

Investigating the Effect of Collusion and Objective Function on Electricity Market through Genetic Algorithm

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Abstract

Collusion in electricity market is one of the different aspects of restructuration in electricity industry. Since in a restructured environment, electricity can be sold and transferred as a commodity, collusion is possible by the use of market power by any of the manufacturers in market. According to producers the solution of collusion can have two aspects: 1) Finding the way of favorable collusion by market producers. 2) Hiding of collusion from electricity inspectors. In this article first an electricity market with three producers has been considered and equilibrium point of Nash for this market has been found. With the use of Genetic Algorithm a condition for collusion of participants in market has been such calculated that income of all three increases. Then through calculating the interest of participants in collusion condition cost function of each of them has been found. For programing and simulating the presented relations MATLAB software has been used. The results showed that the use of objective function can increase the collective interest but the profit of each of units on its own does not have a favorable increase. Therefore, units by the use of genetic algorithms and adjusting the amount of production can increase their profits.

Key words: Collusion, Game theory, Nash equilibrium, Electricity market

INTRODUCTION

Monopoly of power industry has been challenged since 1968. While market players were uncertain of the evolution and change in the future perspective of the market and the price of electricity, after a decade, South American countries and then European ones have been changed structurally. Agreement between the Economic Community of Europe based on establishment of an internal free market, prevents monopoly and competition [6]. Lots of assertions have been represented about the benefits and advantages of a competitive market, but it would be wrong if it is assumed that, market is left free unconditionally and completely. Following this hypothesis, there would be no need to monitor market and it is thought that the

equilibrium point can be found by market spontaneously in which a wise distribution of resources and benefits has been done. The main objective of a business unit is to gain higher profit than the market which prepares that unit for more investments in the future. When the unit share of the market is not at favorable rate which provides its desired profit, unit adopts different ways to increase its profit. Collusion carried out legally in trade associations and consortiums is one of the ways. The collusion is the first phase in the integration of capital on the market, so that independence of business units is maintained in the market. Market conditions, determines the beginning and end of collusion. Given that each unit is looking for making more profit on the market, the estimated profit by each unit is calculated based on the best play of the opponents. Market equilibrium price is a case in which none of the units can increase their profits based on their play. Therefore, the present study aims to investigate the collusion of participants in the electricity market and its impact on energy prices in the electricity market, during which the possibility of collusion among some participants in the market and its effect on the profit and loss of colluding ones and other units will be discussed to respond to the following questions. In terms

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of practical application, the results of this study can be used to control the behavior of units and energy prices.

1. Is it possible to present objective functions for people who are Colluding in electricity market to increase amount of profit for participants?
2. What is the impact of using objective functions on profit of producers?

A review of Previous Research

Electricity market is a niche market in many ways. Due to the small number of players in most markets and the homogeneous nature of the produced goods, it can be considered as an ideal place for collusion. In general, the high elasticity of demand in the market can lead to more difficult conditions in which collusion should be done. Research on collusion modeling of production units in electricity market have been conducted with the help of game theory in which the electricity markets, due to their characteristics cannot be considered as a fully competitive market. Especially because of the relatively small number of producers it can be called a competitive multilateral market. This issue was intensified with the outbreak of crisis of the 90s and in 2001 in the electricity markets of the world. In this case, the power of the constituent factors increased the market price of the competition level. On the one side, there is also the possibility of collusion between market units that cause market prices to go to higher. On the other side, price rising in collusion is affected by the dependence of load on the market. Some examples of collusion in electricity markets have been observed around the world. For instance in England and Wales electricity market in the 1990s, two great companies of PowerGen and National Power without real competition together, had kept prices above the total marginal cost of market [8]¹. In California in 2000 and 2001 joint action of many companies to decline production level led to a serious crisis [5]². Two Major companies of Iberdrola and Endesa in Spain refrained from competing and did not attempt to reduce market price [4]³. In Shanghai, six big energy companies by offering a higher price and reducing the amount of their own production have tried to raise prices of market to their advantage [7]⁴. However, not much work has been done in this field. In recent years,

most of the researches carried out in this field have been conducted in California, especially after the crisis in 2000 and 2001. Previous works have two overall approaches to the issue of collusion. Some researchers have studied the market from the perspective of theory to describe the conditions, and situation of the market and the possibility of collusion [9]⁵. Also, in some cases, collusion is assumed to be equivalent to a kind of monopoly, in which due to differences of collusion with a monopoly, some questions are raised about this assumption [3]⁶. So rather than simulating, a market potential analysis in some specified states of load and price has been used in a dual market [2]⁷.

Game theory is a branch of applied mathematics which is implemented in different fields especially in economics. Game theory tries to provide mathematical methods to determine the best choices and movement for players. Each game has a set of players and a set of strategies or actions. Move selection of actions and strategy by each of the players is done according to the behavior of competitors. Each of the players will try to maximize the value of their payoff function. In case of rational and logical behavior of players in market, the outcome of the game lead to a point or set of equilibrium points in which the highest profit is gained or the lowest loss is imposed on players. Movements of players are chosen based on the principle of their rational behavior. In this situation, players can know the results of their choice and consequently select the best choice. If the optimal strategy can be chosen independently of the behavior of other players, the game has a dominant equilibrium point. High prices will disappoint customers and therefore reduce their level of consumption. In this case, clients look for alternative products or ones at a lower rate. They also seek current market or those in other geographic areas. This will also tempt current producers to reduce prices for their products in a unilateral effort or raise the production level so that they can increase their sales and profits. If current firms attempt to collude in the market, they will gain higher profits rather than competition. This problem makes the producers hesitate about adoption of decision whether to participate in collusion or leave it in order to compete with others. Agreements may

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also encounter the danger of collapse. Hence, collusion is similar to Hawk-Dove scenario in game theory. Therefore in this study, the calculation related to collusion is presented in a condition which cost function is a quadratic function then the relationship between profit gained by participants in Nash equilibrium point and conditions of collusion including different objectives will be achieved.

Collusion by the Three Participants

In this model, three participants with quadratic cost functions (1) to (3) are defined who agreed to have collusion with each other and increase their proposed price to a certain amount. Then the linear model of the cost function for these three producers has been obtained while it has been tested through a simulation. Theoretically, it has been calculated as follows:

$$C_A = 15 + 1.4P_A + 0.04P_A^2 \quad (1)$$

$$0 \leq P_A \leq 120$$

$$C_B = 25 + 1.6P_B + 0.05P_B^2 \quad (2)$$

$$0 \leq P_B \leq 120$$

$$C_C = 20 + 1.8P_C + 0.02P_C^2 \quad (3)$$

$$0 \leq P_C \leq 120$$

$$\pi = 120 - D \quad (4)$$

$$D = P_A + P_B + P_C \quad (5)$$

$$\Omega_i = \pi P_i - C_i \quad (i \in \{A, B, C\}) \quad (6)$$

π in the equations reflects the price of electrical energy that is related to the D (i.e. Amount of Demand) in equation (4). The relationship between price and demand is an empirical relationship which is obtained on the network by collecting information about prices and demand and fitting a downward linear curve. P represents the production amount of each participant while Ω shows the profit of each participant in the electricity market. Power grid structure for simplicity is considered in a way that manufacturers shed their generated power in a pool and consumers get it. As a result, the loss of transmission lines has been ignored. The presence of such losses can be considered as a load and consequently can be modeled. Figure 1 according to equation (1) shows the quadratic cost function of manufacturer A.

According to equation (2) the quadratic cost function of manufacturer B is like Figure 2.

Figure 3 is the quadratic cost function of manufacturer C which has been drawn according to equation (3).

According to equation (4) on-demand price curve as shown in Figure 4 can be obtained as follows.

Equations to calculate the Nash equilibrium can be expressed as follows:

$$\Omega_A(P_A, P_B, P_C) = \pi(D) \cdot P_A - C_A(P_A) \quad (7)$$

In equation (7) the profit of participant A is a function of participant A and two other participants which can be obtained through multiplying the market price in production amount of A minus the cost of production A. Equations (8) and (9) are achieved through multiplying the market price in production amount of B or C minus the cost of production B and C.

$$\Omega_B(P_A, P_B, P_C) = \pi(D) \cdot P_B - C_B(P_B) \quad (8)$$

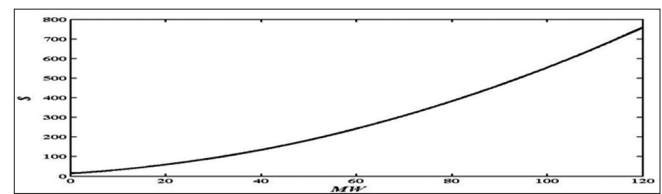


Figure 1: Cost function of participant A

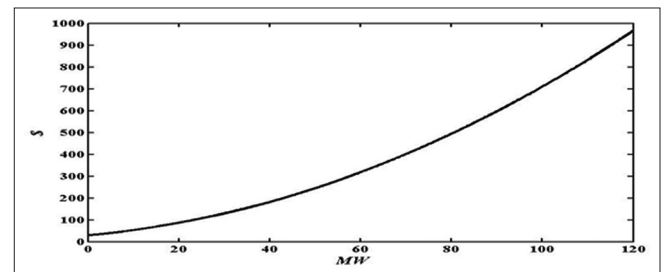


Figure 2: Cost function of participant B

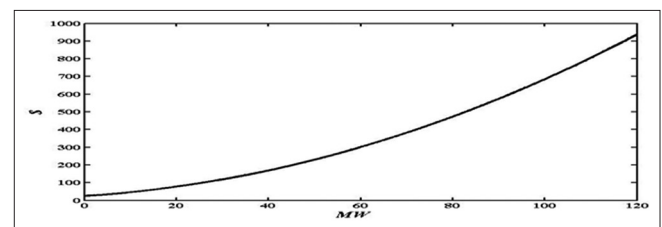


Figure 3: Cost function of participant C

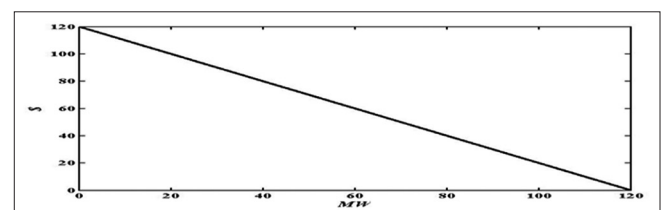


Figure 4: Demand function

$$\Omega_C(P_A, P_B, P_C) = \pi(D) \cdot P_B - C_B(P_B) \quad (9)$$

In order to obtain the Nash equilibrium conditions it is necessary to make sure that none of the manufacturers can increase their profits at the point of equilibrium alone. Mathematically, this can be expressed by zero derivation of the profit of each manufacturer to the production in Nash equilibrium.

$$\frac{\partial \Omega_A}{\partial P_A} = \pi(D) - \frac{d C_A}{d P_A} + P_A \cdot \frac{d \pi}{d D} \cdot \frac{d D}{d P_A} = 0 \quad (10)$$

$$\frac{\partial \Omega_B}{\partial P_B} = \pi(D) - \frac{d C_B}{d P_B} + P_B \cdot \frac{d \pi}{d D} \cdot \frac{d D}{d P_B} = 0 \quad (11)$$

$$\frac{\partial \Omega_C}{\partial P_C} = \pi(D) - \frac{d C_C}{d P_C} + P_C \cdot \frac{d \pi}{d D} \cdot \frac{d D}{d P_C} = 0 \quad (12)$$

Nash Equilibrium, Prices and Profits in Theory Case

According to the equations (10) to (12) result can be obtained as follows:

$$\begin{aligned} \frac{\partial \Omega_A}{\partial P_A} &= \frac{\partial \pi}{\partial D} \cdot \frac{\partial D}{\partial P_A} P_A + \pi - 1.4 - 0.08 P_A \\ &= 2.08 P_A + 118.6 - P_B - P_C = 0 \end{aligned} \quad (13)$$

$$\begin{aligned} \frac{\partial \Omega_B}{\partial P_B} &= \frac{\partial \pi}{\partial D} \cdot \frac{\partial D}{\partial P_B} P_B + \pi - 1.6 - 0.1 P_B \\ &= -2.1 P_B + 118.4 - P_A - P_C = 0 \end{aligned} \quad (14)$$

$$\begin{aligned} \frac{\partial \Omega_C}{\partial P_C} &= \frac{\partial \pi}{\partial D} \cdot \frac{\partial D}{\partial P_A} P_A + \pi - 1.8 - 0.04 P_C \\ &= -2.04 P_C + 118.2 - P_A - P_B = 0 \end{aligned} \quad (15)$$

Through the calculation of (15) and its insertion in the other two equations, we have:

$$\begin{aligned} P_C &= \frac{-P_A}{2.04} - \frac{P_B}{2.04} + \frac{118.02}{2.04} \\ -1.59 P_A - 0.51 P_B + 60.66 &= 0 \\ -0.51 P_A - 1.61 P_B + 60.46 &= 0 \end{aligned} \quad (16)$$

According to the relationships obtained in (16) two equations with two unknowns is obtained by solving these equations the results of the production of units are as Table 1 which is referred as Nash equilibrium point:

The most important characteristic of the Nash equilibrium point is that none of the players can increase their profits

Table 1: Nash equilibrium point of the production of units

Production (A)	Production (B)	Production (C)
29.05	28.36	29.81

Table 2: Price and profit of units

Price (\$/MWh)	Profit A (\$/MWh)	Profit B (\$/MWh)	Profit C (\$/MWh)
32.78	862.83	819.05	885.74

individually and only through changing their productivity power. After obtaining the Nash equilibrium conditions, the aim is to achieve such a production conditions that players gain greater profit than the equilibrium point. Achieving these requirements is not possible without the cooperation of manufacturers together. This mode is referred as collusion. To review the collusion terms and how much each of the producers should produce to benefit more was investigated through genetic optimization algorithm (Table 2).

Introducing Objective Functions

Different objective functions can be expressed for this algorithm. Four kinds of objective functions have been introduced and used in which each one increases profit of producers from a point of view. Parameters that are used to optimize objective functions include the production capacity of each unit that in this question their number is considered to be. Electricity prices and profit of each manufacturer is a function of their production power. If the objective function is the sum of the profits gained by three manufacturers, we have:

$$Obj.Func1 = \Omega_A + \Omega_B + \Omega_C \quad (17)$$

If the relationship (17) is used, it is possible to maximum the total profits, while profits of some players do not change much. Therefore, the prerequisite of mentioned objective function is that manufacturers are required to share their profits with the others in collusion. Way of dividing profits between manufacturers in this case, depends on the agreement of parties. If producers tend to increase profits, each one independently, the following objective function (18) can be used:

$$Obj.Func2 = \sqrt{\Omega_A} + \sqrt{\Omega_B} + \sqrt{\Omega_C}$$

In case of using (18), increase in profits will occur for all producers. If the weighted profit boost is desired, i.e. the manufacturer whose production was more profitable than before collusion, claims that they must have double profit in existing condition of collusion; equation (19) can be utilized:

$$Obj.Func3 = \Omega_A^* (\Omega_A - \Omega_A^*) + \Omega_B^* (\Omega_B - \Omega_B^*) + \Omega_C^* (\Omega_C - \Omega_C^*) \quad (19)$$

Where, Ω_A^* , Ω_B^* and Ω_C^* are the profits of A, B and C producers in the Nash equilibrium. If the aim of the collusion is that the more expensive unit which cannot have appropriate production rate and profits in normal market conditions, produces a greater deal, an objective function can be defined as equation (20), which leads to a relative increase in profits and production rate of more expensive units.

$$Obj.Func4 = \frac{\Omega_A - \Omega_A^*}{\Omega_A^*} + \frac{\Omega_B - \Omega_B^*}{\Omega_B^*} + \frac{\Omega_C - \Omega_C^*}{\Omega_C^*}$$

In order to find the appropriate objective function and earn more profit the studied electricity market has been simulated in the presence of three producers colluded with various conditions of collusion based on objective functions of (17) to (20) by using genetic algorithm. The results of this simulation which includes investigating the production rate of units, checking the amount of profit per unit, and profit boost in different conditions of collusion have been obtained compared to Nash state. Total profit of Participants in collusion who are present in the market has been calculated. Obtained Price from each function in the Table 3 can be observed.

The profit of all manufacturers using different objective functions has been plotted in Figure 5 according to the Table 3 where the profit of each of the four objective functions for each producer has been shown.

As indicated in the Table 3, when the objective function 1 is used, total profits have been increased but profit of each

unit does not impressively increase and only unit C has benefited significantly. In order to achieve satisfaction of two other units the profit of Unit C is required to be divided among all units. This segmentation can be done based on previous profits of each unit in Nash equilibrium and due to those mentioned proportions. Therefore, we have:

$$\begin{aligned} \Omega_A &= 3405.6 \times \frac{862.83}{2567.62} = 1144.42 \\ \Omega_B &= 3405.6 \times \frac{819.05}{2567.62} = 1086.35 \\ \Omega_C &= 3405.6 \times \frac{885.74}{2567.62} = 1174.6 \end{aligned} \quad (21)$$

In this case it seems that this condition is best and fairest state for producers provided that the manufacturer of C consents to divide their profit. Otherwise, the closest state to this situation is when the objective function (2) is used. Although each of the producers' profit is slightly less than C, there is no need to exchange money between producers.

A point that is observed in Table 3 is an increase in electricity prices as a result of collusion among producers in which makes detection of collusion occurrence easy for network supervisor. In this way, manufacturers can implement colluding gradually by changing in the form of the objective function (22) so that the increase in prices seems more natural.

$$Obj.Func5 = \sqrt{\Omega_A} + \sqrt{\Omega_B} + \sqrt{\Omega_C} - k \times (\pi - \pi^*) \quad (22)$$

Where k is the coefficient of gradual progress in collusion demonstrates price in the condition of collusion and is an indicator of price in terms of Nash equilibrium conditions. Manufacturers using objective function (22) have colluded

Table 3: Optimization results using objective functions

	Production A (MW)	Production B (MW)	Production C (MW)	Total profit	Price (\$/MWh)
	A Profit	B Profit	C Profit		
	Profit increase A (\$/h)	Profit increase B (\$/h)	Profit increase C (\$/h)		
Nash equilibrium	29.05 862.83 0	28.36 819.05 0	29.81 885.74 0	2567.62	32.78
Objective.function1	17.93 1035.9 173.07	25.96 831.4 12.35	25.96 1538.3 652.26	3405.6	50.15
Objective.function 2	24.86 1049.6 186.77	24.39 1016.7 197.65	25.4 1077.6 191.86	3143.9	45.51
Objective.function 3	17.86 1044.5 181.67	14.33 882.0 3	26.39 1539.1 653.36	3405.6	61.40
Objective.function 4	15.02	27.91	15.31	3390.94	61.75

gradually to be away from monitoring of electricity market supervisors. Figure 6 shows the way of changes in produced power per unit. The way of changes in profit is observed in Figure 7. Figure 8 indicates graph of price changes during this process.

Collusion by Four Participants

In the previous section, some calculations were done in relation to the collusion of three participants. In this section the number of participants who collude with each other has increased. Four participants have been introduced with quadratic cost functions in accordance with the relations of

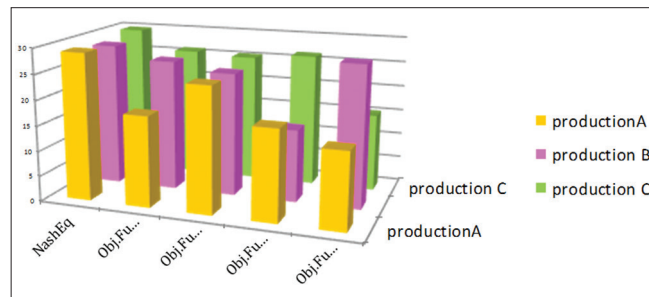


Figure 5: The amount of production in market units

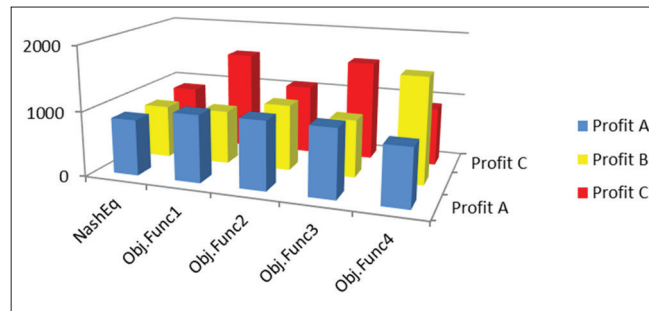


Figure 6: The profit of producers with proposed functions

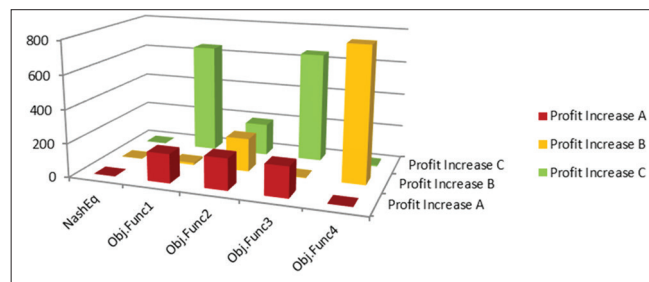


Figure 7: Increase in the profit of producers

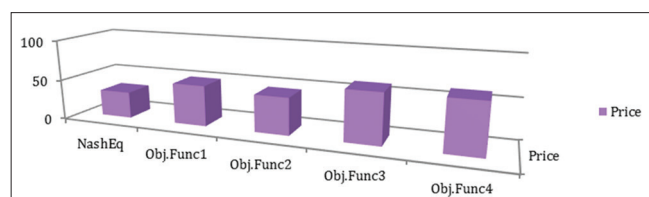


Figure 8: Price at Nash equilibrium and proposed functions

(23) to (26) who have agreed to collude in order to increase proposed price (Figures 9-11).

$$C_A = 15 + 1.4 P_A + 0.04 P_A^2 \quad (23)$$

$$C_B = 25 + 1.6 P_B + 0.05 P_B^2 \quad (24)$$

$$C_C = 20 + 1.8 P_C + 0.02 P_C^2 \quad (25)$$

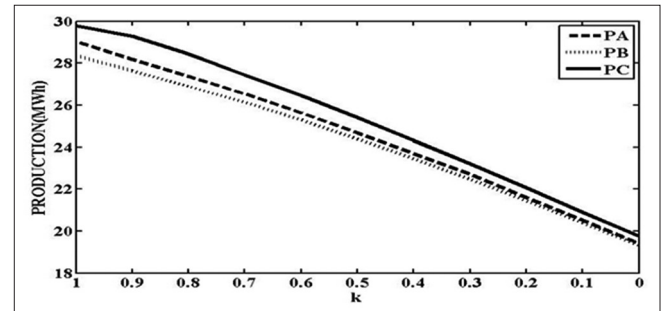


Figure 9: Changes in production per unit during the progressive collusion

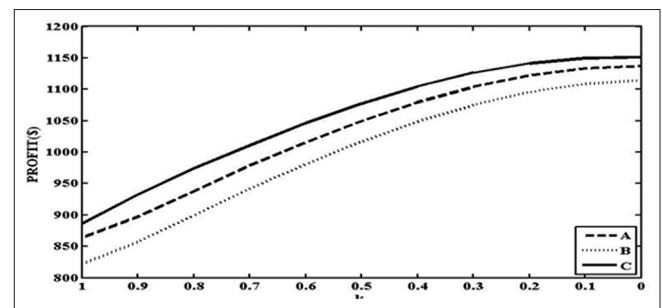


Figure 10: Changes in profit during the progressive collusion

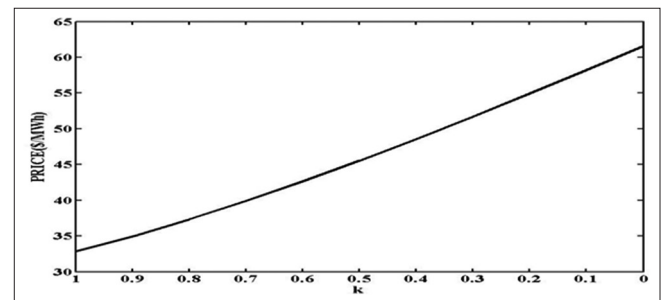


Figure 11: The price changes during the process of gradual collusion

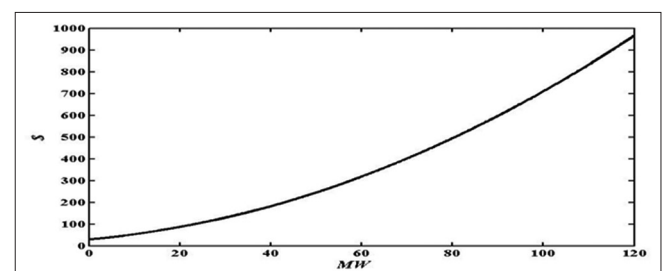


Figure 12: Cost function of participant D

Table 4: Results of Nash equilibrium

	Unit A	Unit B	Unit C	Unit D	Price (\$/MWh)
(MW) production	23.52	22.91	24.04	22.73	26.80
Profit	560.27	526.09	569.43	512.38	

Table 5: Results by using second objective function

	Unit A	Unit B	Unit C	Unit D	Price (\$/MWh)
(MW) production	14.58	14.59	14.78	14.63	61.40
Profit	851.43	837.34	856.91	831.38	

$$C_D = 30 + 1.8 P_D + 0.05 P_D^2 \quad (26)$$

$$\pi = 120 - D$$

$$\pi = 120 - (P_A + P_B + P_C + P_D) \quad (27)$$

Figure 12 is the quadratic cost function of manufacturer D, which is drawn according to equation (26).

Investigation of Nash Equilibrium

In theory, productions of unit, price and profits have been obtained and shown in the Table 4 according to the manufacturers' cost functions and also based on the relations of (7) to (12) and by calculating the Nash equilibrium.

After attaining the conditions of Nash equilibrium, business units try to achieve more profit rather than Nash equilibrium. The results of productions, profit of units and price have been acquired as shown in Table 4 in which the objective function (2) and equation (18) has been used in their calculation.

As shown in Table 5, it is observed that production of business unit has been diminished by using second objective function, but the profit of all units has independently been increased. The market price was also higher than the Nash equilibrium.

CONCLUSION

There is the possibility of collusion with the use of market power by any of the manufacturers of the electricity market. So, producers to achieve higher profit should cooperate and collude with each other. We have tested five objective functions to increase the profits of producers with genetic algorithms was. The results indicated that the use of objective function can increase the total profit but it doesn't have an effective increase on each of the units and only one of the units (unit C) obtains higher benefit that in order to benefit other units, unit C according to previous profits of units in the Nash equilibrium, is obliged to splits its profit with other units. Therefore, units can increase their profits by the use of genetic algorithms and adjusting the amount of power produced.

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