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Market Clearing Price Index with variable demand in Deregulated Electricity Market

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Abstract: In emerging electricity markets, a suitable trading mechanism is required to accommodate the wind power generators. This paper deals with a systematic way for modeling power trading. The paper first introduces a new term the "Market Clearing Price Index", the MCP index.MCP index Calculations have been based on MATRIX LABORATORY.

Keywords: Competitive power market, Bidding, Market clearing price (MCP), MCP Index.

INTRODUCTION

Deregulation in the power industry has changed the monopoly into oligopoly in the generation and trading sectors. In a power exchange, bidders can place their buy and sell bids. In the emerging 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 [1]. In the open competitive power market, there are different stake holders, including generation and transmission companies as well as consumers, participating as independent entities for maximizing their individual benefits. Traditionally, the efficiency measures for the monopolistic electricity industry have been used by the utilities, regulators and consumers to identify areas where there is a potential for performance improvement [2]. Short-term generation of wind farms cannot be predicted with a high degree of accuracy [3]. 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]. 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 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].

I. 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 [xiv]. Restructured electricity markets may provide opportunities for producers to exercise market power, maintaining prices in excess of competitive levels [xv]. 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

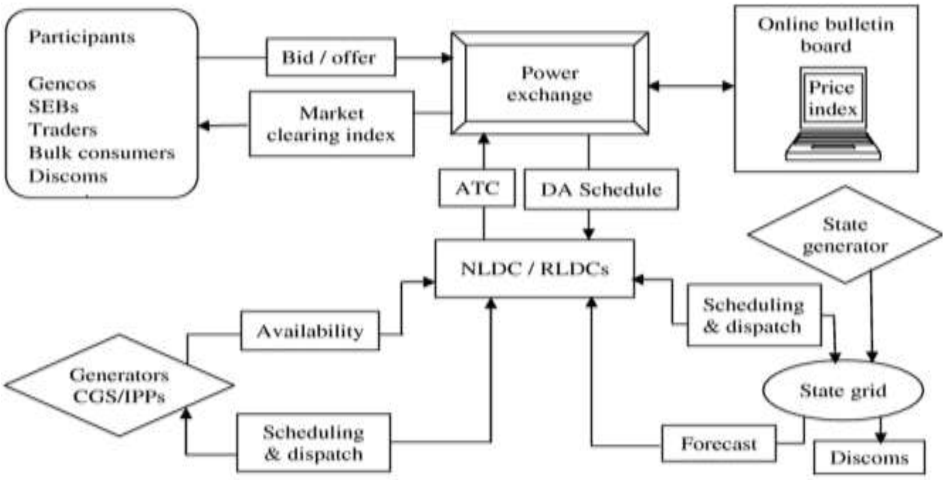

Fig. 1. Competitive power trading market

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. 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).

II. 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].

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

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.

III. 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 demands during the day on half an hour basis.

IV. Analysis

Here four cases has been taken with different number of bidders

Case 1: Variable demand with 2 bidders (Table 1)
Case 2: Variable demand with 4 bidders (Table 2)
Case 3: Variable demand with 6 bidders (Table 3)
Case 4: Variable demand with 9 bidders (Table 4)

Table 1, 2, 3, 4 shows the m_{si} $i.e.$ slopes of the supply curve for 2 bidders, 4 bidders, 6 bidders and 9 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: With 2 Bidders

	m_{si}	Supply (max) in MW	Supply (min) in MW
Bidder-1	0.21	100	10
Bidder-2	0.27	50	05

Table – 2: With 4 Bidders

	m_{si}	Supply (max) in MW	Supply (min) in MW
Bidder-1	0.16	100	10
Bidder-2	0.17	100	10
Bidder-3	0.25	50	05
Bidder-4	0.28	50	05

Table – 3: With 6 Bidders

	m_{si}	S (max)	S(min)
Bidder-1	0.18	50	07
Bidder-2	0.20	100	10
Bidder-3	0.21	100	10
Bidder-4	0.24	50	05
Bidder-5	0.27	50	07
Bidder-6	0.29	100	10

Table – 4: With 9 Bidders

	$m_{si}(\$/MW^2)$	Supply (max) in MW	Supply (min) in MW
Bidder-1	0.16	100	10
Bidder-2	0.18	100	10
Bidder-3	0.20	100	10
Bidder-4	0.22	75	05
Bidder-5	0.24	50	05
Bidder-6	0.26	50	07
Bidder-7	0.27	50	05
Bidder-8	0.28	50	05
Bidder-9	0.30	50	05

Table – 5: m_{di} with 5 customers

	m_{di}	p_{io}($/MW)
Customer 1	0.055	6
Customer 2	0.070	7
Customer 3	0.085	8
Customer 4	0.090	9
Customer 5	0.060	5

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V. 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.

MCP Index (Ip_{mc}) = $\frac{p_{mci}}{p_{mcavg}}$ (4) p_{mci} is the MCP for ith case. i=1,2,3…n

$p_{mcavg} = \frac{i}{n}$ $p_{mcavg} = \frac{23.8613+10.2518+6.8215+5.0535}{4} = 11.4970$ $p_{mcavg} = 11.4970$

For 2 bidders= $\frac{23.8613}{11.4970} = 2.0754$ For 4 bidders= $\frac{10.2518}{11.4970} = 0.8917$

For 6 bidders = $\frac{6.8215}{11.4970} = 0.5933$ For 9 bidders = $\frac{5.0535}{11.4970} = 0.4395$

Fig. 2 shows the supply side bidding curves for 2 bidders. Fig. 3 shows the supply side bidding curves for 4 bidders. Fig. 4 shows the supply side bidding curves for 6 bidders Fig. 5 shows the supply side bidding curves for 9 bidders. Fig. 6 shows the demand side bidding curves for 5 customers. Fig. 7 shows the curves for double side (i.e. supply side and demand side) bidding curves for 9 bidders and 5 customers. Fig. 8 shows the MCP in 48 interval of 30 minutes each in a day with variable demand. Fig. 9 shows MCP Indexes with different number of bidders.

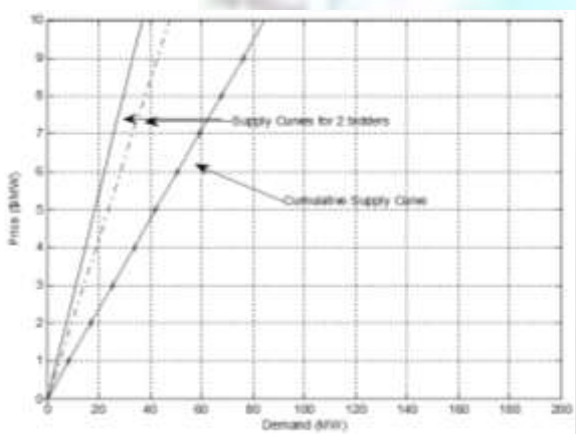

Fig. 2 The supply side bidding curves for 2 bidders

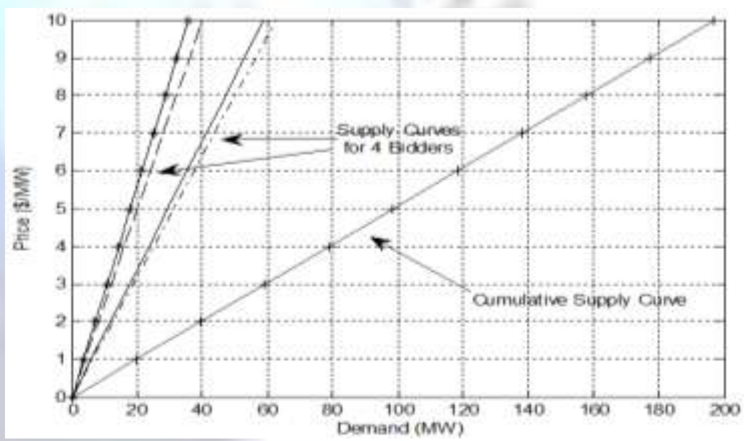

Fig. 3 The supply side bidding curves for 4 bidders

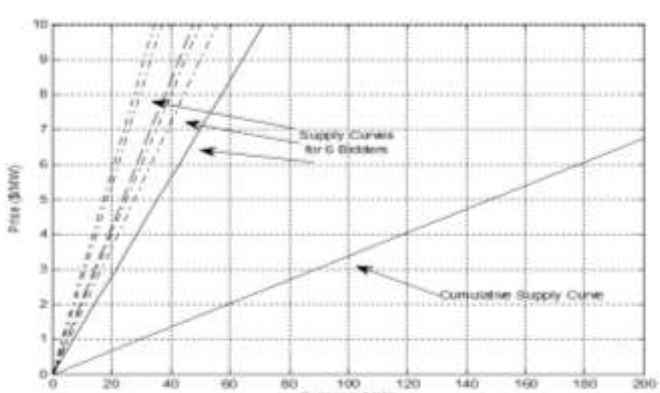

Fig. 4 The supply side bidding curves for 6 bidders

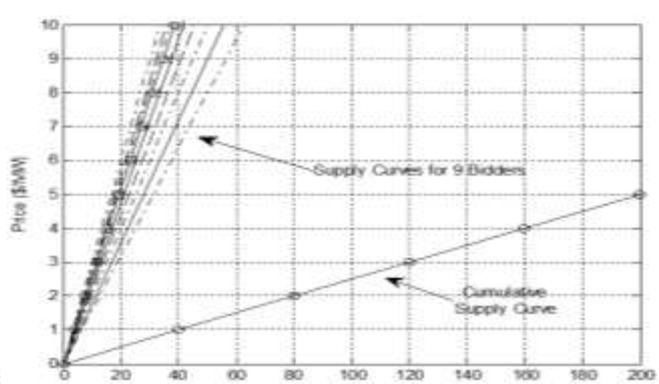

Fig. 5 The supply side bidding curves for 9 bidders

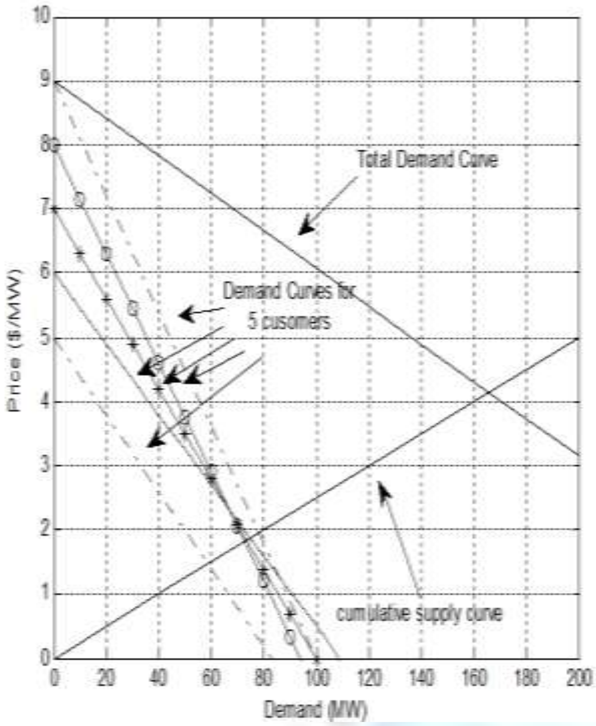

Fig. 6 Demand Curve

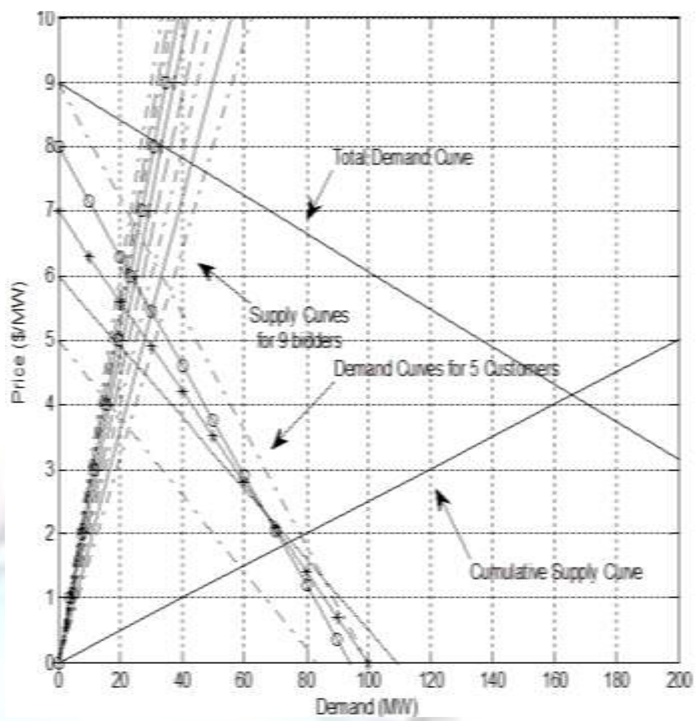

Fig. 7 Supply and Demand Curve

At 80 MW Demand, the MCP is 2.0014$/MW, At 105 MW Demand, the MCP is 2.6268 $/MW
At 120 MW Demand, the MCP is 3.0021$/MW

In this case there are five 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.
Peak Demand is 202 MW at 15.30-16.00 Hours

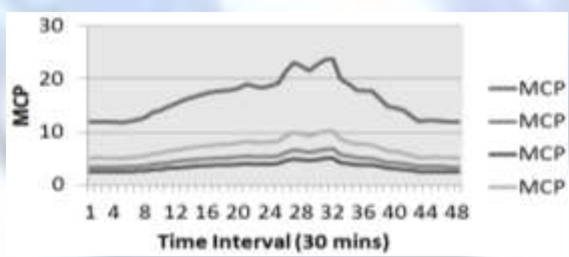

Fig. 8: MCP in 48 slots of 30 minutes with Var. Demand

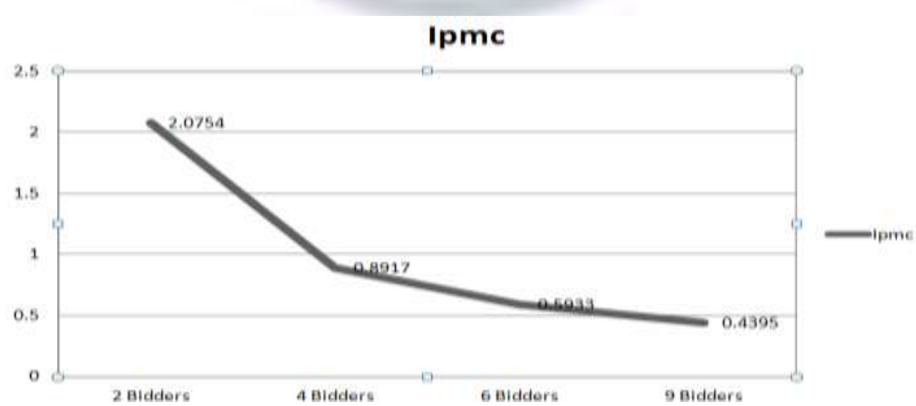

Fig. 9: MCP INDEXES with different no. of Bidders

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Table – 6: MCP with variable demand during 30 minutes slot for a day

Time Interval (hrs)	Demand (MW)	MCP with 2 bidders($/MWh)	MCP with 4 bidders($/MWh)	MCP with 6 bidders($/MWh)	MCP with 9 bidders($/MWh)
00.00-00.30	100.6	11.8834	5.1056	3.3972	2.5167
00.30-01.00	101	11.9306	5.1259	3.4107	2.5268
01.00-01.30	100.4	11.8598	5.0955	3.3905	2.5117
01.30-02.00	100.3	11.8479	5.0904	3.3871	2.5092
02.00-02.30	100.2	11.8361	5.0853	3.3837	2.5067
02.30-03.00	102	12.0488	5.1767	3.4445	2.5518
03.00-03.30	104	12.2850	5.2782	3.5121	2.6018
03.30-04.00	108	12.7575	5.4812	3.6471	2.7019
04.00-04.30	116	13.7025	5.8872	3.9173	2.9020
04.30-05.00	120	14.1750	6.0902	4.0524	3.0021
05.00-05.30	126	14.8838	6.3947	4.2550	3.1522
05.30-06.00	131	15.4744	6.6485	4.4238	3.2773
06.00-06.30	136	16.0650	6.9022	4.5927	3.4024
06.30-07.00	140	16.5375	7.1052	4.7278	3.5024
07.00-07.30	144	16.8919	7.2575	4.8291	3.5775
07.30-08.00	147	17.3644	7.4605	4.9642	3.6775
08.00-08.30	150	17.7188	7.6128	5.0655	3.7526
08.30-09.00	150.7	17.8014	7.6483	5.0891	3.7701
09.00-09.30	151.4	17.8841	7.6838	5.1127	3.7876
09.30-10.00	156	18.4275	7.9173	5.2681	3.9027
10.00-10.30	161.6	19.0890	8.2015	5.4572	4.0428
10.30-11.00	158	18.6638	8.0188	5.3356	3.9527
11.00-11.30	156	18.4275	7.9173	5.2681	3.9027
11.30-12.00	159	18.7819	8.0695	5.3694	3.9778
12.00-12.30	162.4	19.1835	8.2421	5.4842	4.0628
12.30-13.00	182	21.4988	9.2368	6.1461	4.5532
13.00-13.30	196	23.1525	9.9473	6.6189	4.9034
13.30-14.00	190	22.4438	9.6428	6.4163	4.7533
14.00-14.30	183	21.6169	9.2876	6.1799	4.5782
14.30-15.00	192	22.6800	9.7443	6.4838	4.8033
15.00-15.30	200	23.6250	10.1503	6.7540	5.0035
15.30-16.00	202	23.8613	10.2518	6.8215	5.0535
16.00-16.30	170	20.0813	8.6278	5.7409	4.2529
16.30-17.00	161	19.0181	8.1710	5.4369	4.0278
17.00-17.30	152	17.9550	7.7143	5.1330	3.8026
17.30-18.00	151	17.8369	7.6635	5.0992	3.7776
18.00-18.30	150.2	17.7424	7.6229	5.0722	3.7576
18.30-19.00	138	16.3013	7.0037	4.6602	3.4524
19.00-19.30	126	14.8838	6.3947	4.2550	3.1522
19.30-20.00	123	14.5294	6.2425	4.1535	3.0771
20.00-20.30	120	14.1750	6.0902	4.0524	3.0021
20.30-21.00	110	12.9938	5.5827	3.7147	2.7519
21.00-21.30	102	12.0488	5.1767	3.4445	2.5518
21.30-21.00	103	12.1669	5.2274	3.4783	2.5768
22.00-22.30	103	12.1669	5.2974	3.4783	2.5768
22.30-22.00	102	12.0488	5.1767	3.4445	2.5518
23.00-23.30	101	11.9306	5.1259	3.4107	2.5268
23.30-00.00	100.6	11.8834	5.1056	3.3972	2.5167

VI. 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 2 bidders, 4 bidders, 6 bidders and 9 bidders respectively. Table 5 shows the variation of slope of 5 customers. In fig. 5, in the single side bidding, the supply curves shows, as the demand increases, the MCP also increases. Fig. 6 shows the demand curves with 5 customers & the MCP is calculated with the intersection of total Demand Curve and cumulative supply curve. Fig. 7 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 6 shows the MCPs of different no. of bidders with variable demand in 48 intervals (each of 30 minutes)during 24 hours of a day. From the Fig.8 we observe that as the number of bidders increases the MCP decreases and with the increase in demand MCP decreases. Fig. 8 shows MCP in 24 hours with Variable Demand. Peaks of the curves are at the time of highest demand. MCP increases uniformly as the number of bidders increase. Fig.9 shows the indexes with different number of bidders. MCP index increases with the decrease in the number of bidders & vice versa.

VII. Conclusion

In this paper, MCP for different bidders is calculated .MCP INDEX is introduced, which is helpful for the market transparency. The MCP 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. 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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Biographical notes

Dr. Rohit Verma has teaching, research and power industry experience spread over 20 years. He is a Associate Professor in the Centre for Advanced Management and Power Studies at National Power Training Institute, Faridabad and his research focuses on optimization of resources in energy sector. He started his career as an Asst. Engineer (O&M) in a coal based thermal power plants. He is a PhD from JMI University, Delhi. He received his B.Tech. in Mechanical Engineering and an M. Tech. in Energy and environment Management from IIT Delhi. He has been teaching the courses of Global Power Business, Power Station Management, Power Environment interface, Energy Resources & Power plant Systems and Renewable Energy. He has also authored books on Global Power Business, Renewable Energy and Operations Research. He has published 21 research papers in international/national journals and proceedings of international/national conferences.