Dynamic Capacity Withholding Assessment of Generation Companies in Wholesale Electricity Markets considering collusion

Seyed Mostafa Tabatabaei [1*], Mehrdad Setayesh Nazar [2]
[1, 2] Department of Electrical Engineering, Shahid Beheshti University, Tehran, Iran
[1]se_tabatabaei@sbu.ac.ir

***Abstract* — in a multi-polar electricity market, the possibility of forming a cooperative of production units and collusion between them is very high. Collusion between manufacturers can be made economically by increasing group prices or physically and by preventing the production of electrical energy. There have been many references to economic collusion between units and methods of preventing it, but in the case of capacity collusion or physical collusion, very few studies have been done after the occurrence. Therefore, in this paper a new index named Capacity Collusion Index (CCI) is presented to evaluate the collusion between production units and is analyzed from a preventive point of view. Having an index on the issue of collusion between production units prevents the formation of collusion groups, and ISO can help prevent collusion in the electricity market by introducing new laws or changing the old rules of the market.**

Keywords — dynamic capacity withholding; power market; wholesale electricity markets.

I. INTRODUCTION

Electricity Generation Companies (GenCos), by applying various strategies, try to apply market power and profit outside of the competition levels, and in intervals from the time they form groups to bind and increase the price of the wholesale electricity market. All of these strategies are collusion and can occur economically or physically in an electricity market.

There is no indicator for evaluating and analyzing collusion between producers in the wholesale electricity market and many manufacturers, by forming groups, prohibited their production capacity, increase the price of the electricity market, so the detection of susceptible units and preventing their formation is certainly a very useful way Transparency of the electricity market, and avoid collusion.

The effect of collusion on the structure of the grid and the wholesale electricity market will reduce competition in the market and have a negative impact on the security of the power system. A financial or economic co-operation involves offering an over-competitive bidder, and physical co-ordination involves a deliberate reduction in the output of the unit's supplier in the market, even if its output reaches prices above the final price. Physical co-ordination can be achieved through non-proposing, reducing the output level or announcing the withdrawal of a unit.

Since an ISO or energy regulator has accurate information about the cost function of power generation companies, economic co-operation is identified during the evaluation process, and many references have also studied this type of collusion, But according to recent research and regulator reports, it is clear that the physical constraint is not easily identifiable and the conventional tools provided are not sufficient and require more analytical tools and indicators.

In some references, like [1], a new modeling (HHI) that mainly focuses on market strategies and manufacturers, the collusion and market examine powers of producers. In [2], the use of HHI index has led to an incorrect analysis of capacity foreclosure in the electricity market. Reference [3] deals more with economic concepts and expresses the theory of collusion; only in a few cases, it gives examples of the market for the correctness of its claims. Here, the studies are purely economic and there is no reference to the issue of capacity collusion.

Reference [4] discusses the relationship between collusion in the electricity market, capacity barriers, and how fines are taken into account to prevent such cases. For the first time, in this reference, capacity collusion is raised though the reviewed studies are purely analytical and do not provide any indicators for accurately assessing physical collusion. Reference [5] examines the possibility of the presence of production units in a collusion using the non-complete information of other units. Such data as scheduled or emergency exits, available capacity, unit arrival rates, foreclosure rates, etc are non-completely available from the manufacturing units. This study, based on the weight of the market power of the players, identifies the units susceptible to collusion, while some very low-weight units can also have a very important role in collusion (with unwritten contracts).

In [6], physical collusion is observed among the units; however, the studies are repeated only with the use of previous market information, and therefore, no indicators are provided to prevent collusion.

In most of the papers reviewed, the power of the individual or group market (collusion) is economic and physical power or capacity barriers are not seen in them. In articles in which collusion and capacity containment is raised, this review is purely theoretical and has not been considered for any indication. In addition, the indicators used in a few articles to investigate the collusion of manufacturing units have been made after it has occurred and can in no way detect a collusion before it occurs. The primary objective of this study is to examine the potential for collusion in electricity markets and to obtain new analyzes and indicators. By achieving this, it will be clear that there will be a degree of collusion between production units in a well-structured market. achieving this analysis is very useful for observers and market operators.

This paper is divided as follows: Section п presents the model of wholesale electricity market as spot markets using the SFE model. In section III, the manufacturers present the Capacity Collusion Index (CCI). In section IV, the standard networks, 3 and 6 producers evaluated and the groups susceptible to collusion are listed. Conclusions from numerical studies and their comparison are presented in Section V.

II. ELECTRICIY MARKET

In this section, given the concept of physical collusion between production units, the number of producers is assumed to be equal to N and the cost of each producer is as follows:

$$C_i = 0.5 a_i q_i^{\,2} + b_i q_i \tag{1}$$

In Eq. (1), C_i is the production cost of each producer, q_i is the amount of production of each producer, a_i is the slope of the marginal cost of production and b_i is width of the origin of the marginal cost function of the producer.
In this study, the market is designed with a uniform structure and is done in terms of the time interval in the operational planning stage. Also, the load as the sum of the demand function is as follows:

$$\pi = -\alpha Y + \beta \tag{2}$$

In Eq. (2), π is the market settlement price, α is the slope of the linear inverse demand function, β is the origin of the linear inverse demand function and Y is the total market consumption.

The market is a multipolar market and each producer optimizes its profit by choosing production. The function of optimizing the profit of each producer in the market is as follows:

$$\max\ pr = q_i \pi_i - 0.5 a_i q_i^{\,2} - b_i q_i \tag{3}$$

In Eq. (3), pr is the profit function, and each producer is bound to produce in the standard range ($q_i^{\min} \le q_i \le q_i^{\max}$).

By forming a Lagrange function and deriving from q_i, the relations are as follows:

$$L_i = q_i \pi_i - 0.5 a_i q_i^{\,2} - b_i q_i + g_i^{\max}(q_i - q_i^{\max}) - g_i^{\min}(q_i - q_i^{\min}) \tag{4}$$

$$\frac{\partial L_i}{\partial q_i} = -\alpha q_i - a_i q_i - b_i + g_i^{\max} - g_i^{\min} = 0 \tag{5}$$

$$q_i = \frac{\pi - b_i + g_i^{\max} - g_i^{\min}}{\alpha + a_i} \tag{6}$$

$g_i^{\min}$, $g_i^{\max}$ are Lagrange coefficients for maximum and minimum Production and In the market with complete competition (price taker units), α is eliminated and Eq. (6), can be used for fully competitive markets and markets with full competition by price of the multipolar market.

$$q_i^{\,p} = \frac{\pi^p - b_i + g_i^{\max} - g_i^{\min}}{a_i} \tag{7}$$

$$q_i'^{\,p} = \frac{\pi^e - b_i + g_i'^{\max} - g_i'^{\min}}{a_i} \tag{8}$$

$$q_i^{\,e} = \frac{\pi^e - b_i + g_i^{\max} - g_i^{\min}}{\alpha + a_i} \tag{9}$$

If $q_i^{\,p}$ be production in the market with full competition, $q_i^{\,e}$ be production in the multipolar market and $q_i{'}^{p}$ be production in the market with full competition and multipolar market prices, the indicators will be as follows:

$$\Delta q_i^{capacity-withholding} = q_i{'}^{p} - q_i^{e} = \frac{\pi^e - b_i + g_i{'}^{max} - g_i{'}^{min}}{a_i} - \frac{\pi^e - b_i + g_i^{max} - g_i^{min}}{\alpha + a_i} \quad (10)$$

$$\Delta q_i^{capacity-distortion} = q_i^{p} - q_i^{e} = \frac{\pi^p - b_i + g_i^{max} - g_i^{min}}{a_i} - \frac{\pi^e - b_i + g_i^{max} - g_i^{min}}{\alpha + a_i} \quad (11)$$

Eq. (10) is capacity withholding for each producer and Eq. (11) is capacity distortion for each producer.[7-31]

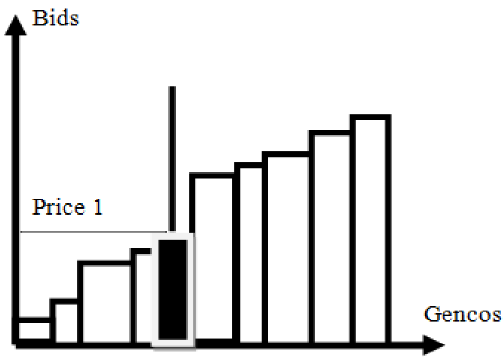
III. CAPACITY COLLUSION INDEX (CCI)

In a full competitive market, manufacturers cannot form groups for collusion, but in a multipolar market, groups of manufacturers are formed and collectively lead to higher prices for wholesale electricity market. This collusion can be made economically and with a collective price offer or with a collective prohibition of production. There are no indicators for detecting capacity collusion, which leads to increasing the price of the electricity market and profits of groups.

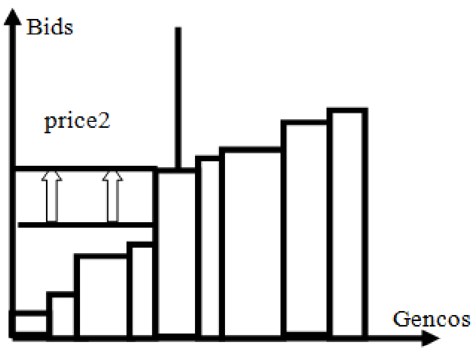
In the case of collusion between production units, collusion in the production of multi-actor from the foreclosure of a single production unit will further increase the price of the electricity market. Therefore, the benefit of the participants in the collusion is also greater than the single quatrains, and it is a great incentive for the collusion in the electricity market.

In Figure 1, it can be seen that with the formation of collusion group the price of the market more increases, and therefore the market regulator must pay more attention to the collusion between the units than to capacity withholding.

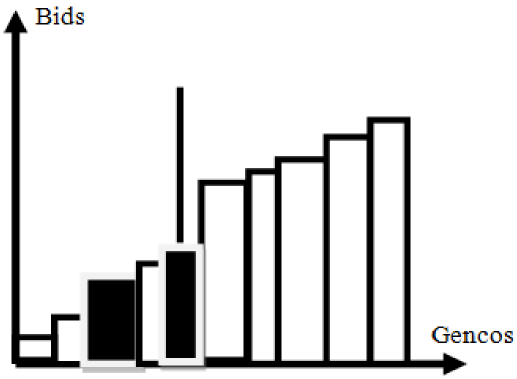
A number of GenCos form a group for increasing their profits in the electricity market. We assume that the group is the only electricity market group; hence, we calculate the DWI for that. More DWI shows the more ability of the GenCos to prevent more capacity and *i* is the number of GenCos in electricity market.



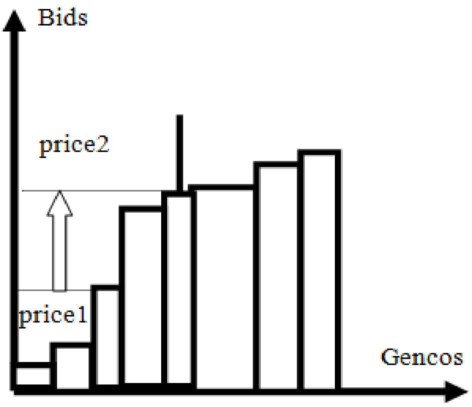
(a)



(b)



(c)



(d)

Fig.1. Comparison between capacity withholding and capacity collusion. (a) Market price before capacity withholding. (b) Market price after capacity withholding. (c) Market price before capacity collusion. (d) Market price after capacity collusion.

Also, a unit in the electricity market can be negotiated with a non-winning unit that has no chance of profitability in the electricity market and, in addition to raising market prices, increases their profits.(Figure 2)

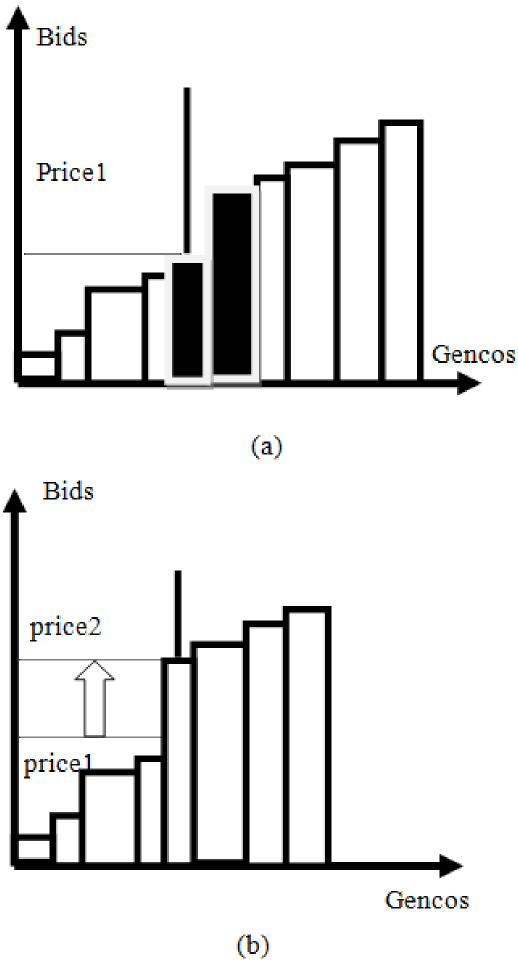


Fig. 2. Increased profits by collusion of the losing unit with the winning unit in the electricity market. (a) Market price before capacity collusion. (b) Market price after capacity collusion.

Capacity collusion can only be assumed that after collusion and it can be guessed that examples of collusion can be identified.

In this paper, for the first time, an index for evaluating and detecting capacity collisions in the electricity market is presented and samples from this survey are tested in the network with 3 and the 18-IEEE network with 5 producers.

A number of GenCos form a group for increasing their profits in the electricity market stop their production And by doing this, they raise market prices.

We assume that the group is the only electricity market group; hence, we calculate the CCI for that. More CCI shows the more ability of the GenCos to prevent more capacity and i is the number of GenCos in electricity market.

CCI, which indicates the ability of collusion in the groups of electricity market, can be obtained as follows:

$$CCI_j = \sum_{i=1}^{N} DWI_i = \sum_{i=1}^{N} \frac{\Delta q_i^{capacity-distortion}}{\Delta q_i^{capacity-withholding}} \qquad (12)$$

DWI_i is Solitary Capacity collusion and the higher CCI shows the more ability of the group for collusion in the electricity market. Also j shows the number of groups formed in the electricity marke for capacity collusion.

IV. NUMERICAL STUDIES

In this section, comparative, structural-behavioral indicators that can be implemented before or after occurrence are used. With the aid of these indicators, the ability of each group for collusion, and a list of susceptible groups of collusion are expressed. First, for the initial study, a system with three production units in a multi-polar market with capacity constraints is considered, and binary groups are evaluated. The information is entered into the program during one hour, and the groups susceptible to collusion are listed. At the end, it becomes clear that the market regulator must prevent the formation of groups in the wholesale electricity market by introducing new laws or making changes in the past laws.

Table 1 shows the information on the supply curve of producers, and Table 2 indicates the information on demand curve.

Table 1 information on the supply curve of producers

Scenarios	Type of compounds
A	(1,2,3) - Without group
B	(1) / (2,3) :unit 2 is withholding
B'	(1) / (2,3) :unit 3 is withholding
C	(2) / (1,3) :unit 1 is withholding
C'	(2) / (1,3) :unit 3 is withholding
D	(3) / (1,2) :unit 1 is withholding
D'	(3) / (1,2) :unit 2 is withholding
E	(1,2,3)

Table 2 information on demand curve

GenCos	a ($/MWh)	b ($/MWh)	q^{min} (MW)	q^{max} (MW)
1	1	12	0/3	30
2	1/5	10	0/8	25
3	2	8	1	20

A. *List of units capable of collusion based on profit*

In the next step, the study is conducted in a group of GenCos and in the dominant collaterals so that the profit for two units and three units is calculated. (e.g, in groups of two manufacturing units, in which groups are more susceptible to collusion). This will continue for the other groups as well. Finally, a list of susceptible units of profit-based collusion is obtained.The scenarios for groups in the market for collusion are shown in Table 3.

Table 3 scenarios of groups formed on the market for collusion

Inverse demand function	α ($/MW^{2}h)	β ($/MWh)
$\pi = -\alpha Y + \beta$	2	90

Furthermore, the market price and production of each unit in each scenario are given in Table 4.

Table 4 market price and production of each unit in each scenario

q_4 (MW)	q_3 (MW)	q_2 (MW)	q_1 (MW)	π ($/MWh)	Scenarios
0	20	25	30	39/334	A
25	20	0	30	47/077	B
20	0	25	30	46/34	B'
30	20	25	0	48/138	C
20	0	25	30	46/34	C'
30	20	25	0	48/138	D
25	20	0	30	47/077	D'

Also, the total profit and profit of each producer after the market implementation and in each scenario is shown in Table5.

Table 5 total profit and profit of each producer in each scenario

$Profit_4$ (\$)	$Profit_3$ (\$)	$Profit_2$ (\$)	$Profit_1$ (\$)	$Profit_{Total}$ (\$)	Scenarios
0	226/68	264/6	370/02	861/3	A
222/79	381/54	0	602/31	1206/64	B
366/8	0	439/75	580/2	1386/75	B'
634/14	402/76	484/7	0	1521/6	C
366/8	0	439/75	580/2	1386/75	C'
634/14	402/76	484/7	0	1521/6	D
222/79	381/54	0	602/31	1206/64	D'

In the last column of the tables above, the amount of power purchased from the momentum market and the profit from it are brought in. In fact, this profit directly or indirectly relates to a unit that has foreclosed its capacity from the market. In fact, it can be said that the manufacturing company, with a ban on capacity from the market and a rise in market prices, sells its reserve capacity in the market for a moment and at a higher price. On the other hand, the unit, by forming a group with other units and preventing its capacity, leads to a rise in the market prices and group profits, and thus can regulate unwritten contracts and divide profits among the group members.

Comparing scenarios B, C and C', it can be concluded that the capacity withholding of unit 1 than the capacity withholding of unit 2, and capacity withholding of unit 2 than capacity withholding of unit 3 will have a greater impact on the market price rises and will increase the profits of all players.

Comparing scenarios B' and C' shows that both of them have withheld their unit 3, but in scenario B', unit 3 does this by colliding unit 2, and in scenario C' unit 3 does this by colliding with unit 1. It is clear that when a unit fails to collide with unit 1, it will gain more profit from this pull-back.

If the gain from collusion is 50%-50% between the members of the group (as showen in Table 6), unit 3 achieves more benefit in collusion with unit 1, it is more likely to form this group; hence, the probability of forming a group between units 1 and 3 is much higher than that between units 2 and 3

Table 6 comparision of the scenarios B' and C'

<table>
<tr><th>$Profit_2$ ($)</th><th>$Profit_3$ ($)</th><th>$Profit_1$ ($)</th><th>$Profit_T$ ($)</th><th>Scenarios</th></tr>
<tr><td colspan="2">$Profit_2$ = $Profit_3$ = 403/275</td><td>580/2</td><td>1386/75</td><td>B'</td></tr>
<tr><td>439/75</td><td colspan="2">$Profit_1$ = $Profit_3$ =473/5</td><td>1386/75</td><td>C'</td></tr>
</table>

Also comparison of scenarios D and D' shows that in collusion between units 1 and 2.

more profit exceeded when the blocking capacity is unit 1, so unit 1 will have priority over unit 2.

Table 7 comparision of scenarios D and D'

$Profit_4$ (\$)	$Profit_3$ (\$)	$Profit_2$ (\$)	$Profit_1$ (\$)	$Profit_{Total}$ (\$)	Scenarios
634/14	402/76	484/7	0	1521/6	D
222/79	381/54	0	602/31	1206/64	D'

The priority of collusion in the electricity market and the formation of binary groups are shown in Table 8.

Table 8 priority of collusion in the electricity market

DWI	CCI	Scenarios
-------	0/233-0/167-0/108	A
0/167-0/108	0/275-0/233	B
0/108-0/167	0/275-0/233	B'
0/233-0/108	0/341-0/167	C
0/233-0/108	0/341-0/167	C'
0/167-0/233	0/4-0/108	D
0/167-0/233	0/4-0/108	D'
0/233-0/167-0/108	0/508	E

In this method, the distribution of profits among the members of the collaborating group is very important. This is usually mentioned in unwritten contracts; therefore, ISO does not have access to it, directly.

B. List of units capable of collusion based on CCI

Contrary to the general DWI index for the electricity market, which is a number between zero-one, and the closer is this indicator to one, the implication is that there is less foreclosure. CCI shows the degree of collusion in the electricity market, and can even have a value of more than one. The higher value of the indicator shows that the target group is more capable of collusion in the electricity market. On the other hand, the DWI group is calculated separately, and it is still possible to determine which actor in the group has a more effective role in increasing the price of the electricity market (Table9).

Table 9 comparision of scenarios in CCI for groups and DWI for each Generation company.

Capacity withholding unit	Binary groups exposed to collusion	Collaborative Priority Based on Divide Profit
1	1و2	1
2	1و2	2
1	1و3	3
3	1و3	4
2	2و3	5
3	2و3	6

Table 10 shows priority of collusion in the electricity market.

Table 10 priority of collusion in the electricity market

Capacity withholding unit	Binary groups exposed to collusion	Collaborative Priority Based on Divide Profit
1	1و2	1
2	1و2	2
1	1و3	3
3	1و3	4
2	2و3	5
3	2و3	6

Each of the A and B methods used, gives the same results and lists the groups that are susceptible to collusion though there are also differences. The point is that in the DWI method, for the time when all units collide with each other, and when no collusion exists, the index is calculated, and thus, the formation of the group cannot be detected. In this sense, using A-method, one cannot find the collusion between all actors. Therefore, the method of using CCI is much more suitable.

Comparing to the profit recognition method used by the manufacturing unit and the CCI method, CCI is more appropriate. Because in the diagnostic method, depending on the profit of the units, the distribution of profits between the members of the collusion group is very important, and this is mentioned in the unwritten contracts, so ISO does not have access to it, directly. Despite the lack of recognition of collusion in the early hours, and with the help of CCI, collision can be avoided easily at a later time with new rules or restrictions.

Finally, the list of groups that in the electricity market have higher ability for collusion is shown in Figure 1. The figure clearly illustrates that in the electricity market, group containg units 1,2, group containg units 1,3, and group containg units 2,3 have the highest ability for collusion orderly. It was also foreseeable that group containg units 1, 2, and 3 or all GenCos have maximum ability for collusion (Fig. 3).

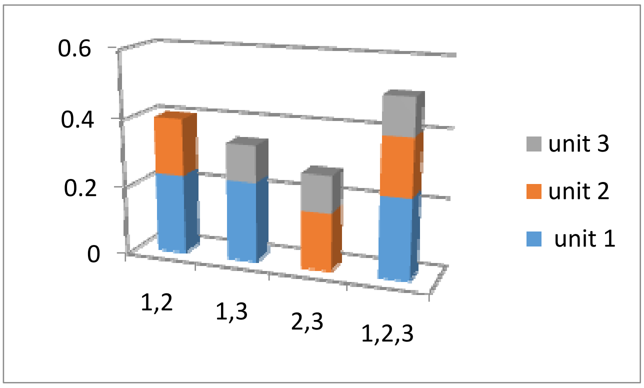


Fig. 3. Ability list for capacity collusion in the electricity market groups

Regarding the units of each group, GenCos 1, 2 and 3 have orderly higher ability for capacity withholding and collusion.

In the following, the collusion studies for a 30-bus IEEE system with 6 manufacturing companies and input parameters are reviewed in accordance with Table 11.

Table 11 information on the supply curve of producers for the IEEE 30 bus

Manufacturer's bus number	a ($/MWh)	b ($/MWh)	q^{min} (MW)	q^{max} (MW)
1	0/075	20	50	200
2	0/35	17/5	50	80
5	1/25	10	15	50
8	0/166	32/5	10	35
11	0/5	30	10	30
13	0/5	30	12	40

Future scenarios for the binary groups and their CCI in the electricity market will be according to Table 12. These scenarios start from the binary groups and continue to groups of 6 producers.

Table 12 scenarios of groups formed on the market for collusion

Scenarios	Type of compounds	CCI
A	(1,2)	1/016
B	(1,5)	1/941
C	(1,8)	2/279
D	(1,11)	2/468
E	(1,13)	0/882
F	(2,5)	1/1934
G	(2,8)	1/5314
H	(2,11)	1/7204
I	(2,13)	0/1344
J	(5,8)	2/456
K	(5,11)	2/645
L	(5,13)	1/059
M	(8,11)	2/983
N	(8,13)	1/397
O	(11,13)	1/261

Then the groups formed on the basis of the CCI computing index are listed in the electricity market.

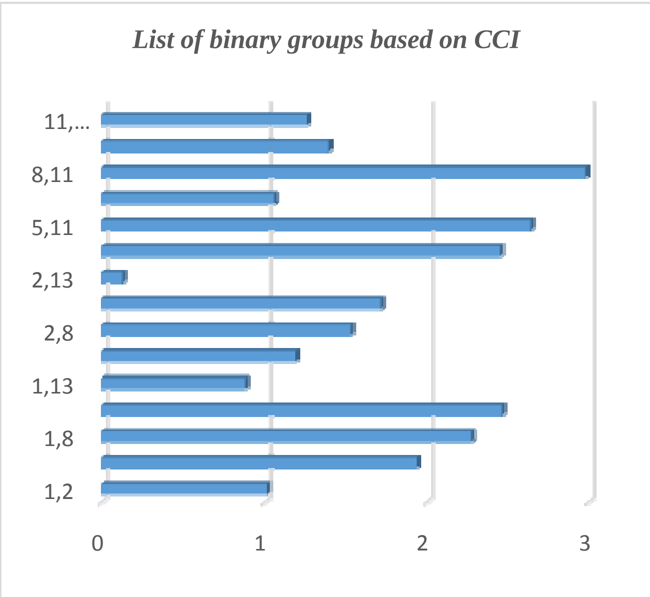


Fig. 4. Ability list for capacity collusion in the electricity market for binary groups

As shown in Fig. 4, the most potential for collusion in the electricity market is for the 8th and 11th bus manufacturers and the lowest ability is for the 2th and 13th bus manufacturers.

Furthermore, the ability of group of 3, 4 and 5 members to be able to capacity collusion in the electricity market is shown in Figures 5, 6 and 7.

As seen in Fig. 5, among the three-members groups in the electricity market, group containg units 5, 8, and 11 has the highest ability, and group containg units 1, 2, and 13 has the least ability to perform collusion in the electricity market.

This is also predictable from the comparison between dual-market electricity markets.

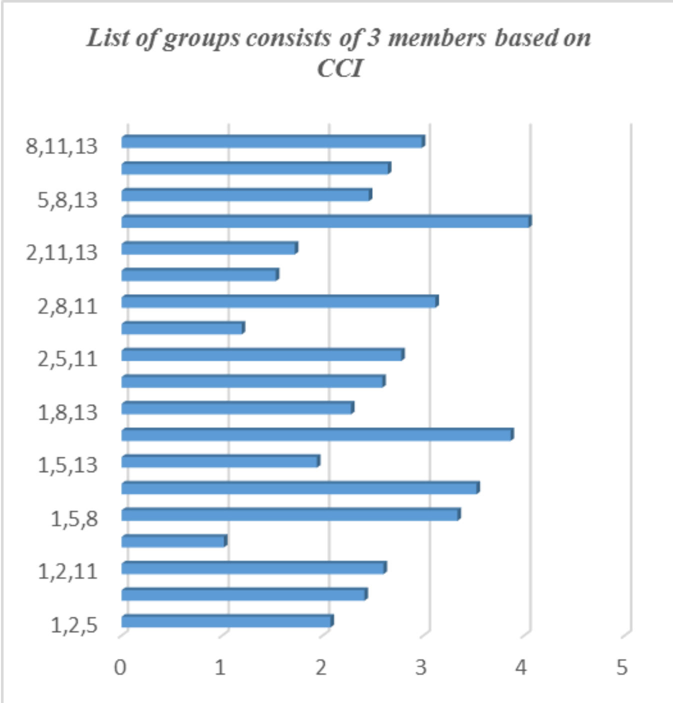


Fig. 5. Ability list for capacity collusion in the electricity market for groups consisting of 3 members

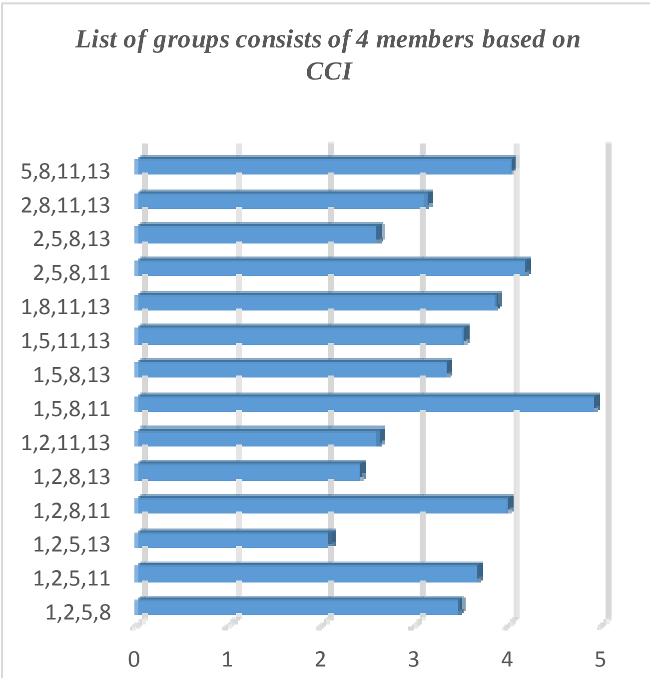


Fig. 6. Ability list for capacity collusion in the electricity market for groups consisting of 4 members

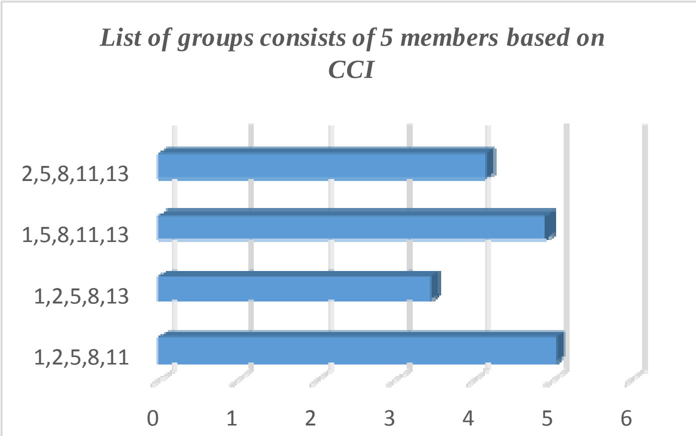


Fig. 7. Ability list for capacity collusion in the electricity market for groups consisting of 5 members

Certainly, the most collusion occurs when all the manufacturers engage in collusion in a group. Therefore, the highest ability to collide is for a group of 6 members.

On the other hand, by comparing Figures 4, 5 and 6, the ability of collution in binary group containg units 8 and 11 is greater than in most of the 3-member and 4-member groups, such group containg units 1, 2, 5, and13 .

The list of producers having more ability to start forming groups with other GenCos and having greater profitability temptation is shown in Fig. 7. Therefore, ISO can observe groups in the market according to their order of importance and power.

V. CONCLUSION

In this paper, structural-behavioral indicators that can be implemented before or after occurrence are used. With the aid of these indicators, the ability of each producer to be prevented, group collusion, and a list of susceptible groups of collusion are expressed, orderly. Initially, a system with three production units in a multi-polar market with capacity constraints is considered, and then the binary groups are evaluated. The information is entered into the program within one hour, and the groups susceptible to collusion are listed. At the end of this step, it becomes clear that the market regulator must prevent the formation of groups in the wholesale electricity market by introducing new laws or making changes in the past laws.

First, the study is conducted in a group of dominant collaterals so that the profit for two units and three units can be calculated. This will continue for the other groups as well. Finally, a list of susceptible units of profit-based collusion is obtained. On the other hand, the unit, by forming a group with the other units and preventing their capacity, leads to a rise in the market prices and group profits; thus it can regulate unwritten contracts and divide profits among the group members.

In the next step, that CCI that shows the degree of collusion in the electricity market and can even have a value of more than one is calculated. The higher value of the indicator shows that the target group is more capable of collusion in the electricity market. Furthermore, the DWI_i is calculated separately, and it is still possible to determine which actor in the group has more effective role in increasing the price of the electricity market.

Each of the A&B methods used gives the same results and gives the list the groups that are susceptible to collusion; however, there are differences as well.

Comparing to the profit recognition method used by the manufacturing units, using CCI is more appropriate because in the diagnostic method, depending on the profit of the units, the distribution of profits between the collusion group members is very important and this is mentioned in the unwritten contracts, so ISO does not have access to it directly. Despite the lack of recognition of collusion in the early hours, and with the help of CCI and with the new laws, collision can be avoided easily at a later time.

Comparing the ability of inhibit the capacity of each of the manufacturers, it is also possible to identify the priority of forming collusion groups in the electricity market. This will help ISO to avoid collusion in the market.

Also, by comparing the process of completion of the groups, units with more market power can be identified and monitored to avoid collusion in the electricity market.

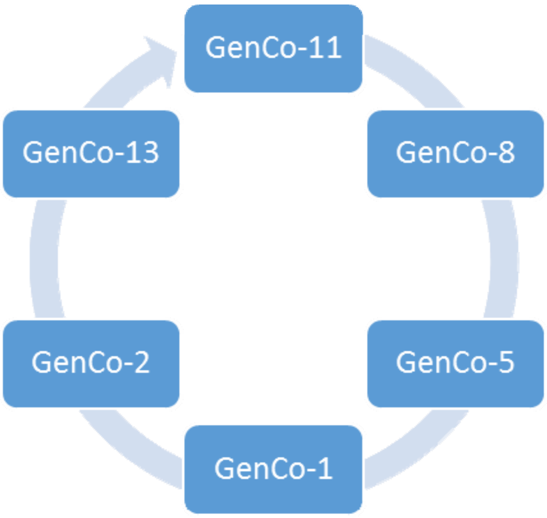


Fig. 8. The arrangement of producers' ability to form a group leading to capacity collusion in the electricity market

References

[1] Stoft S. Power system economics: designing markets for electricity; Wiley-IEEE Press: New York, 2002.
[2] Liu JD, Lie TT, Lo KL. An empirical method of dynamic oligopoly Behavior Analysis in Electricity Markets. IEEE Trans. Power Syst 2006; 5 (2): 499-506.
[3] Bompard E, Wane L, Napoli R. Network constraint impacts on the competitive electricity markets under supply side strategic bidding. IEEE Trans. Power Syst 2006;21(1):160-170.
[4] Badlick R. Electricity market equilibrium models: The effect of parameterization. IEEE Trans. Power Syst 2002; 17 (4): 1170-1176.
[5] Bompard E, Ma Y, Napoli R, Abrate G. The demand elasticity impacts on the strategic bidding behavior of the electricity producers. IEEE Trans. Power Syst 2007; 2 (1):188-197.
[6] Willems B, Rumiantseva ,Weight H. Cournot versus supply functions: What does the data tell us? Energy Economics 2009.
[7] Niu H, Baldick R, Zhu G. Supply function equilibrium bidding strategies with fixed forward contracts. IEEE Trans. Power Syst 2005; 20 (4): 1859-1867.
[8] Chung TS, Zhang SH, Wong KP, Chung CY. Strategic forward contracting in electricity markets: Modeling and analysis by equilibrium method. IEE Pro. Gener. Transm. Distrib 2004; 151 (2): 141-149.
[9] Day CJ, Hobbs BF, Pang, JS. Oligopolistic competition in power networks: A conjectured supply function approach. IEEE Trans. Power Syst 2002; 17 (3): 597.
[10] Green R.J, Newbery DM. Competition in the British electricity spot market. J. Poliot. Econ. 1992; 100 (5): 929953.
[11] Bautista G, Anjos MF, Vannelli A. Numerical study of affine supply function equilibrium in AC network-constrained markets. IEEE Trans. Power Syst 2007; 22 (3): 1174-1184.
[12] Frezzi, P, Garces, F, Haubrich, H.J. “Analysis of Short-Term Bidding Strategies in Power Markets.”IEEE Power Tech, pp. 971-976, 2007.
[13] Salarkheili, Saeed, and Asghar Akbari Foroud. "Market power assessment in electricity markets: supply function equilibrium-based model." International Transactions on Electrical Energy Systems 23.4 (2013): 553-569.
[14] Baranes, Edmond, Marion Podesta, and Jean-Christophe Poudou. "Mixed bundling may hinder collusion." Research in Economics 70.4 (2016): 638-658.
[15] Mohtavipour, S. S., and A. H. Gholami. "A step toward stable tacit collusion in electricity market." Electrical Engineering (ICEE), 2016 24th Iranian Conference on. IEEE, 2016.
[16] Moiseeva, Ekaterina, Mohammad Reza Hesamzadeh, and Ilias Dimoulkas. "Tacit collusion with imperfect information: Ex-ante detection." PES General Meeting| Conference & Exposition, 2014 IEEE. IEEE, 2014.
[17] Tellidou, Athina C., and Anastasios G. Bakirtzis. "Agent-based analysis of capacity withholding and tacit collusion in electricity markets." IEEE Transactions on Power Systems 22.4 (2007): 1735-1742.
[18] Chen H, Wong KP, Chung CY, Nguyen, DHM. A coevolutionary approach to analyzing supply function equilibrium model. IEEE Trans. Power Syst 2006; 17 (3):1019- 1028.
[19] Zhang SX, Chung CY, Wong KP, Chen, H. Analyzing two-settlement electricity market equilibrium by coevolutionary computation approach. IEEE Trans. Power Syst 2009: 8 (3): 1155-1164.
[20] Salarkheili Saeed, and Mehrdad Setayesh Nazar. "Capacity withholding analysis in transmission-constrained electricity markets." IET Generation, Transmission & Distribution10.2 (2016): 487-495.
[21] Fabra, Natalia, Toro, and Juan. “Price War and Collusion in the Spanish Electricity Market.” International Journal of Industrial Organization, vol. 23, pp. 155-181, 2005.
[22] Liu Dun-nan, He Guang-yu, Li Rui-qing, and Chen Xueqing. “Analytical method of Supplier’s Behaviors in Electricity Market. ” IEEE Conference on Power Systems Conference and Exposition, vol. 2, pp. 881-885, 2004.
[23] Xiaohong Guan. “Gaming and Price Spikes in Electric Power Markets and Possible Remedies.” IEEE International Conference on Power System Technology, vol. 21, pp. 58, 2002.
[24] Liu Dun-Nan, Wu Ya-Guang, Jiang Xiao-Liang, He Guang-Yu and Zhang Hua-Qing, “Key Performance Indices To Monitor Bidding Behaviors In Electricity Market.” IEEE Power Systems Conference and Exposition (PSCE '06), pp. 1156-1161, 2006.
[25] Wu Wei-Ku, and Wen Dan-Hui. “Preventing Tacit Collusion in Chinese Electricity Reform,” IEEE International Conference on Service Systems and Service Management, pp. 1-5, June 2007.
[26] Frezzi, P, Garces, F, and Haubrich, H.J. “Analysis of Short-Term Bidding Strategies in Power Markets.” IEEE Power Tech, pp. 971-976, 2007.
[27] Salarkheili, Saeed, and Asghar Akbari Foroud. "Market power assessment in electricity markets: supply function equilibrium-based model." International Transactions on Electrical Energy Systems 23.4 (2013): 553-569.

[28] Tellidou, A.C, and Bakirtzis, A.G. “Agent-Based Analysis of Capacity Withholding and Tacit Collusion in Electricity Markets”, IEEE Transactions on Power Systems, vol. 22, pp. 17351742, 2007.
[29] Feng Kong, and Hongyan Liu. “Analysis of Market Power of Oligopolistic Generators.” IEEE International Conference on Services Systems and Services Management, vol. 1, pp. 2002.
[30] Cau, T. D. H, Anderson, and Edward J. “A Co- Evolutionary Approach to the Tacit Collusion of Generators in Oligopolistic Electricity Markets: Piecewise Linear Bidding Structure Case.” IEEE Congress on Evolutionary Computation, vol. 4, pp. 2306-2313.
[31] Cain, M.B, and Alvarado, F.L. “The Impact of Uncertainty on Incentives to Collude in Electricity Market ”IEEE International Conference on Probabilistic Methods Applied To Power Systems, pp. 433-438, 2004.
[32] Anderson, E. J, and Thai DH Cau. "Implicit collusion and individual market power in electricity markets." European Journal of Operational Research 211.2 (2011): 403-414.
[33] Sapio, Alessandro, and Nicola Spagnolo. "Price regimes in an energy island: Tacit collusion vs. cost and network explanations." Energy Economics 55 (2016): 157-172.
[34] Aliabadi, Danial Esmaeili, Murat Kaya, and Güvenç Şahin. "Determining collusion opportunities in deregulated electricity markets." Electric Power Systems Research 141(2016): 432-441.
[35] Dijkstra, Peter T, Marco A. Haan, and Machiel Mulder. "Industry structure and collusion with uniform yardstick competition: theory and experiments." International Journal of Industrial Organization 50 (2017): 1-33.
[36] Schubert, Jens. "The impact of forward contracting on tacit collusion: Experimental evidence." Journal of Economic Behavior & Organization 119 (2015): 109-123.
[37] Baranes, Edmond, Marion Podesta, and Jean-Christophe Poudou. "Mixed bundling may hinder collusion." Research in Economics 70.4 (2016): 638-658.
[38] Baranes, Edmond, Marion Podesta, and Jean-Christophe Poudou. "Mixed bundling may hinder collusion." Research in Economics 70.4 (2016): 638-658.
[39] Nazir, M. S, and F. D. Galiana. "Fast computation of equilibrium market outcomes considering tacit collusion." European Energy Market (EEM), 2012 9th International Conference on the. IEEE, 2012.
[40] Shafie-khah, M, et al. "Regulatory support of wind power producers against strategic and collusive behavior of conventional thermal units." European Energy Market (EEM), International Conference on the. IEEE, 2016.
[41] Mohtavipour, S. S, and A. H. Gholami. "A step toward stable tacit collusion in electricity market." Electrical Engineering (ICEE), 2016 24th Iranian Conference on. IEEE, 2016.
[42] Moiseeva, Ekaterina, Mohammad Reza Hesamzadeh, and Ilias Dimoulkas. "Tacit collusion with imperfect information: Ex-ante detection." PES General Meeting| Conference & Exposition, 2014 IEEE.
[43] Tellidou, Athina C, and Anastasios G. Bakirtzis. "Agent-based analysis of capacity withholding and tacit collusion in electricity markets." IEEE Transactions on Power Systems 22.4 (2007): 1735-1742.