Market Power Appearance through Game Theoretic Maintenance Scheduling of Distributed Generations

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Abstract – *The oligopoly structure of the market and the network constraints may produce results far from the perfect competition. Maintenance decisions in an oligopolistic electricity market have a strategic function, because GENCOs usually have impacts on market prices through capacity outages.*

This paper describes generation maintenance planning in an oligopolistic environment as a strategic decision. In this paper a game theoretic framework is modeled to analyze strategic behaviors of GENCOs. Each GENCO tries to maximize its payoff by strategically making decisions, taking into account its rival GENCOs' decisions. Some GENCOs own DG units, such as wind, diesel, biomass and fuel cell plants. If different GENCOs find out they have the conditions of exerting market power exact in maintenance periods; they will share their data and they will cause some area monopolies.

Cournot-Nash equilibrium is used for decision making on maintenance problem in Oligopolistic electricity market. The Cournot-Nash problem is modeled as a mixed integer nonlinear programming optimization problem. The analytic framework presented in this paper enables joint assessment of maintenance and generation strategies.

***Keywords**: Cournot-Nash equilibrium, game theory, distributed generation, maintenance scheduling of generating units, market power, monopolistic and Oligopolistic market.*

I. Nomenclature

Variables:

$g_{ij}(t)$	Power generated by unit *j* of GENCO*i* in period *t* (MW).
$G(t)$	Total energy supply in period *t* (MWh).
i	GENCO.
j	Generating unit.
$m_{ij}(t)$	Binary maintenance decision variable for unit *j* of GENCO*i* in period *t* (1 if unit *j* is on maintenance in period *t* and 0 otherwise).
t	Time period.
T	Number of time periods.
$P_i(t)$	Total energy supply of GENCOi in period t (MWh).

Constants:

$\gamma(t)$	Intercept of the linear price/demand curve (\$/MWh).
$\lambda(t)$	Slope of the linear price/demand curve $(\$/(\text{MWh})^2)$.
a	Per unit constant.
$D(t)$	Power demanded in period *t* (MW).
FOR_{ij}	Forced outage rate of unit *j* of GENCO*i*.
G_i	Set of indices of generating units owned by GENCO*i*.
$h(t)$	Hours of period *t*.
I	Number of GENCOs.
MC_{ij}	Maintenance cost of unit *j* of GENCO*i* (\$/MW).
M_i	Maximum numbers of units in maintenance for GENCO*i*.
N_{ij}	Duration of the maintenance outage of unit *j* of GENCO*i*.
$P_{ij}^{\max}$	Capacity of unit *j* of GENCO*i*.
PC_{ij}	Production cost of unit *j* of GENCO*i* (\$/MWh).
$R(t)$	Reserve requirement in period *t*.
$v(t)$	Wind speed in period *t*.
v_{Iij}	Cut-in wind speed of wind unit *j* of GENCO*i*.
v_{Oij}	Cut-out wind speed of wind unit *j* of GENCO*i*.
v_{Rij}	Rated wind speed of wind unit *j* of GENCO*i*.
$WP_{ij}^{\max}(t)$	Available capacity of wind unit *j* of GENCO*i*.
$\varphi(\bullet)$	Wind power curve of wind unit *j* of GENCO*i*.

II. Introduction

One of the optimization problems for mid-term power systems operations planning is Maintenance strategy which seems complicated. Some methods have been proposed recently to solve the maintenance scheduling of generating units. As a matter of fact, it is determining the maintenance duration for individual generators subject to several constraints over a given horizon.

In a centralized electric power system, an appropriate generation maintenance scheduling is derived by the system operator and imposed to producers [1]. The reliability evaluation of maintenance scheduling and least-cost optimization algorithms had been one of the main concerns for the last few decades [2]. In most of the previous works, however, generators are maintained or not for system-wide reliability or least-cost rather than for their own profitability. In the new competitive environment, customers request for high reliability services with lower electricity prices, while GENCOs have to make their own profit [3].

In a competitive market environment, unit maintenance scheduling is determined through multiple interactions between ISO and GENCOs. It is objective law of the market that every economic individual follows its own maximization of benefits; therefore, GENCOs will try to schedule their units for maintenance in order to maximize their benefit. The ISO seeks a generation maintenance annual plan that ensures similar reliability through the weeks of the year, prior to the ISO's coordination process, individual GENCOs should have their own maintenance strategies in advance [3].

In deregulated power systems usually GENCOs have independence to maintain their generators in a decentralized manner [4]. Strategic behaviors of GENCOs can be modeled in a game theoretic framework, and players of the game correspond to GENCOs.

Maintenance of generating units may cause outage of a significant amount of its capacity. Withdrawing generation capacity is a strategic decision GENCOs adopt in order to increase electricity prices. Maintenance decisions is a way of withdrawing some parts of generation capacity for a period of time, therefore, it has potentially major impacts on spot prices and attains a strategic dimension in oligopolistic electricity markets [4].

There are two types of methods for developing bidding strategies in electricity markets: game-based and nongame-based methods. The game-based method, which will be used in this project, utilizes the game theory to simulate bidding behaviors of Gencos and develop Nash equilibrium bidding strategies for them in electricity markets.

Usually, the bidding strategies of Gencos are based on their opponents' bidding behavior, the forecasted demand, and at last but not least power system operating conditions. Hence the bidding strategy problem is formulated as a bi-level problem in which the upper-level sub-problem maximizes Genco's payoffs and the lower-level sub-problem solves the market clearing problem.

In the real markets, many factors or parameters may be effect on the bidding strategy of Gencos. One of the most important parameter is demand elasticity. In a real market, the amount of demand isn't independent of price and price increment is equal to demand decrement. In this condition, Gencos should devise a good bidding strategy with regard to demand elasticity. The other important parameter is Genco's tendency to sell their outputs in the other markets such as ancillary service markets (Reserve, reactive, and …). As known, in the restructured power system, the services, which provide the security and safety of system, are obtained through markets namely Ancillary service markets. In the power systems, the supply for reserve comes from generators, which also supply the energy market; therefore the energy and reserve markets should operate simultaneously. Because of price difference between energy and reserve market, the allocated capacity for each market is very important and will affect on the obtained profit of Gencos [5]. Therefore, Gencos should try to maximize their accumulated profits in both markets with choosing the optimum bidding strategy.

In this study, a game theoretic framework is suggested to solve maintenance scheduling of generating units including DGs under oligopolistic market environment. Gaming considerations can earn GENCOs higher profit because they can effectively exercise market power when their competitors' capacity is on maintenance [4]. The optimal strategy profile is defined by Cournot-Nash equilibrium of the game.

A hypothetical test system is considered to show the applicability of the proposed model. The results obtained point out that maintenance scheduling can be one of the important strategic behaviors whereby GENCOs maximize their profit in an oligopolistic. Their behavior is also compared due to changes in price elasticity.

III. 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 [6]. Market power due to market dominance is a scenario that applies for every imperfect market and it does not belong to electricity markets. On the electricity market, a supplier that is large enough to affect the 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 [7].

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 [8]. 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 [9]. 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 [10].

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.

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 [11].

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 [12]. Conclusively, transmission constraints in the electricity market make it possible even for a small supplier to exploit market power.

IV. Monopoly and Monopolistic Competition

Monopolistic competition is a market structure where there are many firms (like a competitive market), but these firms have some market power (they are able to set price above MC profitably). A monopoly is the only supplier of a good for which there is no close substitute.

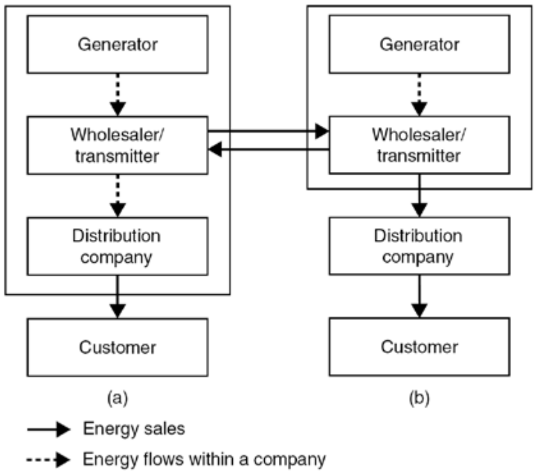

Fig 1. Monopoly model of electricity market based on (Hunt and Shuttle worth, 1996)

The *Minimum Efficient Size* (MES) of a firm in a particular industry provides a rough indication of the number of competitors that one is likely to find in the market for the product of this industry. This MES is equal to the level of output that minimizes the average cost for a typical firm in that industry. The shape of this curve is determined by the technology used to produce the goods. If, as illustrated in Figure 2(a), the MES is much smaller than the demand for the goods at this minimum average cost, the market should be able to support a large number of competitors. On the other hand, if, as shown in Figure 2(b), the MES is comparable to the demand, the market cannot support two profitable firms and a monopoly situation is likely to develop.

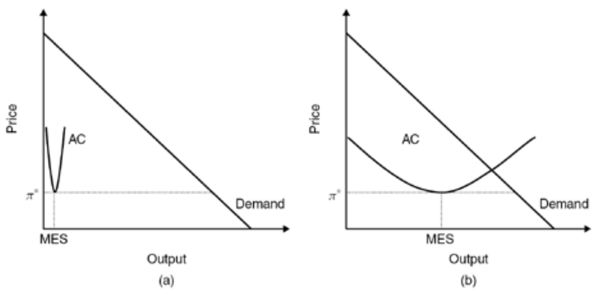

Fig 2. Concept of MES. (a) Competitive market, (b) Monopoly situation

Transmission is a natural monopoly. It is currently almost inconceivable that a group of investors would decide to build a completely new transmission network designed to operate in competition with an existing one. Because of their visual impact on the environment, it is indeed most unlikely that the construction of competing transmission lines along similar routes would be allowed. Furthermore, the minimum efficient size of a transmission network is such that electricity transmission is considered a good example of a natural monopoly.

In general, network constraints increase opportunities for strategic bidding because not all generators are connected in locations where they can relieve a given constraint. In many cases, the number of generators that can effectively affect a constraint is small. Congestion in the transmission network can therefore transform a reasonably competitive global market into a collection of smaller local energy markets. Since these smaller markets inevitably have fewer active participants than the global market, some of them are likely to be able to exert market power. Such scenarios are not easy to detect or analyze [13 , 14].

V. Equations

A. Cournot Model

In order to analyze real markets, economists have developed models between two extreme cases, perfect competition and pure monopoly. Perfect competition is very difficult to attain in electricity industry, mainly because of the small number of players that compete. Oligopoly competition refers to a market structure where a few players coexist. Taking perfect competition and monopoly models as the end points, there is an infinite number of theoretical possibilities for oligopoly models, all of which differ mainly in the assumptions used to characterize market structure and firm interdependencies.

The Cournot model has become a classic in microeconomic oligopoly theory. The Cournot model of oligopoly has arguably been the most successful one, mostly due to its mathematical tractability and ability to represent well short-term and mid-term problems. Cournot games have the following characteristics in common:

- competition occurs only in quantities
- product is homogeneous
- market price is determined by auction
- Players schedule for their production simultaneously.

In the Cournot model, each firm chooses an output quantity to maximize profit. It is assumed that quantities produced are immediately sold. Market price in the model is determined through an auction process that equates industry supply with aggregate demand. Examples of Cournot style auction-based pricing can be found in organized markets such as those for agricultural products like wheat, corn, and rice. The model also assumes that all firms in the industry can be identified at the start of the game, and that decision-making by firms occurs simultaneously [15].

Each firm is sufficiently large to influence market price received by all, and the quantity produced by other firms. Each firm maximizes its own profit given the quantity chosen by other firms expressed as [12].

$$\pi^{i}(q_{i},q_{i'}) = q_{i}\cdot P\left(q_{i},q_{i'}\right) - C_{i}(q_{i}) \qquad (1)$$

$\pi^{i}(\cdot)$	profit of player given the production strategy of all other players i' ;
q_{i}	production strategy of player *i*;
$P(\cdot)$	price as a function of all *q*'s i.e., firms *i*, *i'*, etc. This is the main characteristic of an oligopolistic market that distinguishes such markets from a perfectly competitive one—players can influence market price by changing their production as opposed to a “price taker” behavior exhibited in a competitive market;
$C_{i}(\cdot)$	cost as a function of production strategy q_i .

The solution of the game is obtained by solving a set of simultaneous equations representing the first order optimality conditions for each firm *i* [16].

It is well known that the Cournot oligopoly has a Nash equilibrium in which every firm has its maximum profit while assuming that other firms have fixed their outputs. It is apparent that when all firms have reached such a point, none has any incentive to change unilaterally, and so the situation is viewed as the market equilibrium [17].

The Nash equilibrium formation of Cournot’s duopoly model is shown in Fig. 3. The two axes define the output of the firms. In this model the reaction curve represents how much each firm would produce given the production decision from the other firm. The Nash equilibrium defines where each firm has maximized profit, given the output of the other.

B. GENCOs' Cournot Behavior

The Cournot model is often used to describe the behavior of generating companies (GENCOs) in electricity markets. We consider n GENCOs, assume that each GENCO uses a Cournot model to derive its generation and maintenance scheduling in the market, and obtain some relevant analytical results characterizing the market. GENCOs are assumed to maximize profit according to the Cournot assumption using production quantities as the decision variable. It is considered that the transmission network does not influence the equilibrium, i.e., that no network constraint is binding. Cournot models are often encountered in the technical literature as they adequately represent producer behavior in real-world markets [18].

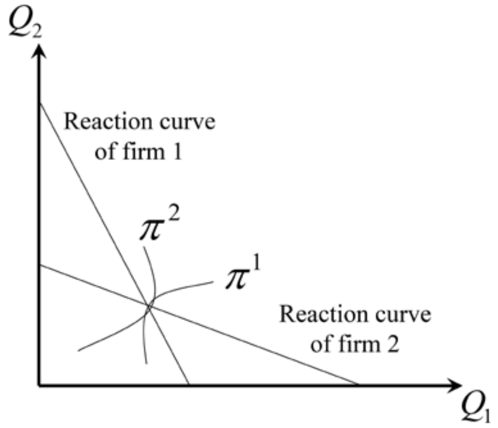

Fig. 3. Nash-Cournot Equilibrium in duopoly model.

A Cournot-Nash equilibrium outcome is characterized by the familiar Nash equilibrium concept that no player can gain any additional profit by changing its own generation strategy while every other player keeps its own generation unchanged [4].

Since GENCOs tend to make repetitive decisions, it is expected that they will learn from the market. For each time period, GENCOs must form an expectation of their rivals' output in the subsequent period in order to determine their own corresponding profit-maximizing quantity for the next period, and so on [19].

VI. Profit Maximization Model

GENCOs would try to extract maximum profit by scheduling their maintenance in a period to meet with least opportunity costs, and to make the most of all other periods when its competitors' generators are scheduled for maintenance. We may think of each GENCO trying to work out the best generation strategy as well as the maintenance decisions by looking at the mutual impact of maintenance on their base reaction function [3 , 4]. Individual GENCOs' objective for Counot-Nash equilibrium is as follows:

$$
\begin{aligned}
Max: \; & \sum_{t=1}^{T}\left(\gamma(t)-\frac{1}{2}\cdot\lambda(t)\cdot G(t)\right)\cdot G(t) \\
& -\sum_{t=1}^{T}\left(\sum_{i=1}^{I}\sum_{j\in G_i} g_{ij}(t)\cdot h(t)\cdot PC_{ij}\right) \\
& -\sum_{t=1}^{T}\left(\sum_{i=1}^{I}\sum_{j\in G_i} MC_{ij}\cdot P_{ij}^{\max}\cdot m_{ij}(t)\right) \\
& -\sum_{t=1}^{T}\left(\sum_{i=1}^{I}\frac{1}{2}\cdot\lambda(t)\cdot P_i^2(t)\right) \qquad (2)
\end{aligned}
$$

Subject to

$$h(t)\cdot\sum_{j\in G_i} g_{ij}(t)=P_i(t) \quad \forall i,\forall t \qquad (3)$$

$$\sum_{i=1}^{I} P_i(t)=G(t) \quad \forall t \qquad (4)$$

$$o\le g_{ij}(t)\le P_{ij}^{\max} \quad \forall t \qquad (5)$$

Equation (2) may be explained as follows [4].

- The first term represents the revenue earned by firms under perfect competition.
- The next two terms represents the costs of firms.
- The first three terms together represent the net market benefit under perfect competition.
- The last term applies the effect of oligopolistic competition to objective function.

The set of constraints of the maintenance scheduling problem of GENCO*i* are given below.

1) Minimum Net Reserve: This constraint ensures a net reserve above a specified threshold for all periods [1]

$$\sum_{i=1}^{I}\sum_{j\in G_i}\left(P_{ij}^{\max}(1-m_{ij}(t))(1-FOR_{ij})-g_{ij}(t)\right)\ge R(t) \qquad (6)$$

$$R(t)=aD(t)\frac{\sum_{t=1}^{T}\left[\sum_{i=1}^{I}\sum_{j\in G_i}\left(P_{ij}^{\max}\left(1-FOR_{ij}\right)\right)-D(t)\right]}{\sum_{t=1}^{T}D(t)}. \qquad (7)$$

In equation (7) minimum reserve constant ensures higher reserve in periods with higher loads, which is an appropriate criterion.

2) Maintenance Outage Duration: The following constraint ensures for each unit that it is maintained the required number of time periods [20]

$$\sum_{t=1}^{T} m_{ij}(t) = N_{ij} \qquad \forall i, \forall j \in G_i. \qquad (8)$$

3) Continuous Maintenance: The constraint below ensures that the maintenance of any unit must be completed once it begins [12]

$$m_{ij}(t) - m_{ij}(t-1) \le m_{ij}(t + N_{ij} - 1) \qquad \forall i, \forall t, \forall j \in G_i. \qquad (9)$$

4) Maximum Number of Units Simultaneously in maintenance: Constraint (10) limits the maximum number of units that GENCO*i* can maintain at the same time [1]

$$\sum_{j \in G_i} m_{ij}(t) \le M_i \qquad \forall i, \forall t. \qquad (10)$$

5) Maintenance Exclusion: This constraint enforces the impossibility of maintaining two prespecified unit of the same GENCO at the same time [12]

$$m_{ij}(t) + m_{ij'}(t) \le 1 \qquad \forall i, \forall t. \qquad (11)$$

It means simultaneous maintenance of unit j and j' of GENCO*i* is impossible.

6) Wind Power Curve: Incorporating wind generators into the existing utility generation scheduling problem add further complexity to the solution methodology. The total available wind generation can be obtained from the wind speed by applying the wind power curve [21].

$$WP_{ij}^{\max}(t) = \begin{cases} o & v(t) \le v_{Iij} \;\; or \;\; v(t) > v_{Oij} \\ \varphi_{ij}(v(t)) & v_{Iij} \le v(t) \le v_{Rij} \\ P_{ij}^{\max} & v_{Rij} \le v(t) \le v_{Oij} \end{cases} \qquad (12)$$

VII. Regulations by ISO

It should be noted that the role of ISO is to ensure system security. Therefore, it must agree with GENCOs on a generation maintenance plan that preserves system security. The ISO solves a maintenance scheduling problem involving all units, independently on which GENCO owns each unit, with the target of maximizing the reliability throughout the weeks of the year. Sufficiently accurate load forecasts for the whole year are considered known [20].

The ISO compares the maintenance outage timing scheduled by GENCOs with its desired timing. If the reliability index of two plans are closed to each other, the ISO accepts the GENCO's decision, If not ISO encourages GENCOs to alter their plan by proposing incentives. The objective function of ISO can be formulated as follow

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$$Max \; \frac{1}{T}\sum_{t=1}^{T} \frac{\left[\sum_{i=1}^{I}\sum_{j\in G_i} P_{ij}^{\max}\cdot\left(1-m_{ij}(t)\right)\cdot\left(1-FOR_{ij}\right)\right]-D(t)}{\left[\sum_{i=1}^{I}\sum_{j\in G_i} P_{ij}^{\max}\cdot\left(1-FOR_{ij}\right)\right]-D(t)} \qquad (10)$$

The ISO considers the constraints mentioned for generating units. It also has a constraint which guarantees a net reserve above a specified threshold for all periods [1]

$$\sum_{i=1}^{I}\sum_{j\in G_i}\left[P_{ij}^{\max}\cdot\left(1-m_{ij}(t)\right)\cdot\left(1-FOR_{ij}\right)\right]-D(t) \ge R(t)\cdot \qquad (11)$$

VIII. Case Study

Results for a hypothetical system which is mostly based on IEEE reliability test system containing some DG units are reported in this section. Consider a system comprising of 17 units, owned by 6 GENCOs. Table I shows a list of GENCOs data and Table II shows the type of generating units with their forced outage rates.

TABLE I
HYPOTHETICAL TEST SYSTEM

GENCOs	Unit	Production Cost ($/MWh)	Capacity (MW)	Maintenance Cost ($/MW)	Maintenance Requirement
GENCO 1	13	17	44	28	4
	14	14	40	12	2
	15	58	22	8	1
	16	60	6	12	1
GENCO 2	8	55	100	16	3
	9	52	36	13	1
	10	50	23	7	2
GENCO 3	5	53	155	21	2
	6	53	155	21	2
	7	53	155	21	2
GENCO 4	11	12	70	7	2
	12	21	60	9	3
GENCO 5	1	72	400	18	3
	2	64	197	23	2
	3	62	197	24	2
	4	64	100	19	1
GENCO 6	17	72	400	20	2

For simplicity, all of the wind generators represented an equivalent wind farm to concentrate on the effects of technique constraints in the test system. All wind generators are assumed to have the same cut-in, rated, and cut-out wind speeds (2.5 m/s, 12 m/s, 25 m/s) respectively. In Fig. 2 wind speed data are shown for 24 periods [3].

TABLE II
GENERATING UNITS SPECIFICATIONS

Unit's type	Capacity (MW)	Forced Outage Rate
Diesel	36,23	0.04
Oil #6	197	0.05
Molten Carbonate Fuel Cell	22	0
Oil #2	100	0.04
Wind Farm	70,60	0.14
Biomass Plant	44,40	0.06
Nuclear	400	0.12
Coal	155	0.04
Phosphoric Acid Fuel Cell	6	0.01

The problem horizon *T* is 24 periods. Periods can have different lengths of time (days, weeks…). The load profile is shown in Fig. 5 [3].

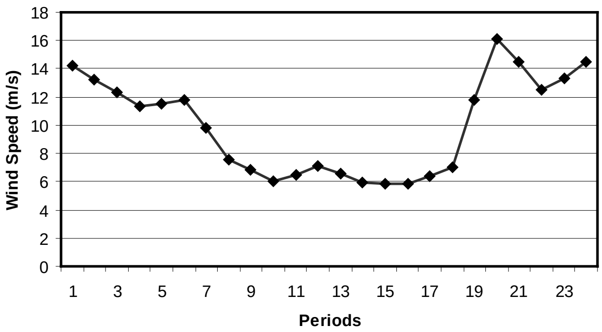

Fig. 4. Wind speed in 24 periods.

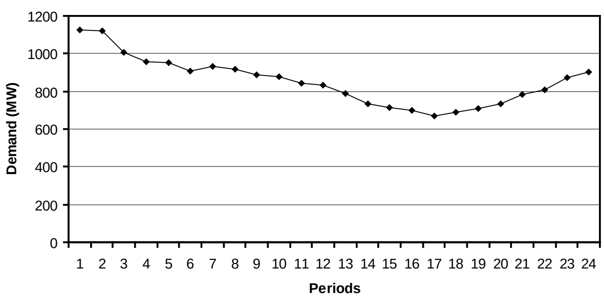

Fig. 5. Demand profile of test system.

In case 1 we consider a system with the inverse load curve being identical for all 24 periods: $\gamma(t) = 900$ and $\lambda(t) = 0.04$. The strategic maintenance scheduling is shown in Fig. 6.

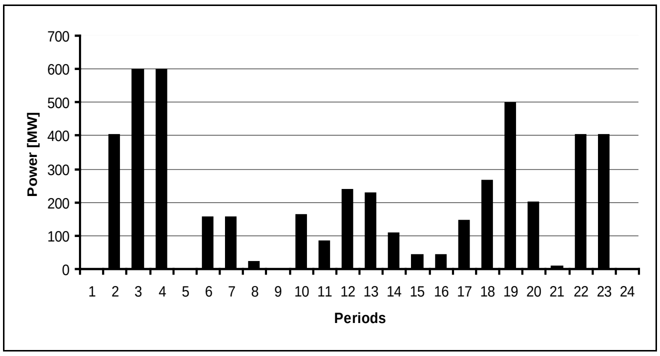

Fig. 6. Maintenance scheduling plan (Case 1).

Next, we consider the load curve to have a higher intercept and be more inelastic with $\gamma(t) = 1000$ and $\lambda(t) = 0.03$ in periods 7 to 18 (case 2). This will shift maintenance of some units from these periods to periods with more elastic load curve (Fig. 7).

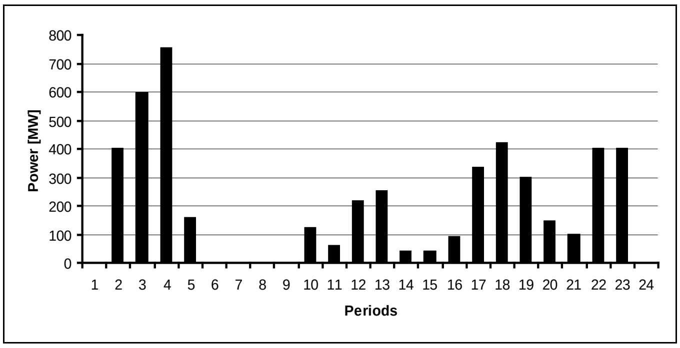

Fig. 7. Maintenance scheduling plan (Case 2).

In case 3 we consider higher price elasticity at low demand periods. Usually at low demand periods, consumers can reduce their consumption when price goes up. In case 4, higher price elasticity is considered for high load periods. Fig. 8 compares maintenance decisions in these two cases.

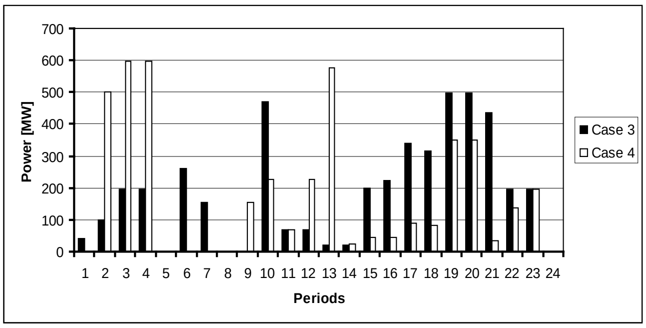

Fig. 8. Maintenance scheduling plan (case 3 and case 4).

It is concluded that GENCOs prefer to put their maintenance outages in periods with higher price elasticity and they prefer to produce energy in inelastic periods.

As it has been mentioned ISO consider reliability in the system. If the reliability index of GENCO plans are closed to ISO plan, the ISO accepts the GENCO's decision, If not ISO encourages GENCOs to alter their plan by proposing incentives. The problem in this situation is network constraints. Energy supplying companies may be accountable for having monopolistic potential, even though there are several other suppliers openly competing with them on the market. If some of these GENCOS share their data and find the above maintenance scheduling plan which maximize their profits they can put their maintenance in the elastic periods. This means that they withdraw some of their production capacities in these periods. As ISO will propose its maintenance scheduling plan these GENCOS will not be able to withdraw in application. So they decide to bid this difference amount of energy at very higher prices. ISO has to buy to prevent reliability problems. This profit maximization is considered as a market power exerting.

IX. Conclusion

In this paper a simple framework which is easy to implement has been reviewed. We proposed this framework before because it requires a reasonably small amount of computing time and a small amount of data communication. Here the framework has been implemented in practice of a case model under considering the monopoly threat. It is presented based on the fact that GENCOs will try to strategically place their maintenance and dispatch their generators taking into consideration their rivals' strategies. But this profit maximization may lead to market power if some GENCOs want to exit the oligopolistic structure and make locational monopolies. The results show that maintenance scheduling of generating units and DGs depend on price elasticity of load curve. The proposed method implicitly assumes that each GENCO is able to at least "predict" the capacity and cost parameters of its competitor GENCOs—a supposition that is not impractical. The game theory which is considered to study electricity markets' behavior is usually based on Cournot game. The application of other models such as Bertrand games and supply function equilibrium which might exhibit a better explanation of a real market should still be further investigated.

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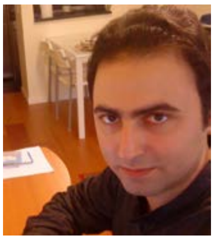

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