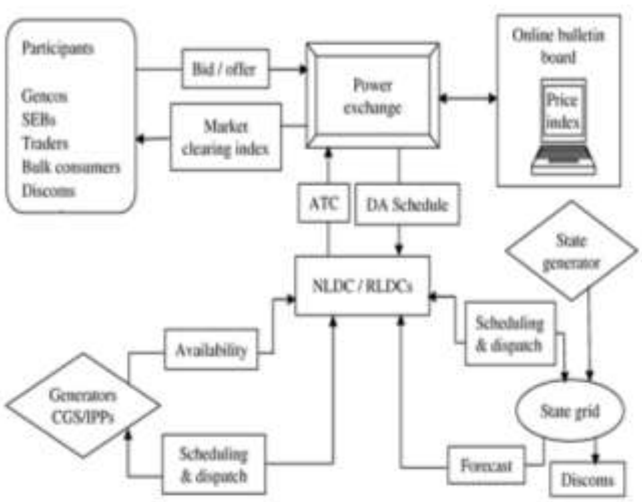

Fig. 1. Competitive power trading market

The MCP is the lowest price that would provide enough electricity from accepted sale bids to satisfy all the accepted purchase bids [2]. The intersection of Demand Supply Curve gives the Market Clearing Price (MCP).

III. Methodology

Some equations of interest are as below [1]:

If there are N_g suppliers who bid into the market, supply curve for fixed demand single side bidding is given by

$$q(p) = p\sum_{i=1}^{N_g}\frac{1}{m_{si}} \qquad (1)$$

Where

N_g is number of suppliers

m_{si} is the slope of supply curve

For the fixed demand D, the market clearing price (p*) will be obtained by solving the following equation [1].

$$D \;= p * \sum_{i=1}^{N_g}\frac{1}{m_{si}} \qquad (2)$$

If there are N_d customers who bid into the market, The MCP (p*) can be obtained by solving the equation

$$\text{Market Clearing Price } (p_*) = \frac{\sum_{i=1}^{N_d}\frac{P_{io}}{m_{di}}}{\sum_{i=1}^{N_g}\frac{1}{m_{si}}+\sum_{i=1}^{N_d}\frac{1}{m_{di}}} \qquad (3)$$

Where N_d is the number of customers and m_{di} is the slope of demand curve

IV. Power Trading with Variable Demand

In India, electricity is a state subject resulting in loose regional power pools wherein each state constituent is responsible for meeting the load within its control area, by using its own generated power and/or through power purchased from the central/joint sector utilities /other constituent utilities/independent power producers (IPPs). Coordinated multilateral model has been adopted for dispatching the available resources. The State Load Dispatch Centers have autonomy of scheduling their own generation while taking into account their daily entitlements (worked out from the declared availability) from external sources. These entitlements from external sources could be through long term or short-term bilateral agreements. The regional grid operator collates all the information regarding the bilateral entitlements & a corresponding requisition furnished by the constituents and issues an exchange schedule (drawl/dispatch schedule). Sometimes moderations may be required in these schedules due to network constraints but once they are finalized these schedules are to be considered as a commitment from the supplier to inject an agreed quantum of energy into the pool at the specified time during the day & from the buyer to consume an agreed amount of energy from the pool during the day. Now in the case of power trading with variable demand, as in real life scenario the demand will be variable during the whole day. The MCP will be different for different demand during the day.

V. Analysis

Here four cases has been taken with different number of bidders

Case 1: Variable demand with 3 bidders (Table 1)

Case 2: Variable demand with 5 bidders (Table 2)

Case 3: Variable demand with 7 bidders (Table 3)

Case 4: Variable demand with 10 bidders (Table 4)

Table 1, 2, 3, 4 shows the m_{si} $i.e.$ slopes of the supply curve for 3 bidders, 5 bidders, 7 bidders and 10 bidders respectively.

Table 5 shows the cumulative supply slopes and MCPs for all the cases with variable demand i.e. 100MW, 150MW and 200MW for 3 bidders, 5 bidders, 7 bidders and 10 bidders respectively. S(max) denotes Maximum Supply in MW and S(min) denotes Minimum Supply in MW, m_{si} is in $/MW^2.

Table-1 m_{si} with 3 Bidders

	m_{si}	S (max)	S (min)
Bidder-1	21	100	10
Bidder-2	30	50	05
Bidder-3	26	50	07

Table-2 m_{si} with 5 Bidders

	m_{si}	S(max)	S(min)
Bidder-1	21	100	10
Bidder-2	30	50	05
Bidder-3	26	50	07
Bidder-4	27	50	07
Bidder-5	29	50	05

Table-3 m_{si} with 7 Bidders

	m_{si}	S(max)	S (min)
Bidder-1	0.25	50	07
Bidder-2	0.20	100	10
Bidder-3	0.15	100	10
Bidder-4	0.30	50	05
Bidder-5	0.26	50	07
Bidder-6	0.17	100	10
Bidder-7	0.16	100	10

Table-4 m_{si} with 10 Bidders

	m_{si}	S(max)	S(min)
Bidder-1	0.21	100	10
Bidder-2	0.25	50	05
Bidder-3	0.20	100	10
Bidder-4	0.15	100	10
Bidder-5	0.30	50	05
Bidder-6	0.26	50	07
Bidder-7	0.17	100	10
Bidder-8	0.16	100	10
Bidder-9	0.27	50	05
Bidder-10	0.29	50	05

Table- 5 m_{di} with 4 customers

	m_{di}	P_{io}($/MW)
Customer -1	0.050	7
Customer-2	0.075	8
Customer-3	0.080	9
Customer-4	0.060	6

Table- 6 Cumulative Supply Slope with Variable Demand for 3, 5, 7, 10 Bidders

		D= 100	D= 150	D= 200
	CSS	p^*(MCP)	p^*(MCP)	p^*(MCP)
CASE 1	11.9414	8.3742	12.5613	16.7485
CASE 2	19.0934	5.2374	7.8561	10.4748
CASE 3	34.9785	2.8589	4.3027	5.7178
CASE 4	46.8924	2.1325	3.1988	4.2651

VI. Market Clearing Price Index

Deregulation of the power industry introduces a new era in strategy and tactics with respect to reliability and transparency. In this paper we introduce a new term called Market Clearing Price Index or MCP Index. The MCP index is calculated with the help of MCPs for different number of bidders. In a competitive power market, it is important to expand or strengthen transmission system in order to deliver power from generators to loads, relieve the congestion of transmission system and provide a fair environment to all market participants. MCP index provides the tool to measure and compare different market participants. In this paper, fundamental rationale for setting up performance criteria is discussed and based on which an index scheme of evaluation is envisaged for use on evaluating performance of various major bidders in the deregulated electricity market. The proposed index scheme is helpful in identifying the basic criteria for evaluating the trading process.

$$\text{MCP Index } (Ip_{mc}) = \frac{p_{mci}}{p_{mcavg}} \qquad (4)$$

p_{mci} is the MCP for ith case. i=1,2,3…n

$$p_{mcavg} = \frac{i}{n}$$

$$p_{mcavg} = \frac{16.7485+10.4748+5.7178+4.2651}{4} = 9.30155$$

p_{mcavg} = 9.30155

$$\text{For 3 bidders} = \frac{16.7485}{9.30155} = 1.80061$$

$$\text{For 5 bidders} = \frac{10.4748}{9.30155} = 1.12613$$

$$\text{For 7 bidders} = \frac{5.7178}{9.30155} = 0.61471$$

$$\text{For 10 bidders} = \frac{4.2651}{9.30155} = 0.4585$$

Fig. 2 shows the supply side bidding curves for10 bidders. Fig. 3 shows the demand side bidding curves for 4 customers. Fig. 4 shows the curves for double side (i.e. supply side and demand side) bidding curves for 10 bidders and 4 customers. Fig. 5 shows the MCP in 24 hours with variable demand. Fig. 6 shows MCP Indexes with different number of bidders.

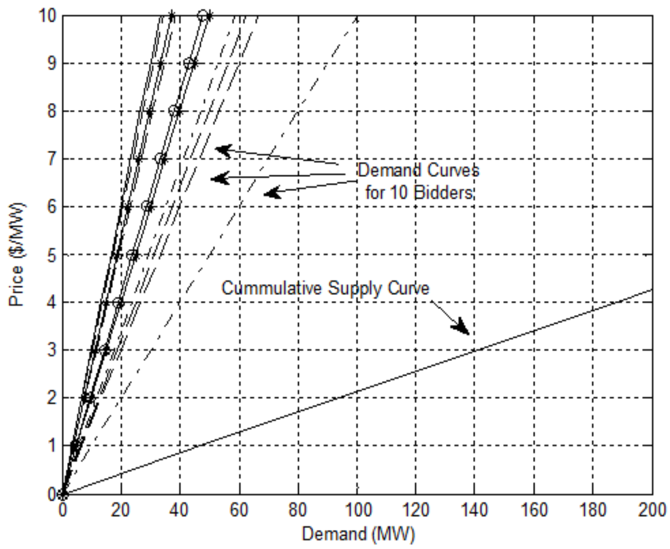

Fig. 2 Supply Curve

At 180 MW Demand, the MCP is 3.8386$/MW

At 140 MW Demand, the MCP is 2.9856 $/MW

At 110 MW Demand, the MCP is 2.3458$/MW

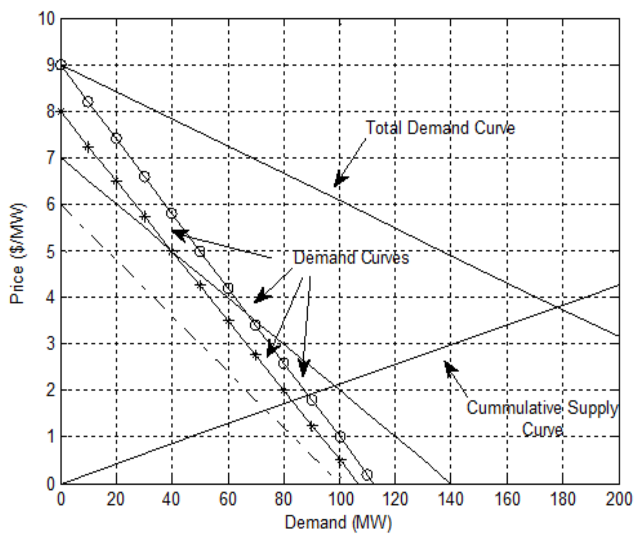

Fig. 3 Demand Curve

In this case there are four customers with their different demand slops; the Total Demand Curve is the Cumulative of all the demand curves. The intersection of cumulative curves gives the MCP.

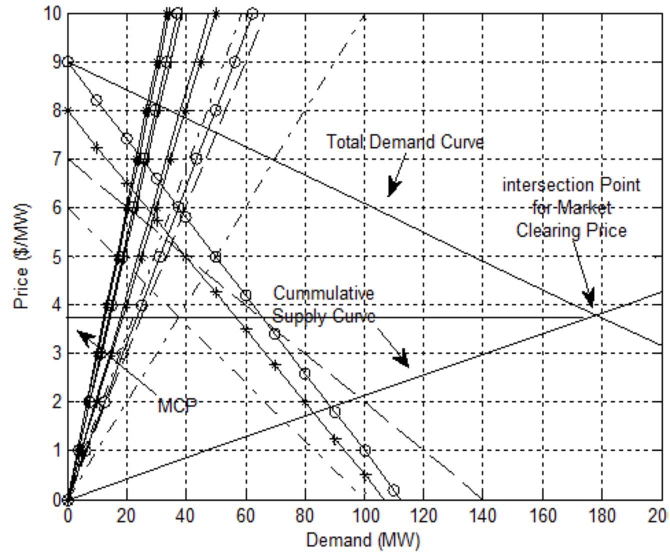

Fig. 4 Supply and Demand Curve

Table 7: MCP with variable demand during the day

Time Interval (hrs)	Demand (MW)	MCP with 3 bidders($/MWh)	MCP with 5 bidders($/MWh)	MCP with 7 bidders($/MWh)	MCP with 10 bidders($/MWh)
1	101	8.458	5.2898	2.8875	2.1539
2	100.4	8.4077	5.2584	2.8703	2.1411
3	100.2	8.391	5.2479	2.8646	2.1368
4	103	8.6255	5.3945	2.9447	2.1965
5	107	8.9604	5.604	3.059	2.2818
6	116	9.7141	6.0754	3.3163	2.4737
7	125	10.4678	6.5468	3.5736	2.6657
8	134	11.2215	7.0181	3.8309	2.8576
9	143	11.9752	7.4895	4.0882	3.0495
10	148	12.3939	7.7514	4.2312	3.1562
11	155	12.9801	8.118	4.4313	3.3054
12	156	13.0638	8.1704	4.4599	3.3268
13	160	13.3988	8.3799	4.5742	3.4121
14	170	14.2362	8.9036	4.8601	3.6253
15	185	15.4923	9.6892	5.289	3.9452
16	**200**	**16.7485**	**10.4748**	**5.7178**	**4.2651**
17	190	15.911	9.9511	5.4319	4.0518
18	186	15.5761	9.7416	5.3176	3.9665
19	160	13.3988	8.3799	4.5742	3.4121
20	134	11.2215	7.0181	3.8309	2.8576
21	125	10.4678	6.5468	3.5736	2.6657
22	107	8.9604	5.604	3.059	2.2818
23	102	8.5417	5.3422	2.9161	2.1752
24	101	8.458	5.2898	2.8875	2.1539

Peak Demand is 200 MW at 16th Hour

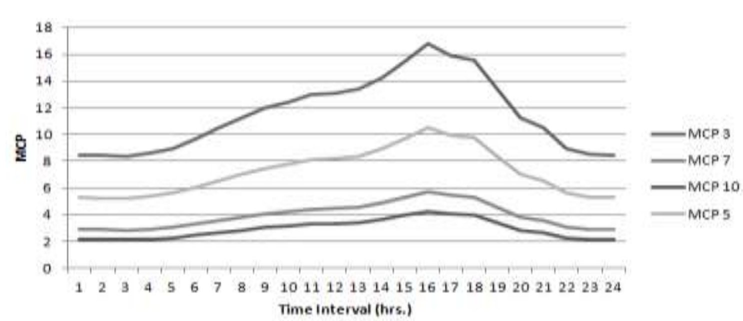

Fig. 5: MCP in 24 hours with Variable Demand

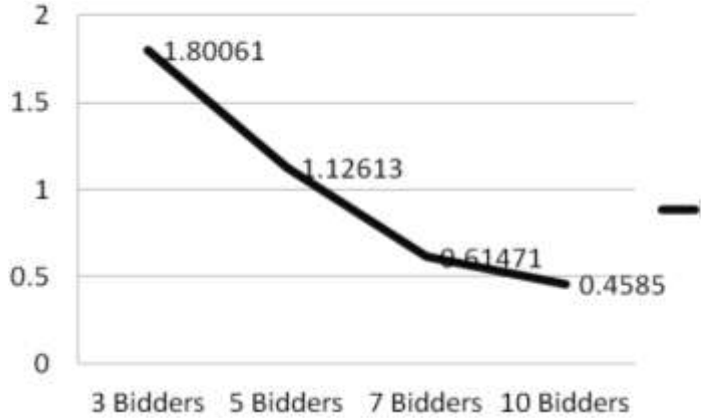

Fig. 6: MCP INDEXES with different number of Bidders

Result and Discussion

With the variable demand during the day MCP varies and It can be analyzed from the above results that the MCP is decreasing as the number of bidders are increasing with the variable demand and vice-versa. Table 1, 2, 3 and 4 shows the variation of supply slopes of 3 bidders, 5 bidders, 7 bidders and 10 bidders respectively. Table 5 shows the variation of slope of 4 customers. Table 6 shows the cumulative supply slope with variable demand (100MW, 150MW, 200MW) of 3 bidders, 5 bidders, 7 bidders and 10 bidders. In fig. 2, in the single side bidding, the supply curves shows, as the demand increases, the MCP also increases. Fig. 3 shows the demand curves with 4 customers & the MCP is calculated with the intersection of total Demand Curve and cumulative supply curve. Fig. 5 shows the double side bidding i.e. supply side bidding and demand side bidding. The line from intersection point terminates at Y-axis give the double side bidding MCP. Table 7 shows the MCPs of different no. of bidders with variable demand during 24 hrs. of a day. From the Fig. we observe that as the number of bidders increases the MCP decreases and with the increase in demand MCP decreases. Fig. 5 shows MCP in 24 hours with Variable Demand. The peaks of the curves are at the time of highest demand. MCP increases uniformly as the number of bidders increase. Fig. 6 shows the indexes with different number of bidders. It is analyzed that MCP index increases with the decrease in the number of bidders and vice versa.

Conclusion

In this paper, MCP for different bidders is calculated .MCP INDEX is introduced, which is helpful for the market transparency. Simulation of the methodology is done with the help of MATLAB. The index evaluation scheme is feasible and practical for use in evaluating the performance of different market participants and the market mechanism in the open competitive environment. This paper may be helpful for electricity market transparency.

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