Abuse of transmission congestion existing naturally or created by bidding strategies in order to exert market power

Abouzar Estebsari, Seyyed Mohammad Sadeghzadeh, Mehrdad Rostami
Faculty of Engineering,
Shahed University,
Khalig-e-Fars free way,
1417953836 Tehran, Iran,
P.O. Box: 18151/159,
Tel: (+98 21)55277560, Fax: (+98-21)55277561,Tehran, Iran

***Abstract*- Market power refers to conditions where the providers of a service can consistently charge prices above those that would be established by a competitive market. Market power assessment within electric power markets requires the consideration of the ever-changing network conditions that result from congestion. This paper explores the effect of changes in network congestion conditions on competitive market. Bidding strategies, such as withholding capacity and bidding at higher price, influence the network and cause transmission congestion. These strategic biddings are analyzed and the impacts of the congestion on the location marginal price (LMP) are demonstrated in detail. Congestion will cause relative scarcity of generating capacities in the congested areas, so generation companies in these areas have location market power. A 9-bus system is used to evaluate the impacts of congestion caused either by low transmission capacity or suppliers' strategic biddings. Focuses are on a transmission network with six sellers in which network constraints give rise to market power opportunities. Finally we compare two bidding strategies which exert market power by abuse of transmission limits and show enhance of location market power in congested area.**

Keywords: Transmission congestion, market power, nodal marginal price, bidding strategy, electricity markets

I. INTRODUCTION

A certain electricity market has one fixed network, a certain set of geographical locations, called nodes or buses, where energy may be injected or withdrawn. The buses are interconnected in a certain way, with transmission lines that each has a certain fixed thermal limit. The thermal limit is the capacity limit to which extent power may flow over the line, without damaging it or burning it off[1]. Furthermore, expansion of the transmission network might be of interest in some cases but it is very expensive and not always of interest to the bigger market participants [2].

Transmission can play a significant role in influencing the incentives of firms to exercise market power with their generation resources, as is demonstrated in a more general model by Joskow and Tirole (1998 and 1999).

Congestions in the transmission network may split a market into regions unable to compete properly with each other. This may cause lack of cheap energy in some areas and surplus in others. It segregates electricity market and limits competition mechanism. Segregation of markets increases location market power and weakens market efficiency in power systems [3].

Since generators' market power has direct impact on normal operation of electricity market, many literatures have discussed the market power in electricity market [4]-[10]. In economics, market power is defined as the ability to alter profitably price away from competitive levels [11]. Market power is a symptom of an uncompetitive industry and exercising market power can raise price and lower market efficiency [12].

If transmission constraints makes it impossible to bring in more power from other regions, buyers who are willing to pay prices that exceed the highest competitive will offer to do so. This leads to a price rise that will keep on going until the supply meets the demand [13].

In this paper the definitions of market power are presented from the views of economics and regulation. Bidding strategies, such as withholding capacity and bidding at high price, are analyzed and the impacts of network congestion on location market power are considered by simulating on a 9-bus system.

In the next part the OPF AC model will be explained briefly, then discuss about simulation in our case study. Congestion will cause relative scarcity of generating capacities in congested areas, so the generation companies in these areas have location market power. We segregate our system by putting transmission limits and investigate the impacts of congestion on generators' profits.

II. MARKET POWER

There are two main reasons why the potential of market power is brought to the electricity market. First there is market dominance and then there are transmission constraints [14]. Market power due to market dominance is a scenario that applies for every imperfect market and not only for the electricity market. On the electricity market, a supplier that is large enough to affect price can exploit market power by either economical withholding or physical withholding. When dealing with economical withholding a seller keeps bidding above the marginal cost of production and thereby driving up the price. Physical withholding simply means that a seller withholds some of its available capacity.

Market power due to transmission constraints makes it necessary to get a full understanding of the topology of the transmission system before starting any plan of detecting the potential for market power [15].

A load pocket is an area where transmission constraints make it impossible to transfer electricity from elsewhere than from the local supplier. If a supplier is placed within a so called load pocket, this participant will have a local market power. A supplier in this case can find himself in a position of monopoly by intentionally create congestion and limit access of competitors. This means that, by getting dispatched at strategic points in the network, a supplier in a load pocket can gain profit even by increasing its generation rather than withholding it [16]. Conclusively, transmission constraints in the electricity market make it possible even for a small supplier to exploit market power.

In a Network loads can't be accurately forecasted and energy can't be stored economically. Demand and supply must be balance all the time in order to maintain the system frequency, voltage, stabilization standards; Kirchhoff's laws and impedance of the whole network determine the power flows in the system [17]. When there is congestion, generating capacity in congested area will be relative scarcity, so congestion results in locational market power and causes invalidation of the optimization of generating resources in the whole network.

The LMP represents the willingness to supply an additional MW of load at a particular location. It is useful to break the LMP into parts to distinguish between costs resulting from network losses and those resulting from network congestion. The LMP includes a reference cost of generation and relative costs of congestion and losses in the system:

LMP = (generation marginal costs) + (congestion cost) + (cost of marginal losses).

The generator marginal cost is taken from a specified reference generator in the system. The congestion cost represents the effect of congestion on the LMP relative to the reference generator marginal cost.

III. AC OPF FORMULATION

The AC optimal power flow problem solved by MATPOWER is a "smooth" OPF with no discrete variables or controls. The objective function is the total cost of real and/or reactive generation [18]. These costs may be defined as polynomials or as piecewise-linear functions of generator output. The problem is formulated as follows:

$$\min_{\theta, V, P_g, Q_g} \sum_i f_{1i}(P_{gi}) + f_{2i}(Q_{gi}) \qquad (1)$$

subject to:

(2)

$$P_i(\theta, V) - P_{gi} + P_{di} = 0 \quad \text{(active power balance equations)}$$
$$Q_i(\theta, V) - Q_{gi} + Q_{di} = 0 \quad \text{(reactive power balance equations)}$$
$$\left|S_{ij}^f(\theta, V)\right| \le S_{ij}^{\max} \quad \text{(apparent power flow limit of lines, \textit{from} end)}$$
$$\left|S_{ij}^t(\theta, V)\right| \le S_{ij}^{\max} \quad \text{(apparent power flow limit of lines, \textit{to} end)}$$
$$V_i^{\min} \le V_i \le V_i^{\max} \quad \text{(bus voltage limits)}$$
$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad \text{(active power generation limits)}$$
$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \quad \text{(reactive power generation limits)}$$

Here f1i and f2i are the costs of active and reactive power generation, respectively, for generator i at a given dispatch point. Both f1i and f2i are assumed to be polynomial or piecewise-linear functions. By defining the variable x as:

$$x = \begin{bmatrix} \theta \\ V \\ P_g \\ Q_g \end{bmatrix} \qquad (3)$$

The problem can be expressed compactly as follows:

Min f(x) (4)

subject to

$$g_1(x) = 0 \quad \text{(power balance equations)}$$
$$g_2(x) \le 0 \quad \text{(branch flow limits)}$$
$$x_{\min} \le x \le x_{\max} \quad \text{(variable limits)}$$

IV. SIMULATION

Matlab version 7.1 is used as simulation environment. For this simulation MATPOWER version 3.2 was used as OPF solver. The simulation study has been done on a 9-bus system with 6 loads and 6 generators. This System is shown in figure 1:

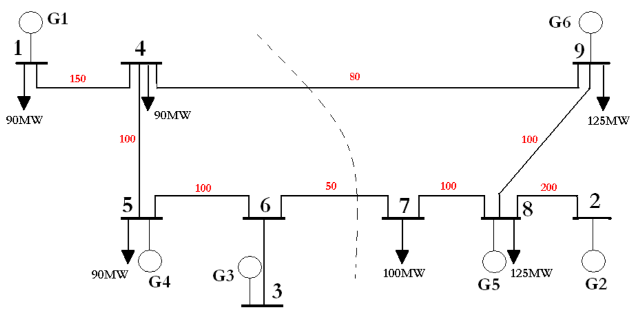

Figure 1. 9-bus system

The following capacities are offered by these generators:

Table 1. The system generators production capacities

Generator	Bus	Pmin(MW)	Pmax(MW)
1	1	10	250
2	2	10	300
3	3	10	270
4	5	10	250
5	8	10	300
6	9	10	300

The cost functions of all these generators are in appendix.

A. Evaluation of congestion impact of the line between buses 4 and 9 on LMPs and producers' profits:

In Fig.1, the generation companies bid at their actual costs, without considering the constraints of line transmission capacity, the active power flow in Line 4-9 is 79.8MW. Then reduce the capacity of the line 4-9 to 40MW in order to evaluate the congestion impact of this line on locational marginal prices and producers' profits. See table 2:

table 2. OPF results in order to Evaluate the congestion impact of the line between buses 4 and 9 on LMPs and producers' profits

Case		G1	G2	G3	G4	G5	G6	Total
Uncong.	ρ /($/MWh)	22.347	21.387	21.478	22.173	21.387	22.023	
	Output/MW	70.00	126.35	75.00	70.00	126.35	155.00	622.70
	Cost / ($/h)	1039.00	2108.54	1099.06	1039.00	2108.56	2828.12	10222.29
	Profit / ($/h)	525.26	593.72	511.79	513.10	593.72	585.51	3323.11
Cong.	ρ /($/MWh)	27.000	21.387	23.225	25.810	21.387	20.744	
	Output/MW	105.23	145.58	75.00	70.00	145.58	82.50	623.90
	Cost / ($/h)	1894.34	2576.18	1099.06	1039.00	2576.24	1277.53	10462.35
	Profit / ($/h)	946.99	537.44	642.84	767.72	537.43	433.86	3866.28
Profit Differences/ ($/h)		421.73	-56.28	131.05	254.62	-56.29	-151.65	543.1700

As it is shown, there is congestion in network in normally competitive conditions while limiting the transmission capacities and the generators number 1, 3 and 4 which are located in congested area, have the suitable conditions to gain much more profit. The outputs of generators, LMPs, generating costs, profits, and profit differences, with or without congestion, are listed in Table 2.

If power losses are neglected and there is no congestion, the LMPs are equal in all the buses, but in this simulation we consider transmission losses. So in both cases there are locational marginal prices. The point is the differences between these two cases in LMPs and the generators profits. When there is congestion in the system, the market is divided into two parts: the congested area and the uncongested area. In the congested area, all LMPs are higher than those without congestion.

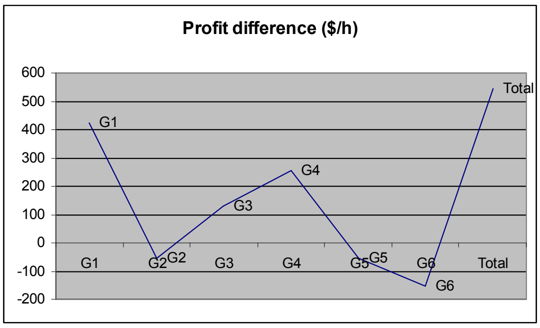

Figure 2. profit difference in simulation part A

When there is congestion, in the congested area the more generating capacities are called upon in order to meet the load requirement. In this example, the incremental generating capacity in congested area is implementing by increasing G1 capacity from 70.00MW to 105.23MW. And you see in figure 2, its profit difference is the most of all.

Because of congestion, the market total generating costs are increased by 240.06$/h and the generators' profits are increased by 543.17$/h. In the same time, the customers have to pay more for energy. Generally congestion has segregated the market.

B. Generators exert strategy bidding to create congestion:

B – 1) The Strategy of bidding at high prices:

As we discuss before, one of producers' bidding strategies is bidding at high prices to create congestion in some transmission lines. In our system, the generator number 1 which had gained the most profit due to congestion has the potential of exerting market power by this bidding strategy. G1 has a linear piecewise cost function and the factor K is added to its initial value to increase its bidding price. The simulation results of this bidding strategy are shown in table 3:

Table 3. G1 bidding strategy at high prices:

K	0	10	10.5	11	11.5	12
/($/MWh) ρ	22.347	27.162	28.470	28.501	28.593	28.703
Output / MW	70.00	46.85	48.25	35.21	27.86	17.884
) $/h / (Cost	1039.00	701.254	585.812	473.261	346.885	188.953
) $/h / (Profit	525.26	571.28	787.86	503.26	449.71	324.37
L9-4	U[1]	C	C	C	C	C

The results in Table 3 show that when the bidding prices of G1 are increased step by step, the LMPs in relevant bus (Bus 1) are decreased gradually. When K is zero, the LMP is 22.347 $/MWh and G1's output is 70MW; when k is 12, the LMP is 28.703 $/MWh and G1's output is 17.884MW. Because the profits of G1 depend on LMP, its output and corresponding generating costs, the G1's profits are increased from 525.26$/h to 787.86$/h (maximum, when k is 10.5), and then reduced gradually. When k is larger than 12, the relevant LMP increase, but G1's outputs decrease, so G1's profits are less than 525.26$/h, which is the profits that G1 gains in normally competitive conditions. When k is 10, Line 4-9 is congested.

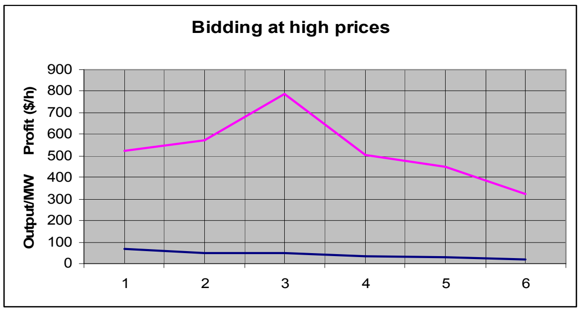

Figure 3. Generators' profits and output power

B – 2) Withholding some capacity to exert congestion and gain more profit

Similarly, G1 bids its actual costs but withhold some capacity, and other generators' bidding curves are the same as those in normal competitive conditions, G1's outputs, profits, LMPs and congestion conditions of Line 4-9 are all listed in Table 4. As you see in part (B – 1) there is no limitation in G1 production capacity and this generator is not constrained by its maximum capacity, because its output share is 70 MW and its maximum capacity is 250 MW. In order to see the effect of this strategy – withholding capacity – we will reduce this maximum capacity which is bided by this company from 70 MW to 20 MW and then run market simulation program.

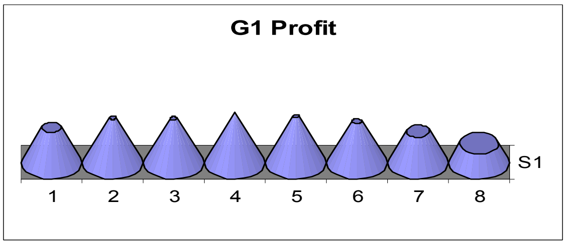

Figure 4. G1 profit by strategy of withholding capacity

From Table 4 we conclude that because the costs of G1 are lower, all of its bidding capacities are dispatched namely, G1's outputs are its bidding capacities. When the bidding capacities of G1 are decreased step by step, the LMPs in relevant bus are increased gradually. G1's profits are increased from 524.04 $/h to 744.45$/h (maximum, when G1's output is 50MW), and then decreased gradually. When the bidding capacity (output) is 60MW Line 4-9 is congested.

From Table 3 and Table 4, we conclude that bidding at high price and withholding capacity both can artificially create transmission congestion. When k is 10 or G1's bidding capacity (output) is 46.85 MW, Line 4-9 begins to congest. When there is congestion, and the generators in congested area bidding at higher price (by increasing k) or withholding capacity (by decreasing G1' bidding capacities), they can gain additional profits.

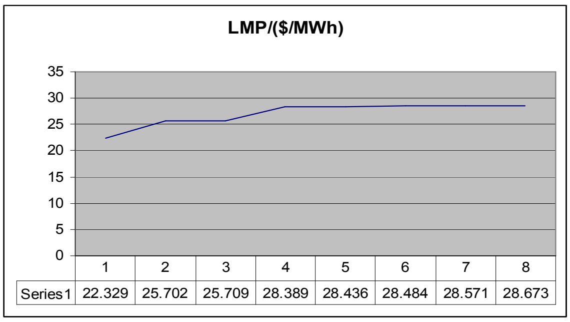

Figure 5. Location marginal prices after exerting bidding strategy of withholding capacity by G1

[1] U means unconstrained and C means constrained.

Table 4. G1'S DATA WITH WITHHOLDING CAPACITY

Bidding/MW	70	60	55	50	45	40	30	20
Output/MW	70	60	55	50	45	40	30	20
/($/MWh) ρ	22.329	25.702	25.709	28.389	28.436	28.484	28.571	28.673
Cost /($/h)	1039.01	846.01	757.76	675.01	597.76	526.01	399.01	294.00
)$/h / (Profit	524.04	660.13	656.23	744.45	681.89	613.37	458.13	279.47
L9-4	U	C	C	C	C	C	C	C

From the above tables, we conclude that the impacts of two bidding strategies (withholding capacity and bidding at higher price) are equivalent. When G1 bids at higher price, G1 gains maximal profit 787.86$/h (when k is 10.5 and G1's output is 48.25MW). When G1 bids by withholding capacity, it also gains maximal profit 744.45$/h (when G1's bidding capacity is 50 MW). So both bidding strategies at the same values result the same profits.

V. CONCLUSION

The grid structure in which the power transactions need to be accommodated in modern electricity markets may impact greatly the market efficiency and, more generally, the market outcomes. Network and commodity of energy have some particular characteristics, in the congested area, all LMPs are higher than those without congestion. If generators bid in strategies to exercise the market power, they can gain high additional profits.

VI. APPENDIX

Table 5.Generators' piecewise linear cost functions

Generators	X0	Y0	X1	Y1	X2	Y2
G1	1500	0	3	0.11	5	150
G2	2000	0	3	0.085	1.2	600
G3	3000	0	3	0.1225	1	335
G4	1500	0	3	0.11	5	150
G5	2000	0	3	0.085	1.2	600
G6	2000	0	3	0.085	1.2	600

For piecewise linear cost:
x0, y0, x1, y1, x2, y2, ...
Where x0 < x1 < x2 < ... and the points (x0,y0), (x1,y1), (x2,y2), ... are the end- and break-points of the cost function.

REFERENCES

[1] Ettore Bompard, Yuchao Ma, Roberto Napoli, and Graziano Abrate, "The Demand Elasticity Impacts on the Strategic Bidding Behavior of the Electricity Producers", IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 22, NO. 1, FEBRUARY 2007

[2] James Bushnell, " Transmission Rights and Market Power", University of California Energy Institute, April 1999 This paper is part of the working papers series of the Program on Workable Energy Regulation (POWER)

[3] Galloway, S (2006), "Introduction to Market Power" [lecture notes]. University of Strathclyde, Glasgow

[4] Yang Jian and G. Jordan, "System dynamic index for market power mitigation in the restructuring electricity industry, "in *Proc. 2000IEEE Power Engineering Society Summer Meeting,* pp 2217-2222

[5] Fernando L. Alvarado, " Market power: a dynamic definition, " in *Proc. 1998 Bulk Power System Dynamic and Control- Restructuring Conf.*

[6] D.Gan and D. V.Bourcier," Locational market power screening and congestion management: experience and suggestions, " *IEEE Trans. On Power Systems*, vol. 17 pp 180 -185, Feb. 2002

[7] Gerald B.Sheble, " Computational auction mechanisms for restructured power industry operation," Kluwer Academic Publishers, 1999

[8] Marija Ilic , Francisco Galiana, and Lester Fink, power system restructuring: engineering and economics," Kluwer Academic Publishers, 1999.

[9] D. Gan and D. V.Bourcier, " A simple method for locational market power screening, " in *Proc. 2002IEEE Power Engineering Society Winter Meeting*, pp 434–439.

[10] R.Moreira e Silva and L.D.B. Terra, "Market power under transmission congestion constraints, " in *Proc. 1999International Conference on Electric Power Engineering*, pp 82

[11] A. Mas-Collel, A. Whinstom, and J. Green, *Microeconomic Theory*. New York: Oxford Univ Press, 1995.

[12] S. Stoff, *Power Systems Economics: Designing Markets for Power*. New York: IEEE/Wiley, 2002

[13] Claudia P. Rodriguez, and George J. Anders, "Bidding Strategy Design for Different Types of Electric Power Market Participants", IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 19 NO. 2, MAY 2004

[14] David A. Kumar. "Market Power in Electricity Supply", IEEE Transactions on energy conversion, Vol.16, No. 4, Pages: 352-353, December 2001.

[15] Mary B. Cain and Fernando L. Alvarado. "Metrics for Application of Revenue Sensitivity Analysis to Predict Market Power Coalitions in Electricity Markets", IEEE Proceedings of the 36th Annual North American Power Symposium, August 9-10 2004 University of Idaho, Moscow, Idaho.

[16] Robert J Thomas Bernard C. Lesieutre and Timothy D. Mount. "Identification of load pockets and market power in electrical power systems, Decision Support Systems," Vol. 40 Issue 3-4 , October 2005, Pages: 517 - 528, ISSN:0167-9236.

[17] Daniel Kirschen and Goran Strbac, "Fundamentals of Power System Economics", **2004** John Wiley and Sons Ltd.

[18] Ray D. Zimmerman and Deqiang Gan. Matpower, user's manual, 24 december ١٩٩٧.