А - доповнення до моделювання електроенергетичного ринку на основі теорії ігор згідно з фізичними обмеженнями

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Реструктуризація енергетичної системи перетворює електроенергетичний ринок з монопольного на конкурентоспроможний, але, через певні технічні причини, цей ринок відрізняється від традиційного ринку. Тому структуру електроенергетичного ринку можна вважати радше олігопольною ніж повністю конкурентоздатною, тобто такою, яка має обмежену пропозицію. На ринку такого типу ціни відрізняються від цін конкурентного ринку, але дорівнюють граничним витратам виробництва. Поведінка суб'єктів ринку змінює цінову рівновагу, або клірингову ціну, тому дослідження різноманітних ситуацій на ринку є актуальним для його суб'єктів. Протягом останнього десятиліття Ігрова теорія стала актуальною для моделювання ринкової поведінки на основі стратегічних рішень суб'єктів ринку. Основним завданням конкурентного ринку є максимізація прибутку, кількості виробників та споживачів, але на олігопольному ринку виробники, з допомогою енергетичного ринку, можуть змінити умови та максимізувати свій дохід. У певній літературі, присвяченій сфері енергетичної системи, зосереджено увагу на моделюванні ринку електроенергетики з допомогою ігрової теорії. В цій роботі пропонується низка найоптимальніших методів моделювання ринку, подається їхня оцінка з погляду кількісного показника та пояснюються їхні загальні риси. Метод, запропонований в цій роботі, включає в себе метод Курно та метод гіпотетичної функції пропозиції. У першій частині, для оцінки діяльності ринку з використанням різних методів моделювання, подано певні оцінювальні показники, як наприклад показники Лернера , показники неприбутковості ринку, показник зменшення прибутку виробника, та показник системного впливу, який показує вплив фізичних обмежень системи. Така оцінка зможе допомогти обрати найоптимальніший метод для моделювання різних енергетичних ринків на сонові аналізу фінансового та технічного становища.

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A Novel on Electricity Market Modeling Based on Game Theory According to Physical Constraints

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This paper conduct a general comparative study on game theory based models for electricity market performance according to network physical constraints. Main paper focus is on quantity based offering method. Therefore, some methods in this category evaluated and market performance index introduced for numerical judgment.

Keywords – electricity market, game theory, cournot equilibrium, conjectural supply function, physical constraints of network

I. Introduction

Scarcity of resources in the energy field leads to increasing energy conversion efficiency, traditional configuration of electricity generation, transmission and distribution process as a monopoly did not provide proper bed for competence. Therefore, many countries restructure their electricity market structure to become closer to competitive infrastructure, certainly the electricity market like other markets does not have complete competition behavior and more inclines as oligopoly structure. According to the microeconomic classic theory in a complete competitive market goods' costs are clear equal to marginal production costs, and producers are price takers, in comparison when supplier's numbers are limited market power let to their swell profit. In this situation evaluation of market participants' behavior must be considered for optimizing bidding strategy. Game Theory is a powerful tool in modeling of the strategic situation in economic literature. Game theory also used for modeling of electricity market in recent years [1], [2]. In this paper electricity market clearing model and game theory fundamental presented, and some modeling method compared.

II. Electricity Market

Principally, the electricity market is a market-based competition. Various types of structures introduced in literatures [3, 4]. This paper focus on a type of models called bilateral, in this method each supplier would directly or indirectly to consumers. Consumers can also purchase to order from any of vendors.

The two most common deals structures popularity are:

1. Cash market, cash market prices based on the theory of Accepted the offer.

2. The offer market, based on the latest accepted offer theory.

In each of these structures, a non-profit organization named ISO (Independent System Operator) supervise technically and financially market. In this arrangement, any of supplier or consumers offers their bid to market, and ISO manages market supply and demand. Interaction between demand and supply formed price.

A typical demand and supply curve based on price depicted in Fig. 1.

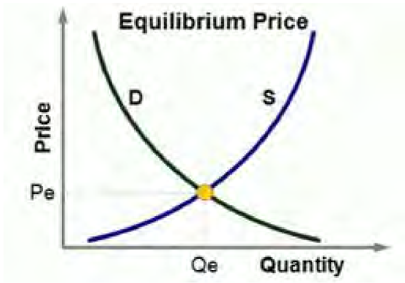

Fig. 1

As shown in Fig. 1, increasing price cause to increase supply, because lead to more profit for suppliers and suppliers motivate to more production. On the contrary consumers decrease demand for controlling their outcomes. This dynamic interaction cause to change price until reach to equilibrium point called market clearing price. This price maximized both supplier and consumer revenue. Fig. 2 illustrate every participants' profit.

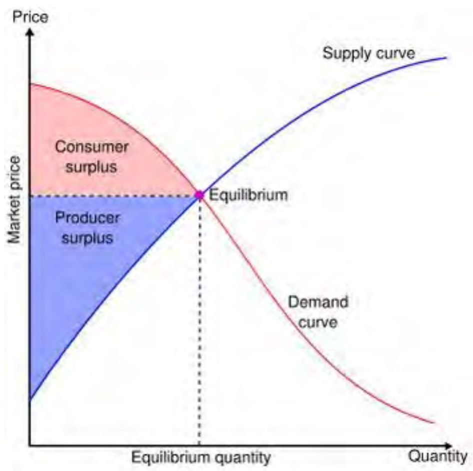

Fig. 2

Difference between maximum price that consumer want to pay for a good or service and clearing price called consumers' surplus and difference between minimum price that satisfy supplier to start production and clearing price called producer surplus. ISO duties are maximize supplier and consumer profit that summation of these two items called social surplus according to network constraints. This action mathematically can be expressed as Eq. 1[5]

$$\max S^{s} = f(q,H,e,B^{m},p,a^{m}) \quad (1)$$

Where S^{s} is social surplus, q is the demand vector. □ and e are intercept and slope intercepted demand respectively, is power production vector, B^{m} and a^{m} are intercept and slope value of marginal production cost in that order.

Network constraints are:

- Production must be equal to consumption.
- Transmission line cannot be overloaded
- Production unit have a minimum and maximum generation limits that must considered.

III. Game Theory

Game theory is a useful tool in the last six decade for modeling oligopolistic markets. Game theory basic elements include:

- Game: Any strategic situation
- Player: All participants in strategic situation can change game output with him/her decision
- Actions: option available to a player.
- Common knowledge: Knowledge that a player has when making a decision.
- Strategy: Rules that tell a player which action to take at each point of the game.
- Outcomes: The results that unfold
- Payoffs: The utilities that each player realizes for a particular outcome.
- Equilibria: Equilibrium is a steady result.

In this method, market evaluated as a game between several rational players, which try to maximize their income under predetermined rules called game rule. Any action based on rational decision and available information for each player to maximize profit called strategy. Games in this theory can be categorized as dynamic and static. Electricity market model as a dynamic market.

IV. Electricity Market Modeling

Main problem in the electricity market for each supplier is maximizing their revenue. Each supplier unit income can be written as Eq. 2

$$\max S_{g}^{G} = l_{g} p_{g} - a_{g}^{m} p_{g} - \frac{1}{2} b_{g}^{m} p_{g}^{2}, \forall g \in G \quad (2)$$

Where S_g^G is surplus of producer g, l_g is offered price of g[th] supplier. Solving this problem is subject of many papers. Several methods used for in these papers, which can be categorized in two main groups

- Price based model
- Quantity based model

Price based model is not beneficial in the oligopoly market. Consequently, many work focus on quantity based modeling include Cournot model in this method of modeling. Suppliers are assumed to offer quantities in the market equilibrium price. A Cournot – Nash's equilibrium is quantities such that no player has an incentive to deviate unilaterally from it. Electricity markets have been modeled using Cournot method under constrained and unconstrained discussed in previous. Suppliers are assumed to bid their output quantity separately and ISO clears the market to balance supply and demand. Literature that use of the Cournot approach for some purpose in [6] and [7] this method used for evaluation of market power, in [8] transmission capacity topic discussed, and in [9] clearing prices modeled.

Second popular modeling method is Conjectural Supply Function (CSF) [10]. In a supply function model, the suppliers are supposed to offer supply curves, and the supply function equilibrium is reached when no player can profit by unilaterally deviating from the equilibrium play. These models are more accurate but their analysis complex, also in first method decision of each supplier independent from the competition condition but in third method, every supplier can predict the completion conditions and act according to the other's decision.

For numerical comparison of these two methods several markets assessing indices used that include [5]:

- Lerner Index
- Market inefficiency Index
- Producer surplus deviation Index
- Network impacts Index

Lerner index describes market power to deviate from clearing price from marginal production cost. Eq.3 depicted Lerner index calculation method.

$$s = (l - l^P) / l \quad (3)$$

Where l is price at a desired bus at oligopoly market, and noticeable that superscript P show perfect competitive condition in all formulas. Market inefficiency index designate normalized social surplus deviation in an oligopoly market from the perfect competition condition. This index evaluates all market participants', supplier and consumer, revenue. This index mathematically can be expressed as Eq. 4

$$x = (S^s - S^{sP}) / S^{sP} \quad (4)$$

Where S^s is social surplus at If S^G designate supplier's surplus, Eq. 5 show formula for this index

$$i = (S^G - S^{GP}) / S^{GP} \quad (5)$$

Network constraints as mentioned previously, limit complete perfect condition and cause deviation prices from that equilibrium point. Last factor shows these physical limitations effects.

$$t = (S^s - S_u^s) / S_u^s \quad (6)$$

Eq. 6 shows network constraints impact, where subscript u denotes parameter value with constraints' impact.

For assessing market efficiency any of these indices can be used.

Conclusion

This paper contains a brief introduction about electricity market after restructuring from monopoly to oligopoly. Game theory introduced as a useful tool for market performance evaluation. This performance should include both financial and technical issues. Technical constraints cause to rising market power that lead to declining consumer surplus and growing prices, therefore this is not ignorable issue in electricity market modeling. Between game theory modeling methods, quantity based offering is more useful hence this paper focus on this type of modeling method and compare those. In last section some performance indices introduced for comparing this method numerically.

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