A GAME OF CLUSTERED ELECTRICITY GENERATORS

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ABSTRACT

A GAME OF CLUSTERED ELECTRICITY GENERATORS

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Turkish Electricity Market is modeled as a non-cooperative game with complete information in order to simulate the behavior of market participants and analyze their possible strategies. Player strategies are represented with multipliers in a discrete strategy set. Different market scenarios are tested through different game settings. As the novelty of this thesis, similar market participants are clustered and treated as single players in order to apply game theory in an efficient way. Generators are clustered using Agglomerative Hierarchical Clustering and Square Sum of Deviations is used as the proximity measure. The game is constructed with three players that reflect the main characteristics of the market participants. Clusters and game scenarios are constructed using the real market data of the Turkish Electricity Market at four different time points in 2008 and results are compared. Clustering results reflect the actual installed capacity distribution based on the main companies and fuel types in Turkish Electricity Market. According to four games of clustered electricity generators, when there is not enough competition in the market, dominant player is advised to submit bids with lower price for energy surplus cases and offers with higher price for energy deficit cases. However, when there is competition in the market, players are advised to submit offers with lower price in order to take a share of the limited demand for up-regulation.

Key words: Electricity Market, Game Theory, Cluster Analysis, Bid Curve

ÖZ

KÜMELENMİŞ ELEKTRİK ÜRETİCİLERİNE İLİŞKİN BİR OYUN

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Piyasa katılımcılarının davranışlarının simüle edilmesi ve olası stratejilerinin analiz edilmesi için Türkiye Elektrik Piyasası tam bilgi ile işbirlikçi olmayan bir oyun olarak modellenmiştir. Oyuncuların stratejileri ayrık strateji kümesinde çarpanlarla yansıtılmıştır. Çeşitli piyasa senaryoları farklı oyun durumlarıyla test edilmiştir. Bu tez ile getirilen bir yenilik olarak oyun teorisinin verimli bir şekilde uygulanması için benzer piyasa katılımcıları kümelenip tek bir oyuncu olarak ele alınmıştır. Üreticiler Hiyerarşik Toplama yöntemi ile kümelenmiş ve Sapmaların Karelerinin Toplamı yakınlık ölçüsü olarak kullanılmıştır. Piyasa katılımcılarının temel özelliklerini yansıtan üç oyuncu ile oyun kurulmuştur. 2008 yılındaki dört farklı zaman dilimi için Türkiye Elektrik Piyasasının fiili piyasa verileri kullanılarak kümeler ve oyun senaryoları oluşturulmuş ve sonuçlar karşılaştırılmıştır. Kümeleme sonuçları, Türkiye Elektrik Piyasasındaki belli başlı şirket ve yakıt tipleri bazında güncel kurulu güç dağılımını yansıtmaktadır. Kümelenmiş elektrik üreticilerine ilişkin dört oyuna göre piyasada yeterli rekabet olmadığında, hakim oyuncunun enerji fazlası olan durumlar için daha düşük fiyatlı yük atma teklifleri vermesi ve enerji açığı olan durumlar için daha yüksek fiyatlı yük alma teklifleri vermesi önerilmektedir. Ancak, piyasada rekabet olduğunda oyuncuların yük alma için sınırlı olan talepten pay alabilmeleri için daha düşük fiyatlı yük alma teklifleri vermesi tavsiye edilmektedir.

Anahtar kelimeler: Elektrik Piyasası, Oyun Teorisi, Küme Analizi, Teklif Eğrisi

To my family and my future wife

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CHAPTER 1

ELECTRICITY MARKETS

Recently, there is huge shift in Electric Power Industry. During the last 10-15 years electricity markets were established all over the world. Still, new markets are being established in emerging countries like Romania and Turkey and old electricity markets are becoming more and more complex and sophisticated like NordPool in Nordic countries and NETA in United Kingdom. These changes in electricity markets trigger other changes in the industry. According to Park, Kim, Kim, Jung, and Park (2001) "traditionally, generation resources have been scheduled so as to minimize system-wide production costs while meeting various technical and operational constraints including demand-supply balance over the system. Recently, the electric power industries around the world are moving from the conventional monopolistic or vertically integrated environments to deregulated and competitive environments, where each participant is concerned with profit maximization rather than system-wide costs minimization." In a similar way, Ferrero, Rivera and Shahidehpour (1998) state that "in the deregulated and competitive environment emphasis is given to benefit maximization from the perspective of participants rather than maximization of system-wide benefits." Furthermore Ferrero et al. (1998) point out "as deregulation evolves, pricing electricity becomes a major issue in the electric industry. And participants of deregulated energy marketplaces are able to improve their benefits substantially by adequately pricing the electricity."

1.1. Development of Turkish Electricity Market

In line with the developments in world, Turkish Electricity Market has experienced a continuous change through the years. As in many European countries, Turkish electricity industry was dominated by a state-owned vertically integrated company, TEK. The first law setting up a framework for private participation in electricity was enacted in 1984, ending the monopolistic position of TEK. This law forms the legal basis for private participation through build-operate-transfer (BOT) contracts for new generation facilities, transfer of operating rights (TOR) contracts for existing generation and distribution assets, and the auto producer system for companies wishing to produce their own electricity. These contracts enabled private companies to establish power plants or operate plants while TEK was still keeping the ownership rights of the assets. In this framework, “competition for the market” has begun.

In May 1994, transmission and distribution were vertically decomposed by dividing TEK into two companies: TEAŞ (Turkey Electricity Generation and Transmission Company) and TEDAŞ (Turkey Electricity Distribution Company). In 2001, generation, transmission and trade functions were separated by dividing TEAŞ into three companies: EÜAŞ (Electricity Generation Company), TEIAŞ (Turkey Electricity Transmission Company) and TETAŞ (Turkey Electricity Trade Company)

Turkish Electricity Market Reform officially began on March 3, 2001 when Electricity Market Law No. 4628 was enacted. Then, Turkish wholesale electricity market activities started at December 2003 with the Financial Settlement Communiqué. Balancing and Settlement Regulation (BSR) came into force in November 2004, and virtual operation started. Financial operation of balancing and settlement mechanism has been going on since August 2006 and complementary regulations are being made meanwhile.

At the moment current market structure is composed of Bilateral Contracts Market and Balancing Mechanism. Current Balancing and Settlement Mechanism will deeply change with the final Balancing and Settlement Regulation (BSR). According to the final BSR three main components of Balancing Mechanism will be Day Ahead Balancing, Real Time Balancing and Ancillary Services. On the Bilateral Contracts Market side, Financial Market that allows derivative instruments will be available in the midterm. Relevant details of the current market structure are given in the next part. However, within the scope of this thesis it is not aimed to exhibit the complete and full aspects of the current Turkish Electricity Market structure. For further details, Electricity Market Balancing and Settlement Regulation (2004) should be consulted.

1.2. Balancing and Settlement Mechanism

According to Balancing and Settlement Regulation Applications Booklet of TEİAŞ (2008) electricity market design differentiates from other goods market designs owing to its three characteristics that are:

1. Electrical energy cannot be stored easily as other goods
2. Electricity flow is subject to physical rules and does not follow commercial contract flow.
3. Transmission system congestions seriously limit commercial transactions.

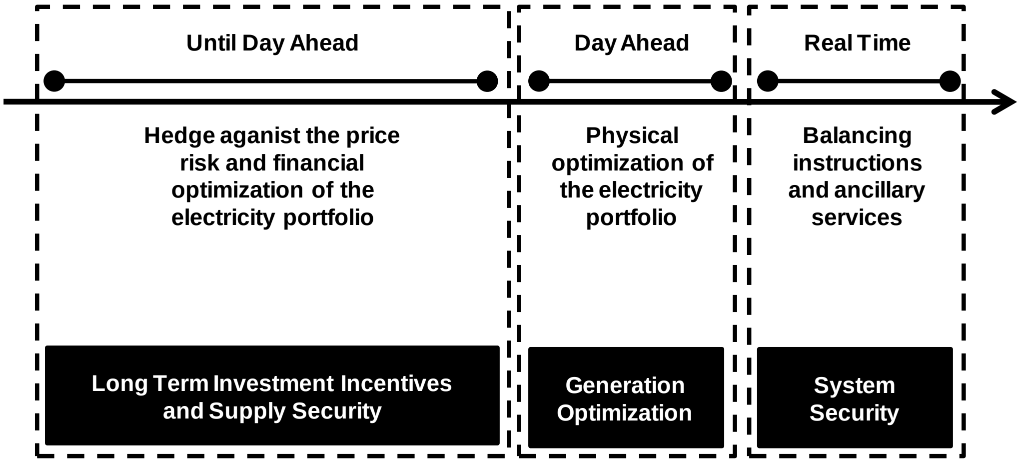

Figure 1 – A Generalized Electricity Market Structure

Balancing and Settlement Mechanism is summarized on Figure 1. As mentioned before, current market structure is composed of the Bilateral Contracts Market and Balancing Mechanism. Until day ahead, bilateral contracts market is in force with the aim of hedging against the price risk and financial optimization of electricity portfolio. Bilateral contracts market is not a regulated market. Consumers and generators find each other and sign long term bilateral agreements. With long term agreements, bilateral contracts market provides long term investment incentives and security of supply. On the other hand Balancing Mechanism, which starts on day ahead and continue in real time, is completely regulated according to the provisions of Electricity Market Balancing and Settlement Regulation (2004). Balancing Mechanism consists of two phases that are day ahead planning and real time balancing. Details of these phases are explained in the following sections.

Most of the electricity trade, approximately 85-95%, takes place in bilateral contracts market. Remaining 5-15% of electricity trade takes place through Balancing Mechanism. However, as electricity demand should be exactly equal to the electricity supply at every moment, Balancing Mechanism has a vital importance for a stable system.

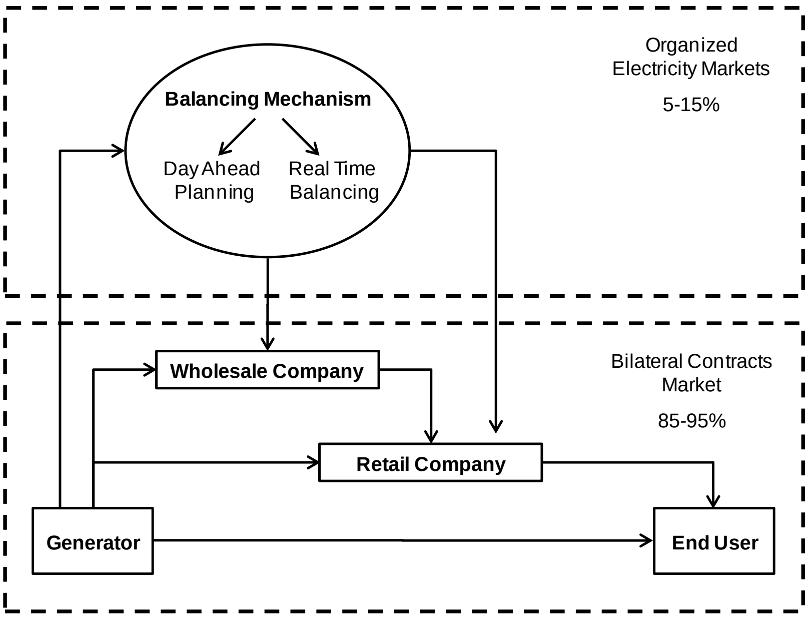

Figure 2 – Energy Sales in Bilateral Contracts Market and Organized Electricity Markets

As seen in Figure 2, which is extracted from Balancing and Settlement Regulation Applications Booklet of TEİAŞ (2008), retail companies sell electricity to end users and buy it from generators and/or wholesale companies through bilateral contracts. In a similar way wholesale companies sell electricity to retail companies and buy it from generators through bilateral contracts. Also it is possible that generators sell electricity by bilateral contracts directly to end users that are large consumers. However, electricity demand is volatile and it is impossible to meet the exact demand with bilateral contracts. For this reason, wholesale companies and retail companies buy electricity from Balancing Mechanism to meet the remaining demand and generators sell their excess generation to Balancing Mechanism. Trade in Balancing Mechanism constitutes the organized electricity markets.

1.2.1. Balancing Mechanism

Article 6 of the Electricity Market Balancing and Settlement Regulation (2004) states that “balancing mechanism shall ensure supply of sufficient and good quality energy with low-cost in a continuous manner.” The market participants within the scope of Balancing Mechanism are legal entities holding generation, auto-producer, auto-producer group, wholesale or retail licenses.

Everyday before 14:30, market participants submit daily generation schedule, available capacity and minimum stable generation figures covering the 24 hour period between 00:00 and 24:00 hours for the following the day. An example that shows the relationship between these parameters is exhibited in Figure 3.

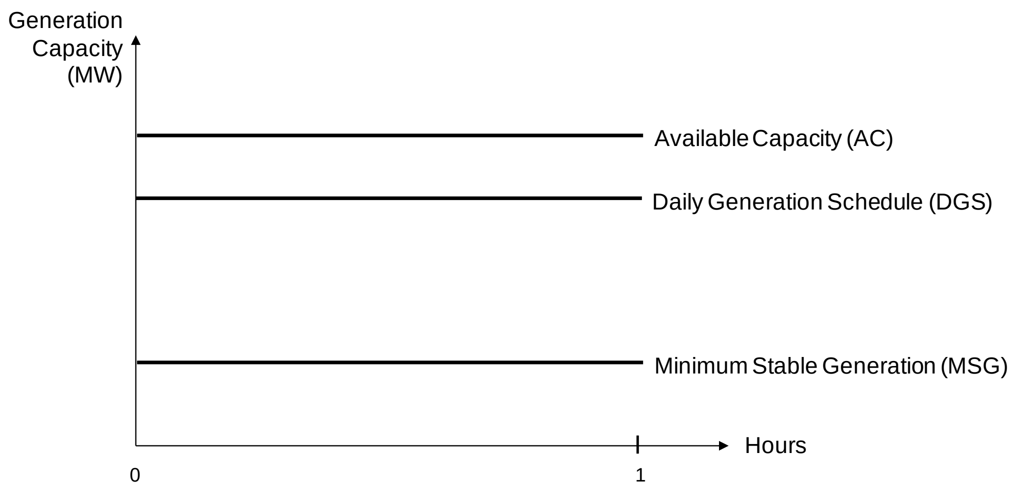

Figure 3 - Technical Parameters of Generators

Daily generation schedules shall be either between minimum stable generation and available capacity or zero. Daily generation schedules represent the results of Bilateral Contracts Market. Through daily generation schedules generators submit the volumes that they sell through Bilateral Contracts Market. If generators do not take part in any trade through Bilateral Contracts Market, then they submit daily generation schedules as zero. Still, they can sell electricity through Balancing Mechanism. The capacity between the daily generation schedule and available capacity is the *offer volume* which is the volume of possible increase in generation. On the other hand, the capacity below daily generation schedule is the *bid volume* which is the volume of possible decrease in generation. Following the instructions of System Operator, generators increase or decrease the generation level through up-regulation or down-regulation respectively. Depending on the level of daily generation schedule, there might be two levels of offer and bid volumes. Offer and bid volumes for different levels of daily generation schedule are represented in Figure 4.

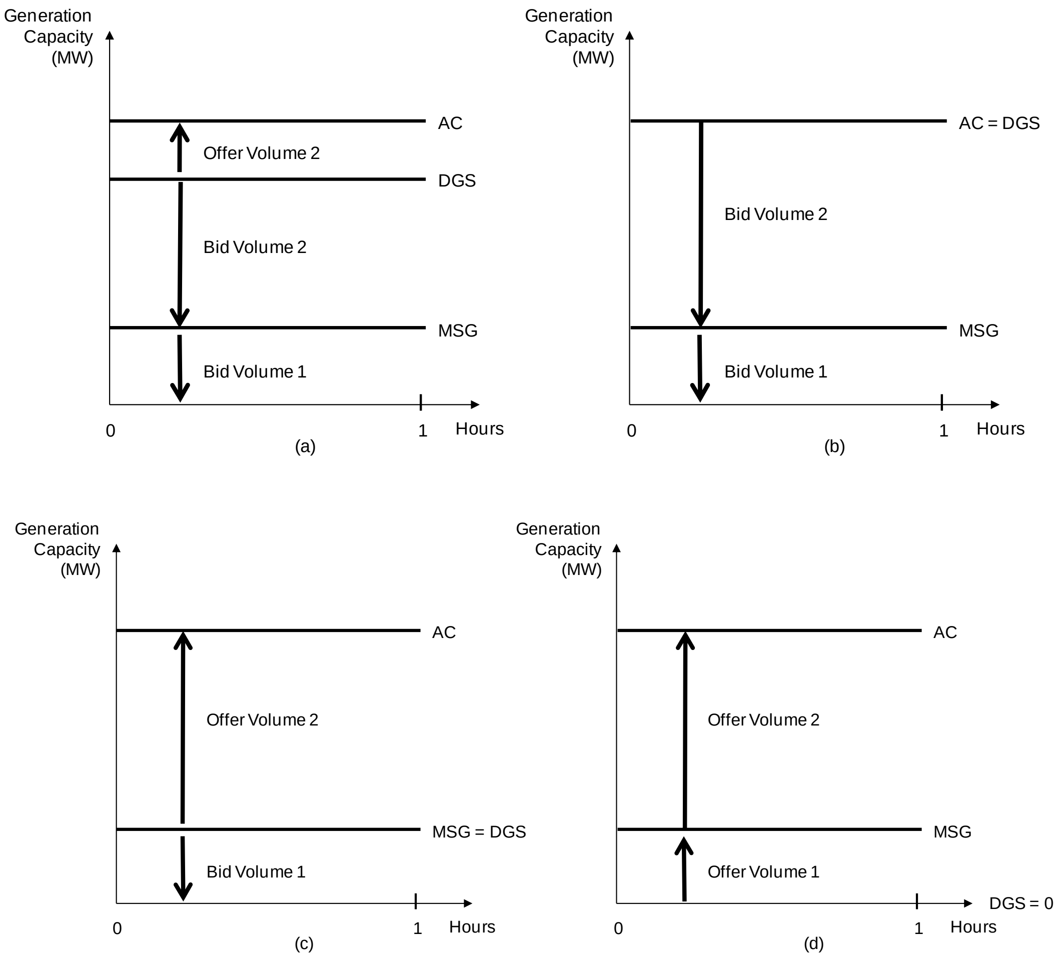

Figure 4 – Offer and Bid Volumes

As seen in Figure 4 offer and bid volumes of generators are calculated according to daily generation schedule, available capacity and minimum stable generation that are submitted daily by the market participants. For the different levels of daily generation schedule, corresponding offer and bid volumes are exhibited on (a), (b), (c) and (d) in Figure 4.

Beside the technical parameters (daily generation schedule, available capacity and minimum stable generation), offer and bid prices are submitted over three settlement periods (day: 06:00-17:00, peak: 17:00-22:00 and night: 22:00-06:00) and two levels of offer and bid prices for a month. These offer and bid prices can be updated twice in a month within the context of Balancing Mechanism. Offer prices are the unit prices requested by market participants for *up-regulation*. In other words, market participants ask for at least the amount of offer price for every MWh of generation increase. Bid prices are the unit prices requested by market participants for *down-regulation*. In other words, market participants are ready to pay at most the amount of bid price for every MWh of generation decrease and get that volume of electricity from the market in return.

All these technical parameters, offer and bid prices submitted by market participants are used for evaluation of bids and offers both in day ahead planning and real time balancing phases within the context of Balancing Mechanism. According to Article 6 of the Electricity Market Balancing and Settlement Regulation (2004) "the bids and offers shall be accepted or rejected after being evaluated with regard to offer and bid prices, up-regulation, down-regulation requirements, system constraints and associated data of the market participant in a non-discriminatory manner."

Data flow in balancing mechanism is summarized in Figure 5, which is extracted from Balancing and Settlement Regulation Applications Booklet of TEİAŞ (2008). Daily generation schedule, available capacity, minimum stable generation, offer and bid prices that are submitted by market participants are first evaluated for day ahead planning. Based on the evaluation, day ahead up-regulation and down-regulation instructions are issued to market participants. Then, all the submitted information is used again for the real time balancing. In real time, due to the variation in demand and supply real time up-regulation and down-regulation instructions are notified to market participants. Both in day ahead planning and real time balancing phases system congestions and reserve requirements are considered during the evaluation. Details of the evaluations are described in the following sub-sections.

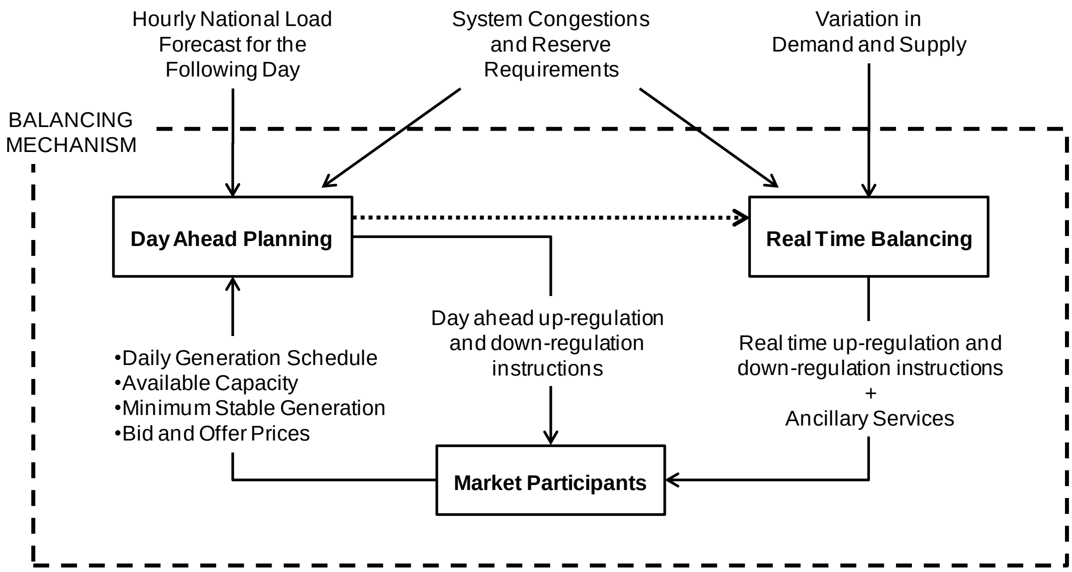

Figure 5 – Data Flow in Balancing Mechanism

As seen in Figure 5, day ahead planning and real time balancing phases are tightly connected to each other. Both use the same technical parameters and bid/offer data. Moreover, real time balancing is carried out according to the actual results of day ahead planning.

1.2.1.1. Day Ahead Planning

Article 42 of the Electricity Market Balancing and Settlement Regulation (2004) explains the day ahead planning process as follows:

a) Each day by 09:30 national load forecast for the following day shall be announced by System Operator to all balancing mechanism participants.

b) Each day between 09:30 and 14:30; daily generation schedule, available capacity, minimum stable generation figures shall be submitted by market participants.

c) Each day between 14:30 and 16:00; System Operator shall carry out scheduling activities for all market participants. Based on the technical parameters, offer and bid prices, bids and offers are evaluated to meet the national load requirements. After the evaluation, up-regulation and/or down-regulation instructions for day ahead activities shall be issued to market participants by System Operator.

d) Each day between 16:00 and 16:30; market participants can check the consistency of the instructions issued by System Operator with the associated data and can object for the instructions that are inconsistent.

e) Each day between 16:30 and 17:00; System Operator shall evaluate the objections and shall issue the corrected instructions to the market participants.

The national load forecast for the following day, which is announced by System Operator within the time period mentioned in item a) above, might be more than daily generation schedules or less than daily generation schedules or equal to daily generation schedules at each hour of the following day. Probability of occurrence of equality is very low. Such equality occurs only in a few hours in a year. However, when sum of daily generation schedules does not meet the national load forecast for the following day at an hour, System Operator either down-regulates or up-regulates some of the generators at that hour as presented in Figure 6.

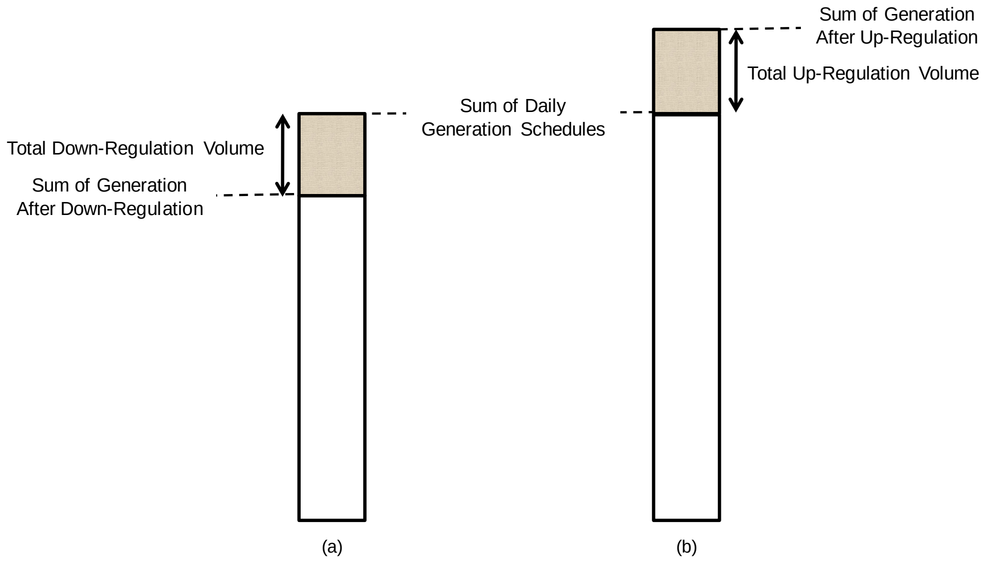

Figure 6 – Meeting the National Load Forecast for an hour of the Following Day

As in case (a) in Figure 6, when national load forecast for the following day is less than the sum of daily generation schedules at an hour, System Operator down-regulates some of the generators until total down-regulation volume is achieved at that hour. As in case (b) in Figure 6, when national load forecast for the following day is more than the sum of daily generation schedules at an hour, System Operator up-regulates some of the generators until total up-regulation volume is achieved at that hour. Sum of planned generation after down-regulation or up-regulation shall be equal to national load forecast for the following day at every hour. Besides the national load forecast for the following day, System Operator considers system congestions, reserve requirements, technical constraints, transmission and distribution constraints while down-regulating or up-regulating the generators.

Based on the national load forecast for the following day and sum of daily generation schedules submitted by market participants, methodology of up-regulating some of the generators is explained in Figure 7 with a similar approach proposed by Erten (2006).

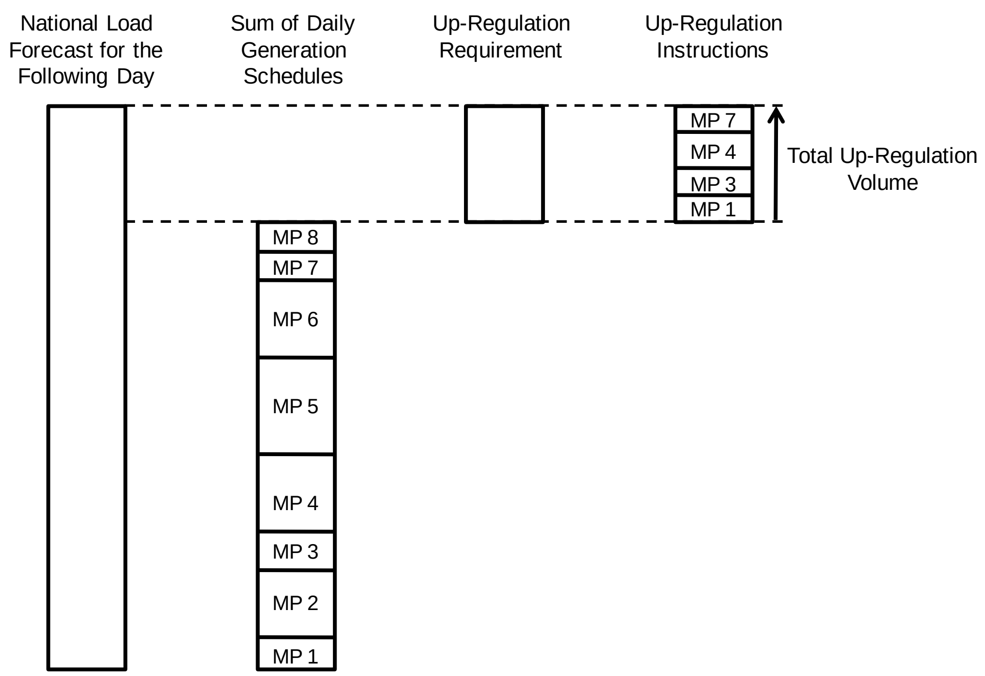

Figure 7 – Up-Regulating Some of the Generators

In this example, market participants (MP) 1 to 8 submit their daily generation schedules based on their bilateral agreements for an hour. Sum of daily generation schedules of these 8 market participants is not enough to meet the national load forecast for the following day at that hour. Therefore, there is up-regulation requirement. By giving up-regulation instructions to market participants 1, 3, 4 and 7; up-regulation requirement is met at that hour. Sum of the volumes of these instructions, in other words total up-regulation volume, is equal to the up-regulation requirement.

In order to select which generators will be up-regulated at that hour, System Operator should evaluate the offers of the market participants within the time period mentioned in item c) above. The methodology of this evaluation is explained in Figure 8.

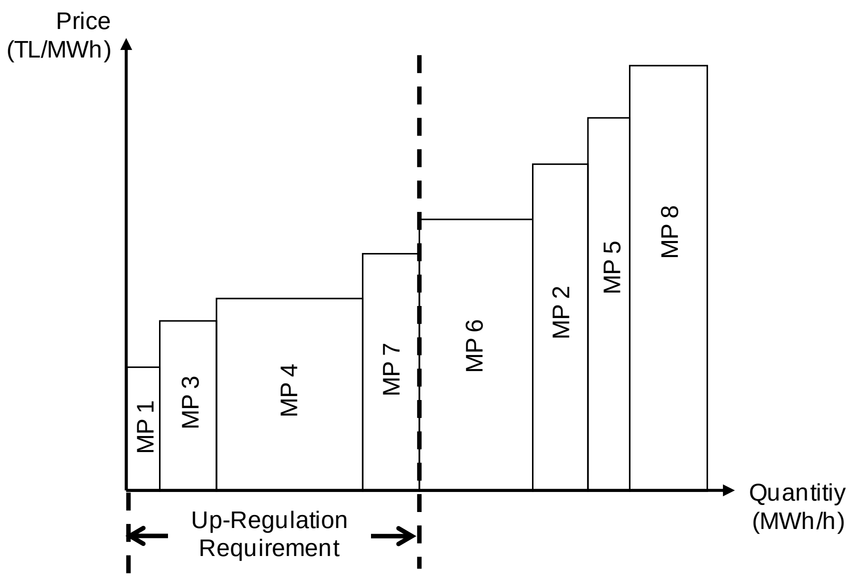

Figure 8 – Merit Order for Up-Regulation

System Operator ranks the offers of the market participants, corresponding to that hour, in increasing price. This ranking is called merit order. In Figure 8, each block labeled with the number of the market participant (MP) represents an offer. Widths of the blocks represent the offer volume and heights of the blocks represent the offer price. System Operator selects the offers starting with the one with the smallest price until the up-regulation requirement is met. Selected generators are instructed to generate more than their daily generation schedules in real time at that hour, in order to meet the national load forecast for the following day. Selected generators sell the volume that is equal to their daily generation schedules through bilateral agreements and sell the volume that is equal to up-regulation instruction to balancing mechanism at that hour.

The Methodology of down-regulating some of the generators is explained by Erten (2006) with a similar approach to the one in Figure 9.

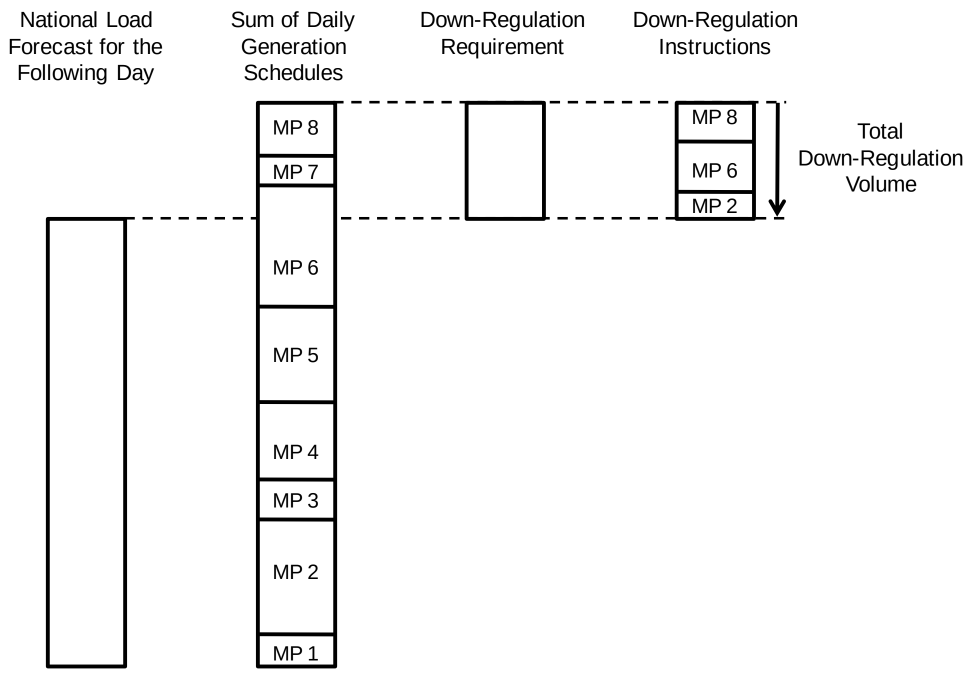

Figure 9 – Down-Regulating Some of the Generators

In this example, market participants (MP) 1 to 8 submit their daily generation schedules based on their bilateral agreements for an hour. Sum of daily generation schedules of these 8 market participants is more than the national load forecast for the following day at that hour. Therefore, there is down-regulation requirement. By giving down-regulation instructions to market participants 2, 6 and 8; down-regulation requirement is met at that hour. Sum of the volumes of these instructions, in other words total down-regulation volume, is equal to the down-regulation requirement.

In order to select which generators will be down-regulated at that hour, System Operator should evaluate the bids of the market participants within the time period mentioned in item c) above. The methodology of this evaluation is explained in Figure 10.

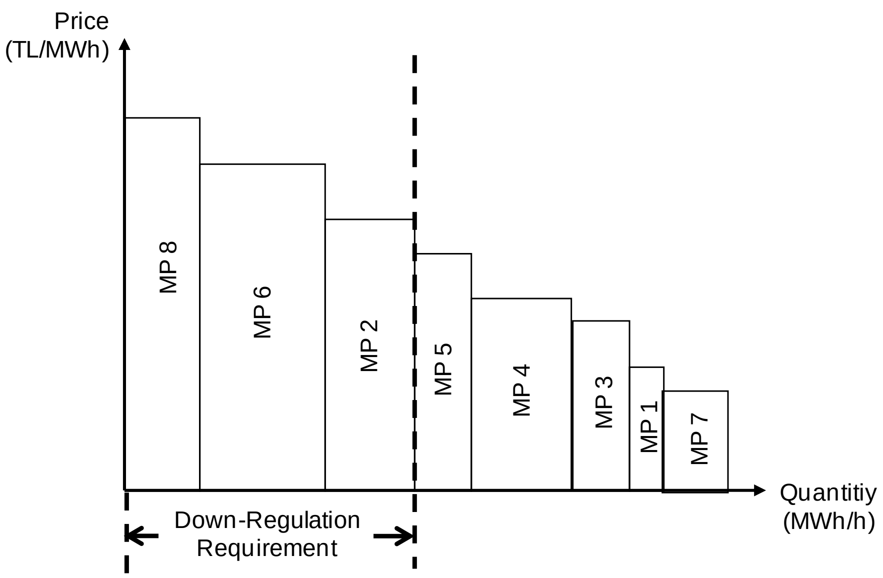

Figure 10 – Merit Order for Down-Regulation

System Operator ranks the bids of the market participants, corresponding to that hour, in decreasing price. This ranking is called *merit order*. In Figure 10, each block labeled with the number of the market participant (MP) represents a bid. Widths of the blocks represent the bid volume and heights of the blocks represent the bid price. System Operator selects the bids starting with the one with the highest price until the down-regulation requirement is met. Selected generators are instructed to generate less than their daily generation schedules in real time at that hour, in order to meet the national load forecast for the following day. In other words, selected generators buy electricity energy equal to the instruction volume from the balancing mechanism instead of generating that volume at that hour. In this way, they can still meet the requirements of bilateral agreements that have been signed, while generating less than their daily generation schedules.

This procedure is repeated for every hour of the following day within the time period mentioned in item c) above through the aid of software, Market Management System. Market Management System is a web based software, which is online 7 days and 24 hours, serves between 4,000 and 10,000 requests originating from 640 users per day. Market Management System is designed for implementation of Electricity Market Balancing and Settlement Regulation. Users can access the application securely without additional software installation, directly using an internet browser through 128-bit SSL encoding.

After resolving the objections regarding instructions within the time periods mentioned in item d) and e) above, all the up-regulation and down-regulation instructions become valid for every hour of the following day. Through daily generation schedules and up-regulation, down-regulation instructions an hourly schedule for generators is prepared by System Operator for the following day. National load forecast for the following day is met at every hour of the following day according to this schedule. However, in real time, when electricity is generated and consumed, supply and demand fluctuations occur. The System Operator balances the active electricity withdrawn from the system or supplied to the system in real time by up-regulation, down-regulation instructions, frequency control and demand control services within the context of Real Time Balancing that is explained in next sub-section.

1.2.1.2. Real Time Balancing

As electricity cannot be stored in a cost effective way, demand and supply balance should be maintained every moment in real time. In the context of real time balancing either generation of market participants is increased or decreased in order to meet changing demand in real time. On the other hand, frequency control and demand control services are provided in accordance with relevant provisions of Electricity Market Grid Code (2003) and Electricity Market Ancillary Services Regulation (2008).

Except for a few hours in a year, at every hour energy surplus or energy deficit occurs in real time due to demand and supply imbalances. Rarely demand and supply is exactly equal to each other in real time. Demand and supply imbalances result in frequency deviations. These imbalances and resulting frequency deviations are firstly attempted to be corrected by automatic systems such as primary and secondary frequency control. When primary and secondary control services are deemed insufficient to offset the energy imbalance, generation of market participants is increased or decreased manually by up-regulation or down-regulation instructions. These instructions are notified after evaluation of bids and offers of the market participants in accordance with the methodology explained in previous sub-section. Following the instructions, market participants increase or decrease their generation level in a predetermined time. In this way, demand and supply balance is tried to be attained. However, energy deficits due to large scale failures in transmission lines or generators may not be offset by such measures.

When considerable energy deficit occurs due to large scale failures in transmission lines or generators and this situation results in sudden and considerable decrease in system frequency, demand control services are activated. In the scope of demand control, demand of predetermined consumers is disconnected from the system in case system frequency decrease to the frequency level determined previously by TEİAŞ. By this way, demand is curtailed instead of increasing the supply. Therefore, demand and supply balance is achieved and system security is ensured.

1.2.2. Settlement Mechanism

According to Article 7 of the Electricity Market Balancing and Settlement Regulation (2004), settlement shall include the activities and administrative procedures performed by the TEİAŞ for the purpose of identification of the receivables and/or payables related to energy withdrawn and/or surplus of market participants due to;

a) Their accepted bids and offers,
b) Their bilateral contract notifications,
c) The energy amounts subject to settlement supplied to and/or withdrawn from the system,

and fulfilling financial transactions arising from these activities.

TEİAŞ purchases the energy sold by market participants due to acceptance of their offers or sells the purchased energy to the market participants due to acceptance of their bids on behalf of the market. TEİAŞ shall not incur any losses or profits due to energy purchase and sale transactions performed on behalf of the market. TEİAŞ is not a participant of the market; instead it is a counterpart in the system.

The accepted bids and offers shall be settled monthly based on hourly prices. The same hourly system marginal prices shall be applied for all the accepted offers of market participants selling to the market or for all the accepted bids of market participants buying from the market for the purpose of balancing for the relevant hour. As at each hour either net energy surplus or net energy deficit occurs, each hour single system marginal price represents either electricity sale or purchase price depend on the net energy surplus or net deficit situation. On the basis of marginal pricing principle, electricity sold or purchased is uniformly priced.

Based on the national load forecast on day ahead and based on the realization of energy deficit or surplus in real time, generators are up-regulated or down-regulated by System Operator. In order to select which generators will be up-regulated or down-regulated, System Operator evaluates the offers or bids of the market participants in line with the methodology explained in previous section. According to merit order, the offer price of the last selected generator for up-regulation determines the System Marginal Price for that hour as in Figure 11.

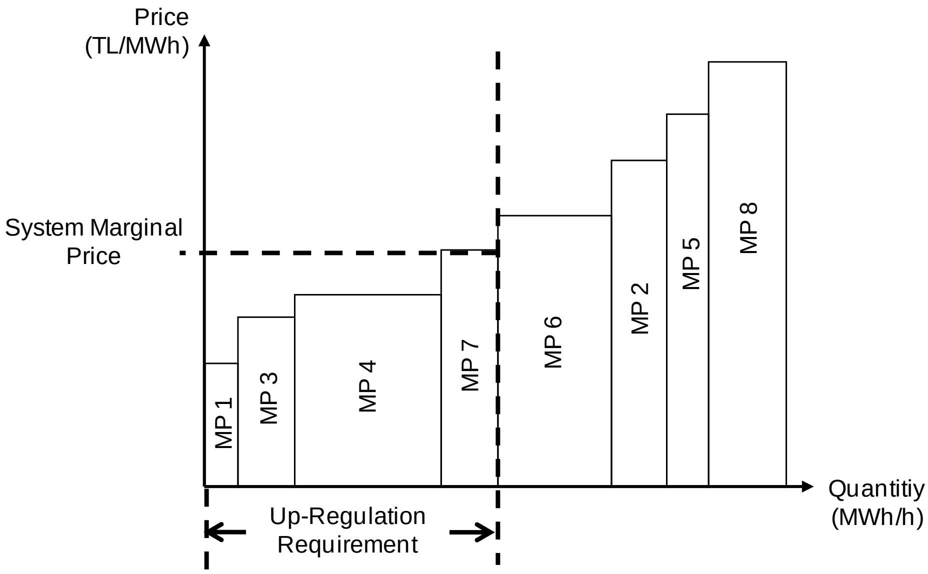

Figure 11 – Calculation of System Marginal Price for Offers

The determined System Marginal Price, which is equal to the offer price of the last selected generator, is uniformly applied to all accepted offers. In Figure 11, market participants 1, 3, 4 and 7 are paid over the same System Marginal Price, even though offer price of market participants 1, 3 and 4 is lower than the System Marginal Price. Through the determination of hourly system marginal prices in line with the marginal pricing principle, participants were given the opportunity to bid their marginal costs. As explained by Ren and Galiana (2004), "under marginal pricing principle generators may still earn a profit even if they offer to generate at their true costs." For instance market participant 4 in Figure 11 would earn a profit equal to the difference between System Marginal Price and its offer price, even if its offer price is equal to its marginal cost.

In a similar way, the bid price of the last selected generator for down-regulation according to the merit order determines the System Marginal Price for that hour. Figure 12 explains this procedure.

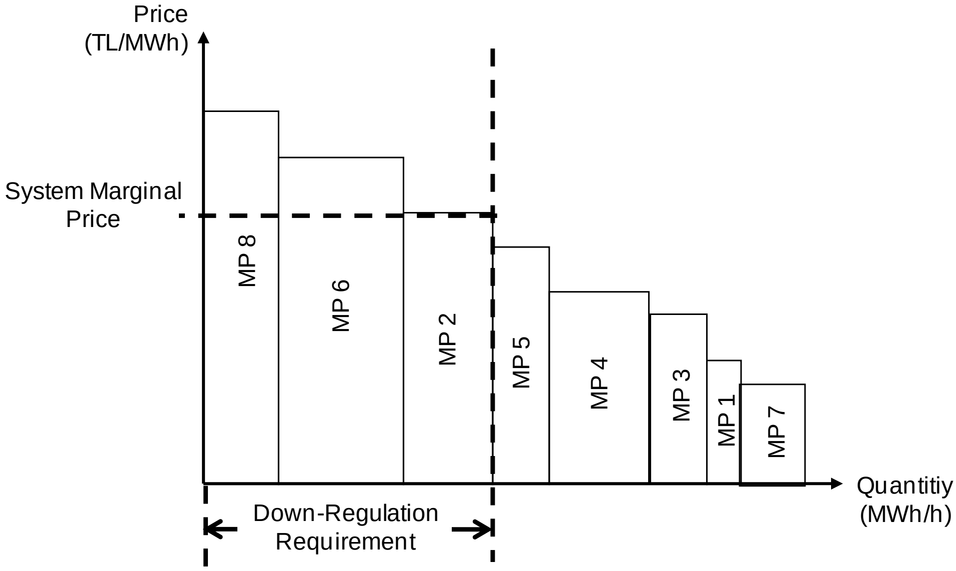

Figure 12 – Calculation of System Marginal Price for Bids

The determined System Marginal Price, which is equal to the bid price of the last selected generator, is uniformly applied to all accepted bids. In Figure 12, market participants 8, 6 and 2 pay over the same System Marginal Price for the electricity purchased from the market, even though bid price of market participants 8 and 6 is higher than the System Marginal Price. In other words, market participants 8 and 6 are ready to pay more than the System Marginal Price to buy electricity from the market. Since marginal pricing principle motivates market participants to bid at their marginal costs, selling electricity at a price less than their bid price would still increase the overall benefit in the system in the long run.

1.3. Future Market Structure

As mentioned in Part 1, according to the Electricity Market Balancing and Settlement Regulation (2009), Balancing Mechanism will be composed of Day Ahead Balancing, Real Time Balancing and Ancillary Services. It is expected that Bilateral Contracts will be complemented with Financial Market that allows derivative instruments in the midterm.

Day Ahead Balancing will be maintained through Day Ahead Market. Prior to the Day Ahead Market there will be a transition phase in the market design and Day Ahead Scheduling will be operational during this transition phase. While one or several trade zones, and portfolio based bids are foreseen for the Day Ahead Market, Day Ahead Scheduling is a simpler version and balancing mechanism entity based bids will be submitted for a single zone. Only generators and consumers will be eligible to submit bids to the Day Ahead Scheduling, whereas in Day Ahead Market there won't be discrimination of participant categories and generators, consumers, traders/speculators, retailers and distributors will be able to submit bids.

Day Ahead Market will serve as a market place for transparent and non-discriminatory trade of electricity and produce a reliable price index for electricity transacted in Turkey. Also, it will serve as a tool for initial balance of the Turkish electricity system and electricity market surveillance. Optimization of the use of transmission and generation capacity throughout the country will be provided by Day Ahead Market. Moreover, it will help to promote competition in the electricity market in Turkey. Eventually, mentioned predictions above will cause Real Time Balancing Market to shrink, system operation load of National Load Dispatch Center to diminish and so system security will be maintained.

In the midterm Bilateral Contracts Market will be complemented with Financial Markets. Financial Markets are the markets, where the contracts for the delivery of electricity at a future date are traded. Under ideal market conditions, daily prices give an idea about possible future prices. However, future price variations cause a considerable risk. Introduction of Financial Markets will maintain price stability and allow investors to develop better risk mitigation plans through hedging. Derivatives such as futures, forwards and options will be introduced to the market. In this way, further long term capacity investment will be fostered.

Another important issue that will deeply affect the future market structure is demand side participation. Demand side participation will allow consumers to adjust their consumptions according to the changing price levels, maintain short term supply security and prevent spontaneous price increases. Consumers may adjust their consumptions mainly in three ways: demand reduction, load shifting, and resource alteration. Potential demand side participants are consumers in industries that require extensive energy (steel, metallurgy, etc.), wholesalers, auto producers, industrial zones, retailers and municipalities. Effect of demand on market price is measured by flexibility of demand. From 2009 to 2011, eligible customer limit will be gradually decreased and planned to be zero in 2011, meaning every end-user will have freedom to choose its own supplier and participate on the demand side according to the Strategy Document.

CHAPTER 2

PROPOSED APPROACH

It was possible to optimize system-wide benefits just with cost minimization in electric power industry. However as the electricity markets evolve all around the world, such cost minimization became deficient because of the increasing level of competition. In the competitive environment, profit is not only dependent upon the cost but also on price that is formed in market. Under marginal pricing principle, usually market price is set by other players in the market. As Park et al. (2001) mention “conventional least-cost approaches for generation resource schedule can not exactly handle real-world situations any longer.” In order to handle the real-world situations of the electricity market, it is possible to apply various modeling and simulation techniques. These techniques try to replicate the behavior of electricity market participants and reflect the actual electricity market structure. Application of game theory might be used to create a realistic electricity market model and simulate behavior of market participants.

2.1. Application of Game Theory

This thesis aims to analyze the strategies of market participants in the Turkish Electricity Market with a methodology based on game theory. Recently, there are many similar works on game theory application to electricity markets. Ferrero, Shahidehpour and Ramesh (1997) model the electricity market as a strategic game in which participants play against each other in order to maximize their own benefits and the strategy that participants follow is the bid for pricing transactions.

Also, Ferrero, Rivera and Shahidehpour (1998) present a game theoretical approach for price definition by participants and model the problem as a non-cooperative game with incomplete information. Kleindorfer (2001) explores the use of strategic gaming to support the evaluation of business strategies and policy options in the evolving electric power market. Park et al. (2001) adopt the game theory to model and analyze the transactions in an electricity market in a continuous strategy space. Azevedo and Correia (2005) model double bilateral contract auctions for electric energy purchase and sale in Brazil using Bayes' rule and game theory to aid the agent in its bid definition. Menniti, Pinnarelli and Sorrentino (2007) suggest using the new theory of evolutionary games and the concept of near Nash Equilibrium to simulate the electricity market in the presence of more than two producers.

It is possible to model Turkish Electricity Market with game theory through a similar approach. Within the scope of this thesis, Turkish Electricity Market is modeled as a non-cooperative game with an assumption of complete information. Player strategies are represented with multipliers in a discrete strategy set and different market scenarios are tested through different game set-ups.

However, the large number of players in Turkish Electricity Market present difficulties in application of game theory in modeling. As the novelty brought by this work, similar market participants are clustered and treated as single players in order to apply game theory in an efficient way. Therefore, Turkish Electricity Market is modeled with only three players that reflect the main characteristics of the market participants.

2.2. Clustering Electricity Market Bids

Market participants have many distinct characteristics such as their installed capacity, ownership structure, location, fuel type, technology. However from the market point of view their most important characteristics are their bids and offers which carry certain hints about these characteristics. There are many works on clustering points with attributes. Regarding electricity sector, for instance, an order-specific clustering algorithm is applied to a data set describing regional electricity demand as a function of time in order to identify seasonal trends in a set of time-ordered data by Marton, Elkamel, and Duever, (2008). However, bids and offers in electricity market are curves rather than points. Kim, Park, Park and Joo (2005) classify generation companies according to the slope of their bidding function and analyze the feasibility of Nash Equilibrium using game theory. However this approach is a basic clustering application and insufficient to utilize the full prospects of the clustering. Therefore, the average electricity price difference integration model proposed by Hao, Jianhua, Zhenxiang, Dongming, and Weizhen (2004) is adapted to Turkish Electricity Market within the scope of this thesis.

Clusters are formed using the real market data of the Turkish Electricity Market for selected time points in 2008, in order to represent the different market conditions. Generators are clustered using Agglomerative Hierarchical Clustering and Square Sum of Deviations is used as the proximity measure.

CHAPTER 3

CLUSTERING BIDS IN TURKISH ELECTRICITY MARKET

In order to apply game theory in an efficient way for Turkish Electricity Market, large numbers of generators in Turkish Electricity Market should be represented by smaller number of players. Especially, bidding characteristics, which will be treated as the strategies of players should be emphasized. At this point, clustering the bid curves of the players in Turkish Electricity Market is an effective technique of reflecting a large set with a smaller model. Tan, Steinbach, and Kumar, (2005) state "Cluster analysis divides data into groups (clusters) that are meaningful, useful, or both."

Hao et al. (2004) suggest "an average electricity price difference integration model that can transform the unit's biding curve of power producer in market into a one-dimensional feature vector which can reflect the change of bidding curve, so can implement classification of unit's biding using cluster." In that work, a cluster analysis is conducted with bids data of July-September 2002 from Zhejiang electricity market (China). Analysis result shows that data conversion using average electricity price difference-integration model can solve the classification problems of bidding curve in electricity market and it is feasible to use this method to study producer's bidding classification.

As mentioned before in the current structure of Turkish Electricity Market, there are two levels of bids for down-regulation and two levels of offers for up-regulation, which occur according to the submitted technical parameters (daily generation schedule, available capacity and minimum stable generation), offer and bid prices. On the other hand, Electricity Market Balancing and Settlement Regulation (2009) allows 15 levels of bids for down-regulation and 15 levels of offers for up-regulation. As the available market data is based on the current structure of the Turkish Electricity Market, in the scope of this thesis data based on the two levels of bids for down-regulation and two levels of offers for up-regulation model will be utilized.

As explained in Chapter 1, market participants submit technical parameters that determine the bid quantities on an hourly basis and system marginal prices are also calculated on an hourly basis. Four representative hours from 2008 are selected to reflect certain features of the market: i) the hour in which up-regulation volume is closest to 2008 average and ii) the hour in which down-regulation volume is closest to 2008 average are analyzed in order to represent an average energy deficit or surplus case, iii) the hour in which the maximum up-regulation volume in 2008 occurs and iv) the hour in which the maximum down-regulation volume in 2008 occurs are analyzed in order to represent case of large volume of trade.

Average of the up-regulation volumes in 2008 is 2643 MW. On 13.07.2008 between 11:00-12:00 hours exactly 2643 MW up-regulation occurred. The average of the down-regulation volumes in 2008 is 1597 MW. On 23.03.2008 between 7:00-8:00 hours 1560 MW down-regulation occurred and this volume is the closest to the average of the down-regulation volumes in 2008. Maximum up-regulation volume occurred on 27.04.2008 between 10:00-11:00 hours and the corresponding volume is 7986 MW. Maximum down-regulation volume occurred on 14.12.2008 between 6:00-7:00 hours and the corresponding volume is 6272 MW.

3.1. Normalization of Offer and Bid Curves

In electricity markets each offer or bid is represented by price and quantity pairs. Generators that have different installed capacities or consequently different available capacities submit different quantities into the market. While large generators offer hundreds of MWs, other small scale generators submit only a couple of MWs. In a similar fashion, generators with different fuel types or ownership structures and consequently with different strategies submit different levels of prices. These prices may be as high as 2000 TL/MWh for up-regulation and may be as low as 0 TL/MWh for down-regulation. In order to compare the bids and offers of different generators for clustering purposes, an effective normalization should be applied.

Hao et al. (2004) suggest normalization of quantity component of each offer and bid according to available capacity of each generator and normalization of price component of each offer and bid according to the upper limit of the market price. Normalization of quantity component according to available capacity could be applied in Turkish Electricity Market with ease. However price component cannot be normalized according to the upper limit of the market price, as there is no such upper limit or bid cap for the Turkish Electricity Market. In the present study, quantities are normalized with respect to the available capacities and prices are normalized with respect to the highest price offered at that hour.

Let $P_{g,h}$ (TL/MWh) be the actual offer or bid price and $P^*_{g,h}$ (TL/MWh) be the normalized offer or bid price of generator *g* at hour h; let $Q_{g,h}$ (MWh) be the actual offer or bid quantity and $Q^*_{g,h}$ (MWh) be the normalized offer or bid quantity and $AC_{g,h}$ (MWh) be the available capacity of generator *g* at hour *h*, for every h and g=1, 2, …, n. Then

$$P^*_{g,h} = \frac{P_{g,h}}{\max\{P_{1,h}, P_{2,h}, \ldots, P_{n,h}\}} \quad (1)$$

$$Q^*_{g,h} = \frac{Q_{g,h}}{AC_{g,h}} \quad (2)$$

The bid and offer quantity normalization can only be applied for the bids and offers of the generators that have available capacity different than zero.

3.2. Segmentation of Offer and Bid Curves

Bids or offers which are composed of price and quantity pairs represent offer or bid curves. In order to cluster the curves "the average electricity price difference integration model" suggested by Hao et al. (2004) might be utilized. Bids or offers in Turkish Electricity Market are composed of at most two levels of prices and quantities. Therefore, normalized offer or bid curves, f (Q*) = P* are only simple step functions. An example normalized offer curve, divided into n segments is shown in Figure 13.

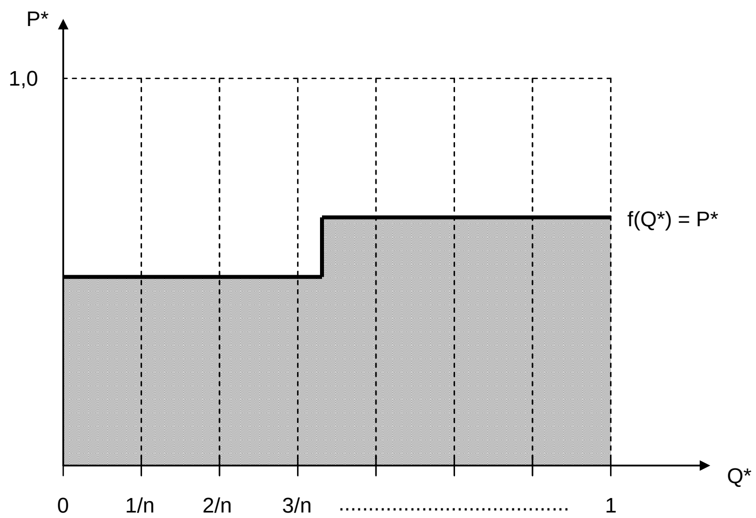

Figure 13 - Segmentation of the Normalized Offer Curve

Hao et al. (2004) suggest dividing offer and bid curves into 20 segments for cluster analysis. Since there are at most two levels of prices and quantities for each of the bids and offers in Turkish Electricity Market, 5 segments would be sufficient. Therefore offer and bid curves for a given hour, each of them divided into 5 segments, will constitute a total of 10 segments. The area below each of the curve segment is calculated according to Formula 3, which is explained in next part.

3.3. Areas and Arrays

Let $A_{g,h,f,i}$ be the area below *f* (*f* = "*o*" or "*b*" for offer and bid curves respectively) in the i^{th} segment for generator *g* at hour *h* and $f\left(Q^{*}_{g,h,i}\right)$ be the corresponding normalized price function at the normalized quantity of $Q^{*}_{g,h,i}$ of generator *g* at hour *h*. Then

$$A_{g,h,f,i} = \frac{f\left(Q^{*}_{g,h,i}\right) + f\left(Q^{*}_{g,h,(i-1)}\right)}{2} \times \frac{1}{5} \qquad (3)$$

as illustrated by using 5 segments in Figure 14.

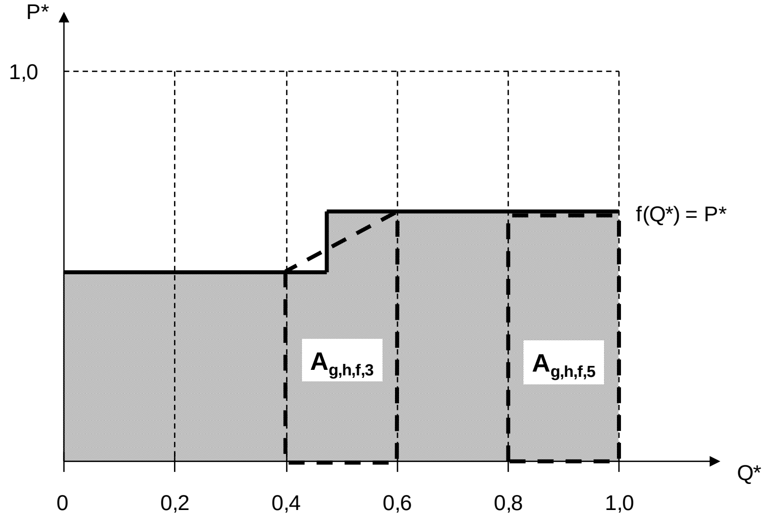

Figure 14 - Normalized Offer Curve Divided into 5 Segments

5 areas for offers and 5 areas for bids are calculated this way for generator *g* at hour *h* and these areas constitute a 10 dimensional array that represents the bidding strategy of generator g at hour h. This 10 dimensional array is represented as

$$L_{g,h} = \lfloor A_{g,h,b,1}; A_{g,h,b,2}; A_{g,h,b,3}; A_{g,h,b,4}; A_{g,h,b,5}; A_{g,h,o,1}; A_{g,h,o,2}; A_{g,h,o,3}; A_{g,h,o,4}; A_{g,h,o,5} \rfloor \quad (4)$$

The array that is composed of 10 areas represents the bidding strategy of a generator. Once the $L_{g,h}$ arrays are calculated for all the generators that have nonzero available capacity at hour *h*, generators can be classified into clusters according to their bidding strategies using one of the clustering techniques.

3.4. Clustering Technique

There are two main types of clustering: hierarchical and partitional. Tan et al. (2005) defines hierarchical clustering as “set of nested clusters that are organized as a tree” and partitional clustering as “a division of the set of data objects into non-overlapping subsets (clusters) such that each data object is in exactly one subset”. According to Tan et al. (2005) hierarchical clustering techniques are old but still widely used. Since these techniques are also used by Hao et al. (2004) for clustering the bids in electricity market, hierarchical clustering techniques have been utilized for clustering the bids in Turkish Electricity Market.

Tan et al. (2005) define two approaches for hierarchical clustering. First is “Agglomerative Hierarchical Clustering” (Forward Clustering) that starts with the points as individual clusters and at each step merges the closest pair of clusters. Second is “Divisive Hierarchical Clustering” (Backward Clustering) that starts with one all inclusive cluster and it splits a cluster at each step until only one singleton clusters of individual points remain. In both approaches, it is possible to stop at any step depending on the target number of clusters. Tan et al. (2005) state that agglomerative hierarchical clustering is the most commonly used. In order to utilize agglomerative hierarchical clustering techniques proximity between clusters should be defined. Most common proximity measures are

- Nearest Neighbor (Single Link): Distance between the closest neighboring points in the clusters

- Farthest Neighbor (Complete Link): Distance between the farthest neighboring points in the clusters
- Average Linkage: Average distance between all pairs in the clusters
- Centroid Linkage: Distance between the centroids of clusters
- Sum of Squared Deviations (Ward's Method): Sum of squared Euclidean distances of points from the centroids of clusters

Proximity measures other than sum of squared deviations result in clusters with single or a few points for bids in Turkish Electricity Market. Hao et al. (2004) also suggest this measure for classification of bid curves, since other proximity measures produce "bad" classification results on small clusters and produce seriously uneven number of units on large clusters. Therefore cluster analysis is carried out with agglomerative hierarchical clustering technique and proximity between clusters is defined according to the sum of squared deviations.

3.5. Clusters

As defined in Part 3.3, a 10 dimensional array, $L_{g,h}$ which represents the bids and offers of generator *g* at hour *h*, is calculated for all the generators that have nonzero available capacity at the hour *h*. Based on these arrays, generators are classified into clusters with Agglomerative Hierarchical Clustering using sum of squared deviations as the proximity measure. Using Matlab 7.0 functions

```
Y = pdist(X,'euclid');

Z = linkage(Y,'ward');

T = cluster(Z,'maxclust',3);
```

where, X is the Nx10 matrix composed of the $L_{g,h}$ arrays, N generators are classified into 3 clusters according to their offer and bid strategies at the given time points. The results are summarized in Table 1.

Table 1 – Summary of Clusters

Date	Hour	Number of Generators	Number of Clustered Generators	Cluster sizes
14.12.2008	6:00-7:00	171	142	19, 62, 61
27.04.2008	10:00-11:00	171	132	8, 53, 71
23.03.2008	7:00-8:00	171	134	15, 71, 48
13.07.2008	11:00-12:00	171	134	27, 62, 45

On 13.07.2008 between 11:00-12:00 hours, 171 generators submitted bids and offers and 137 of them have nonzero available capacity. When these 137 generators are classified into 3 clusters, one cluster has only 3 generators while the second and third clusters have 62 and 72 generators respectively. Sum of available capacities of the 3 generators in first cluster is only 91 MW, which constitutes the 0.35% of the total available capacity. When generators are classified into 5 or 10 clusters, these 3 clusters still remain as outliers. Considerably uneven cluster sizes hinder modeling the electricity market as a game. As explained in Chapter 2, similar generators are clustered and treated as single players in order to apply game theory in an efficient way. Therefore, a cluster that constitutes only the 0.35% of the total available capacity only with three generators may distort the results. So, these three outlier generators are ignored and remaining 134 generators are classified into 3 clusters.

On four different days and time, generators are clustered. Therefore some generators may be included in one cluster on a day and may be included in another cluster on another day. Out of the 102 generators that have available capacity more than zero on all of the four days of analysis, 76.47 % of the generators are classified to the same cluster on three or four days. According to this result, it can be concluded that most of the generators submit offers and bids in a consistent way and their strategies do not vary much from day to day.

CHAPTER 4

PLAYERS AND THEIR STRATEGIES

In the previous Chapter, clusters are constructed according to the offer and bid strategies of the generators at the given time points. Each cluster includes price and quantity values for certain number of generators' bids and offers. At the first sight, these values seem to be different than each other. However, a detailed analysis reveals that they share common traits, which cause them to be included in the same cluster.

These clusters, the group of generators, are players of the bidding game. Players are expected to differ from each other in terms of available capacity, daily generation schedule, minimum stable generation, offer and bid price. In literature, any study on creating a player from a cluster of generators is not encountered. Even though there are some works on clustering electricity market participants and their bids, such as Kim et al. (2005) and Hao et al. (2004), these works are focused only on clustering and do not treat clusters as players. Therefore a method is developed here, in order to apply the game theory on clusters.

Some of the attributes of the generators in a cluster will be the basis of cluster strategy. Therefore, aggregating or averaging these attributes is an important issue. If group of generators in the same cluster is treated as a single player then this player's available capacity could be represented by the sum of the available capacities of the generators in this cluster. In a similar fashion, daily generation schedule and minimum stable generation could be represented by the sum of relevant attributes of the generators in this cluster. As a drawback of this approach, daily generation schedule might be less than the minimum stable generation for some players. Alternatively, player's minimum stable generation might be represented as the smallest minimum stable generation of the generators in the cluster. But then, the ratio of minimum stable generation and available capacity for every player would be improper. Therefore, the approach of aggregating minimum stable generations of the generators in the cluster is used. As explained in Chapter 1, these quantities are used to calculate the offer and bid quantities in Turkish Electricity Market. Therefore, offer and bid quantities for these players could be calculated based on the aggregated values. On the other hand, taking the average of the offer and bid prices of the generators in the cluster is more appropriate to represent the offer and bid price of the relevant player.

As cluster analysis is repeated for four time points, four different player sets are formed. For different time points, the player configuration is similar but not exactly the same. As explained in Part 3.5, Out of the 102 generators that have available capacity more than zero on all of the 4 days of analysis, 76.47 % of the generators are classified to the same cluster on 3 or 4 days. Therefore, same players represent mostly the same generators for different days of analysis. Although, generators submit various bids and offers for different time points, characteristics of players do not change much from day to day. So, players are named with the same notation of Player 1, Player 2 and Player 3 for all the days of analysis.

In these player sets Player 1 has the smallest available capacity while Player 2 has more than half of the available capacity. Rest of the available capacity is supplied by Player 3 and its available capacity share varies between 35% to 45%. This player schema is very parallel to the actual Turkish Electricity Market structure. As of 16.04.2009, total installed capacity in Turkey is 42,080 MW. Turkish Electricity Market is dominated by state owned Electricity Generation Company (EUAŞ) which constitutes more than half of the installed capacity. 22% of the installed capacity is controlled by state owned wholesale company, TETAŞ. Rest of the market share is distributed among privately owned generators. Distribution of the installed capacity according to the companies is as shown in Figure 15

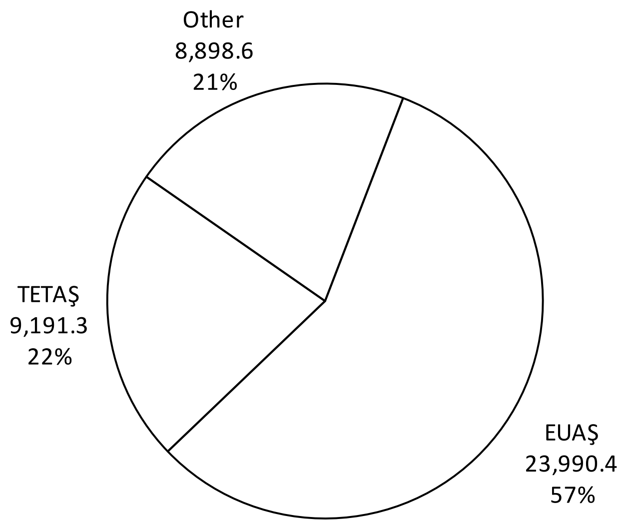

Figure 15 – Distribution of Installed Capacity (MW) according to Companies

However analyzing distribution of the installed capacity among companies is not enough to understand the current player characteristics in Turkish Electricity Market. Distribution of the installed capacity according to the fuel types should also be analyzed as in Figure 16.

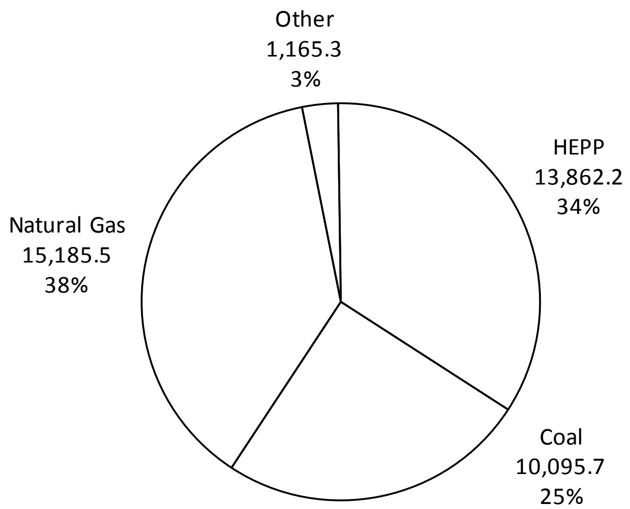

Figure 16 – Distribution of Installed Capacity (MW) according to the Fuel Type

Natural Gas fueled power plants constitute the largest share of installed capacity with 36%. Natural Gas fueled power plants are followed by Hydroelectric Power Plants (HEPP) which constitutes the 33% of the whole installed capacity. Coal which includes the imported coal, hard coal and lignite has a share of 24%. Finally other fuel types such as diesel, fuel oil, naphta, bio-fuels, geothermal, wind constitute only 7% of the installed capacity. Out of these fuel types marginal cost of the coal is cheapest. After recent price hike in natural gas, marginal cost of the natural gas fueled power plants become higher. Still, the fuel types classified under others have the highest marginal costs. These costly generators are usually dispatched only during the peak hours. Pricing the costs of hydroelectric power plants is difficult and it is known that these power plans usually bid around System Marginal Price.

Composition of clusters may not match exactly with distribution of installed capacity according to companies or fuel types. In other words, the generators that are included in a cluster may not match exactly with the generators that are owned by a company or that use the same fuel type. As actual identity of the bidders is strictly confidential information and not used within the scope of this thesis, such comparison cannot be made directly. However, there is a clear similarity between the actual installed capacity distribution according to companies and players that are formed according to the proposed clustering approach. On the other hand, when thermal power plants (coal and natural gas) grouped together, distribution of the installed capacity according to fuel type is also similar to the players that are formed according to the proposed clustering approach.

The similarity between the player scheme and the actual Turkish Electricity Market structure shows that proposed clustering approach makes sense for Turkish Electricity Market and could be used to represent the players in Turkish Electricity Market.

A detailed description of the cluster structures at different time points is given below.

On 14.12.2008 between 6:00-7:00 hours, three players are formed according to the clustering results and above procedure. Proportion of available capacities of each player is illustrated in Figure 17.

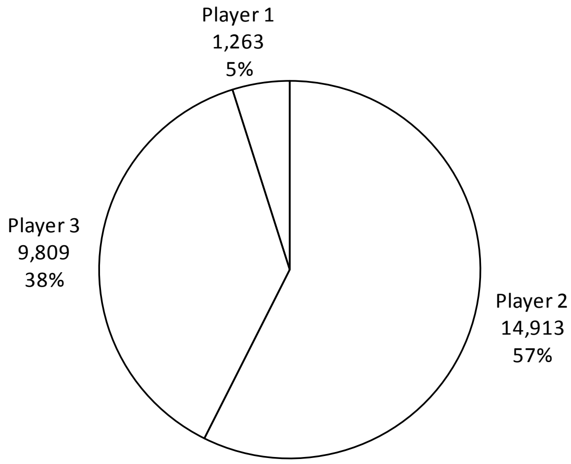

Figure 17 – Available Capacities (MW) of Players on 14.12.2008

Available capacity, daily generation schedule, minimum stable generation, offer and bid prices of the players are shown in Table 2.

Table 2 – Technical Data, Bid and Offer Prices of Players on 14.12.2008

Players	Available Capacity (MW)	Daily Generation Schedule (MW)	Minimum Stable Generation (MW)	Offer Price 1 (TL/MWh)	Offer Price 2 (TL/MWh)	Bid Price 1 (TL/MWh)	Bid Price 2 (TL/MWh)
Player 1	1,263	1,263	232	251.82	285.87	70.18	112.52
Player 2	14,913	14,908	12,774	180.63	195.60	18.83	50.23
Player 3	9,809	177	2,879	243.94	250.28	38.02	48.27

On 27.04.2008 between 10:00-11:00 hours, three players are formed according to the clustering results and above procedure. Proportion of available capacities of each player is illustrated in Figure 18.

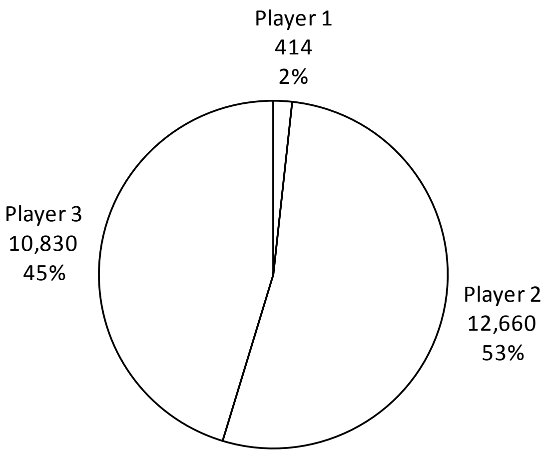

Figure 18 – Available Capacities (MW) of Players on 27.04.2008

Available capacity, daily generation schedule, minimum stable generation, offer and bid prices of the players are shown in Table 3.

Table 3 – Technical Data, Bid and Offer Prices of Players on 27.04.2008

Players	Available Capacity (MW)	Daily Generation Schedule (MW)	Minimum Stable Generation (MW)	Offer Price 1 (TL/MWh)	Offer Price 2 (TL/MWh)	Bid Price 1 (TL/MWh)	Bid Price 2 (TL/MWh)
Player 1	414	414	247	193.24	214.43	69.21	102.84
Player 2	12,660	12,648	11,086	148.93	156.63	19.19	38.55
Player 3	10,830	237	3,174	181.65	191.32	30.96	48.91

On 23.03.2008 between 7:00-8:00 hours, three players are formed according to the clustering results and above procedure. Proportion of available capacities of each player is illustrated in Figure 19.

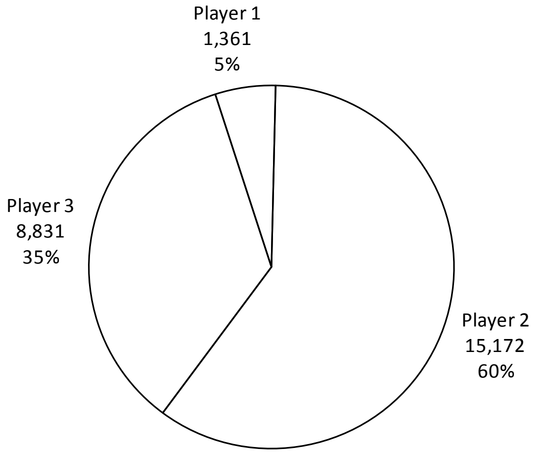

Figure 19 – Available Capacities (MW) of Players on 23.03.2008

Available capacity, daily generation schedule, minimum stable generation, offer and bid prices of the players are shown in Table 4.

Table 4 – Technical Data, Bid and Offer Prices of Players on 23.03.2008

Players	Available Capacity (MW)	Daily Generation Schedule (MW)	Minimum Stable Generation (MW)	Offer Price 1 (TL/MWh)	Offer Price 2 (TL/MWh)	Bid Price 1 (TL/MWh)	Bid Price 2 (TL/MWh)
Player 1	1,361	1,360	482	151.51	173.12	57.28	92.90
Player 2	15,172	14,321	12,593	164.21	172.10	19.14	44.11
Player 3	8,831	80	2,599	194.73	196.28	32.43	37.58

On 13.07.2008 between 11:00-12:00 hours, three players are formed according to the clustering results and above procedure. Proportion of available capacities of each player is illustrated in Figure 20.

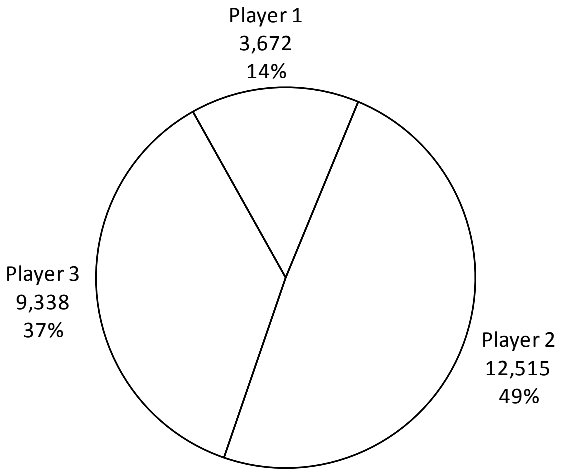

Figure 20 – Available Capacities (MW) of Players on 13.07.2008

Available capacity, daily generation schedule, minimum stable generation, offer and bid prices of the players are shown in Table 5.

Table 5 – Technical Data, Bid and Offer Prices of Players on 13.07.2008

Players	Available Capacity (MW)	Daily Generation Schedule (MW)	Minimum Stable Generation (MW)	Offer Price 1 (TL/MWh)	Offer Price 2 (TL/MWh)	Bid Price 1 (TL/MWh)	Bid Price 2 (TL/MWh)
Player 1	3,672	0	1,429	220.49	223.30	25.04	39.41
Player 2	12,515	7,687	6,996	214.63	234.86	27.99	54.67
Player 3	9,338	9,218	7,435	161.67	166.17	71.67	115.33

CHAPTER 5

THE GAME

The first important text about game theory appeared in 1944 with the famous book “Theory of Games and Economic Behavior” by John von Neumann and Oskar Morgenstern. In 2004 Princeton University Press, published a 60th anniversary edition of the book and described it as "the classic work upon which modern-day game theory is based”. Since 1944 game theory evolved a lot and it has been applied to several fields such as economics, biology, engineering, military, politics and international relations. For sure, John Forbes Nash contributed to the game theory considerably in 1950s and introduced the solution concept known as *Nash Equilibrium*. Nash (1951) introduced the concept of non-cooperative game developed methods for mathematical analysis of such games. The famous game known as Prisoner's Dilemma was discovered in 1950 by Melvin Drescher and Merrill Flood and then was formalized by Albert W. Tucker who gave it its name and wrote the first article about it.

Carmichael (2005) defines game theory as “a technique used to analyze situations where for two or more individuals (or institutions) the outcome of an action by one of them depends not only on the particular action taken by that individual but also on the actions taken by the other (or others)” As mentioned in the definition, game theory analyses the strategic situations where one’s reward or success is not only dependent to his or her decisions but also on other parties involved. This explanation might be adapted easily to many real life situations, where our success is heavily dependent on decision of our competitors, colleagues, boss or partner. Winston (1994) mentions that “game theory is useful for making decisions in cases where two or more decision makers have conflicting interests". Three important concepts in game theory and their brief explanations are;

- Players: A participant in a strategic game
- Strategy: A player's plan of action for the game
- Pay-off: Measure of how well the player does in a possible outcome of a game

Combination of player's strategies that are best responses to each other constitute the equilibrium in a game. According to Carmichael (2005), "if the players choose their equilibrium strategies they are doing the best they can, given the other players' choices. The equilibrium of a game describes the strategies that the rational players are predicted to choose when they interact." Out of many equilibrium concepts that have been developed, most famously known is the Nash Equilibrium.

Games can be classified with respect to cooperation, player and strategy, player and pay-off, order, history, strategy set and knowledge.

- **Cooperation:** Games can be modeled as either cooperative on non-cooperative based on assumptions on player's cooperation opportunities. If players are allowed to communicate, make credible agreements and cooperate with each other, then games are modeled as cooperative and if they are not allowed, then games are modeled as non-cooperative.
- **Player and Strategy:** Same strategies may result in same or different pay-offs for different players. If same strategy result in same pay-off for all players or in other words, if the pay-offs for playing a particular strategy not depend on who is playing them, then game is symmetric. If pay-offs of different players are different than each other for the same strategy, then game is asymmetric.
- **Player and Pay-off:** According to the sum of player pay-offs for all combinations of strategies, games are either constant sum or non-constant sum. If sum of the pay-offs of the players are constant then it is a constant sum game and a non-constant sum game otherwise. In constant sum games players have completely conflicting interests; increase in one's reward

means decrease in other’s. Zero sum game is a special case of constant sum game in which sum of player pay-offs for all combinations of strategies are zero.

- **Order:** In strategic situations players may decide their strategies in an order or decide at the same time. If players have to decide at the same time or decide without aware of others’ decisions, then it as a simultaneous move game. If players decide in some sort of order and players have some knowledge about earlier players’ decisions and can respond to it, then it is a sequential move game (dynamic game).
- **History:** Depending on the knowledge of players regarding history of the game, it is called perfect or imperfect information game. If all players know the decisions previously made by all other players, then it is a perfect information game. In imperfect information games, players have partial or even no information about the decisions made in earlier stages.
- **Strategy Set:** Games can be classified as discrete or continuous game according to the available strategy sets. While players choose their strategies among finite number of alternatives in discrete games, continuous games allow players to choose a strategy from a continuous strategy set.
- **Knowledge:** Each player’s knowledge about strategies and related pay-offs of other players determines the game type as complete information or incomplete information. If every player knows the strategies and payoffs of the other players, then it is a complete information game and incomplete information game otherwise.

5.1. Modeling Electricity Markets Using Game Theory

As mentioned before game theory can be applied to electricity market in order to create a realistic electricity market model, simulate behavior of market participants and finally, analyze the possible strategies of market participants. The electricity markets can be modeled as games where players are market participants, strategies are bids and payoffs are revenues or net profits. In such games solution can be determined in a continuous or discrete strategy domain using the Nash Equilibrium idea.

Aforementioned criteria that determine the type of the games should be analyzed for electricity market games in order to reveal the distinct specifications of electricity markets and clarify the type of the games that will be focused. Characteristics of electricity market games according to the mentioned criteria are summarized in Table 6

As seen in Table 6, electricity market games exhibit some distinct characteristics regarding above criteria. Some of the criteria might be determined in different ways based on the assumptions or requirements of the model. These choices will be clarified and justified in the following parts.

Table 6- Characteristics of electricity market games

Cooperation	Generally modeled as non-cooperative, however there might be collusions or collaborations in the market
Player Strategy	Same strategies result in different profits for each market participant (Asymmetric)
Player Pay-off	As market participants do not share a common revenue, instead they supply the electricity demand at marginal price; increase in profit of one market participant does not require other participants to lose money (Non-constant sum)
Order	Market participants need to bid in a predefined time interval without knowing the other market participants' bids (Simultaneous move)
History	Market participants only have partial information about the moves made in earlier stages. (Imperfect information)
Strategy Set	There might be infinitely many bid alternatives for each market participant. However, it might be modeled as discrete or continuous
Knowledge	Each Market participant has full information on his pay-off but lacks information other player's pay-off (generally modeled as Incomplete Information but might be modeled as complete information under certain assumptions)

5.2. A Game Model for Turkish Electricity Market

Many similar works model electricity markets as non-cooperative games, while Ferrero et al. (1997) allow coalitions and inside the coalitions coordinate the strategies as in a cooperative game. As mentioned by Akkaya (2003) Article 4 of the Law on the Protection of Competition prohibits agreements and concerted practices between undertakings. Due to this provision market participants are not allowed to form collaborations, coalitions or collusions in bidding to electricity market. Therefore Turkish Electricity Market can be modeled as a non-cooperative game.

In Turkish electricity market bid data is strictly confidential. No player can access to bid data of other players and no such historical data is published for statistical purposes. Park et al. (2001) mentions that in some countries such as Chile, Peru and Korea all information such as cost function of each generating entity in the market is revealed in public. However, this is not the case in Turkey. In some studies incomplete information case is transformed to complete information by utilization of Bayesian approach. For instance; Ferrero et al. (1998) suggests modeling the participant’s unknown characteristics as participant’s type and assigning basic joint probability distribution to these types. In another recent work, Azevedo and Correia (2006) try to transform the belief of a market participant regarding other market participants’ bids to information through conditional probabilities. Such approaches require determination of complex probabilities which sets the work apart from real life situation. Furthermore, detailed bid information or cost function is still needed for the player types. Under these circumstances, an assumption for complete information without Bayesian approach is acceptable for the reasons of practicality in the scope of this thesis. Clusters formed in Chapter 4 will supply the necessary information regarding the bids of each player in line with the complete information assumption.

Ferrero et al. (1998) defines the demand as a function of the spot price. However, in Turkish electricity market most of electricity trade takes place through bilateral contracts and only a small fraction of the demand is met through balancing market. Moreover, tariff is determined by the government for the consumers connected to the distribution grid and they are not directly affected by the prices formed in balancing market. Therefore, demand elasticity is nearly zero. Within the scope of this thesis demand elasticity would not be considered and realized demand figures will be utilized. Also, the transmission constraints and network losses will be ignored. Regarding market participants, additional constraints such as interruptible power from contracts, contingencies in local resources and etc. will also be ignored.

5.2.1. Player Characteristics

As mentioned in Chapter 4, group of generators in the same cluster are treated as a single player in this thesis. The characteristics that define a player are his offers and bids. While offer and bid prices are explicitly specified, offer and bid volumes are calculated according to the available capacity, daily generation schedule and minimum stable generation in Turkish Electricity Market as explained in Chapter 1. Therefore with the characteristics determined in Chapter 4 for every cluster, offer and bid prices and volumes can be specified for every player. These characteristics will be basis for the strategies of players.

5.2.2. Player Strategies

Player strategies are mainly related to offer and bid prices. Azevedo and Correia (2006) suggest multipliers that adjust the bid curves to model the behavior of each agent. Ferrero et al. (1997) model three strategies for players by adjusting the slope of bid curve of the generators. In Ferrero et al. (1998) they adjust the slope of the bid curve by a coefficient and calculate strategy vectors for each player. Torre (2004) suggests multipliers to adjust the production level instead of price and model strategies as low, medium or high production. These four examples suggest a discrete strategy set for players. On the other hand, Park et al. (2001) model the strategy of each player in a continuous space and calculate the Nash Equilibrium with a hybrid framework combining a graphical approach and an analytical method. For Turkish Electricity Market, discrete strategies such as high price, normal price and low price would allow us to reach generalized suggestions under different market conditions. These suggestions are extremely useful for market participants. Strategies of players will be modeled with coefficients multiplied with offer and bid prices of the players. The three multipliers that will be applied to every player are k_1, k_2 and k_3. Values of the multipliers are respectively 1.1, 1.0 and 0.9. Therefore multiplier k_1 represents the strategy of high price, multiplier k_2 represents the strategy of normal price and multiplier k_3 represents the strategy of low price. Other values might also be assigned for the multipliers but for an initial analysis, 10% high or low prices would represent the real life market strategies successfully. Under marginal pricing principle, market participants are not expected to bid very different from their marginal costs. Graphical representation of the player strategies is shown in Figure 21.

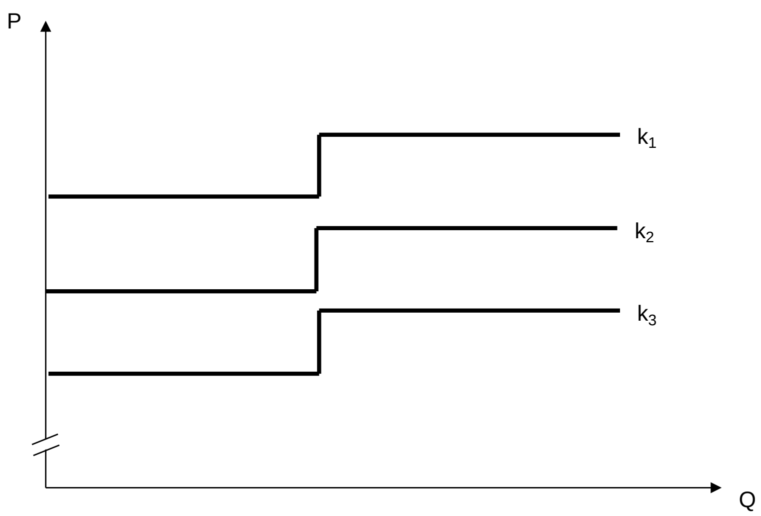

Figure 21 - Strategies of Players

5.2.3. Market Scenarios

In electricity markets, there are three possible market scenarios regarding the relation of demand and supply. These are energy surplus, energy deficit and energy balance. Energy balance requires that supply meets the exact demand and probability of occurrence of such a case is very low. When energy balance occurs on day ahead according to the notified demand and supply, there would not be any trade in day ahead market. Under these circumstances there is no need to inspect energy balance scenario in this thesis. On the other hand energy surplus and energy deficit cases are highly important as market scenarios and affect the bidding strategies. As explained in Chapter 1, when there is energy surplus in the market, system operator down-regulates some of the market participants by evaluating their bids. In other words, System Operator notifies them to decrease their generation. Similarly, when there is energy deficit in the market, system operator up-regulates some of the market participants by evaluating their offers. In other words, System Operator notifies them to increase their generation.

On the other hand, amount of energy surplus or energy deficit determines the volume of the trade on day ahead. When there is high energy surplus, System Operator accepts more bids in order to balance the supply and demand. In a parallel way, when there is high energy deficit, System Operator accepts more offers in order to balance the supply and demand. Therefore amount of energy surplus or deficit affects the volume of trade and as a consequence degree of competition.

In order to assess the strategies of players under different market conditions, four market scenarios will be modeled. Energy surplus case is modeled with two market scenarios, one being the average amount of surplus and other being the high amount of surplus. In a similar fashion, energy deficit case is modeled with two market scenarios, one being the average amount of deficit and other being the high amount of deficit. Lowest energy surplus and lowest energy deficit cases are ignored since these cases are very close to energy balance scenario and volume of trade is very limited. In Chapter 3, generators are clustered for these four time periods using the most recent market data, namely; when energy surplus is on the average, when energy surplus is highest, when energy deficit is on the average, when energy deficit is highest in Turkish Electricity Market in 2008. For the corresponding days and hours, realized demands for up-regulation or down-regulation are used as the market scenarios.

In some studies, market scenarios are modeled in a similar way. Azevedo and Correia (2006) model two scenarios to represent energy surplus tendency and energy scarcity tendency. It is also possible to model the market scenarios according to parameters other than demand and supply. Ferrero et al. (1998) model two scenarios for the high and low fuel prices. In both works, market scenarios are coupled with occurrence probabilities and used to calculate expected pay-offs. However, in this thesis different market scenarios are analyzed separately in order to assess the strategies of players under different market conditions to come up with valuable strategy suggestions for each type of player under different market conditions.

5.2.4. Pay-off Calculation

For electricity markets it is possible to define pay-off of a generator in many different ways. Revenue, net profit or even opportunity price might be used to calculate the pay-off of the players. Ferrero et al. (1997), (1998) define the pay-off as the difference between revenue at spot price and total of incremental costs, in other words net profit. Similarly, Park et al. (2001) use profit of each entity as the pay-off. However, generators in Turkey do not have complete information regarding the other generators' cost functions. Since, this game is modeled as a complete information game; such pay-off calculation would violate the game model. Because of a similar reason Azevedo and Correia (2006) measure the pay-off in terms of the generators' opportunity price and calculate it by subtracting the bid price from marginal price. This approach is in line with the complete information assumption, as it does not require the cost function of other players, but leads to another obstacle. Player strategies are modeled as offer and bid prices at different levels. Therefore for the marginal generator that determines the marginal price alternating strategies would not change the pay-off, if the merit order does not change due to alternating strategies. As marginal price will be equal to that generator's offer or bid price, pay-off of that generator would be always zero. However, that generator would get more revenue or profit by shifting to high price strategy by increasing the offer price or to low price strategy by decreasing the bid price. For these reasons, measuring the pay-off in terms of the generators' opportunity price would not reflect the change in the revenue or the profit of the marginal generator, when merit order does not change by alternating strategies.

The reasons discussed above require another approach for calculation of the pay-offs. Using revenue as the pay-off would be best for Turkish Electricity Market. This approach would ignore the cost functions, which is strictly confidential. Revenue of each generator is calculated by multiplying the marginal price by

$$R_g = P \times Q_g \tag{5}$$

where, R_g is the revenue of generator *g*, P is the marginal price, Q_g is the accepted offer or bid volume of generator *g.*

As explained in Chapter 1, P and Q_g are calculated based on the energy surplus or deficit situation through merit order. If there is an energy deficit in the system and it is required to up-regulate some of the generators, then offers are ranked in increasing order. System Operator selects the offers starting with the one with the smallest price until the up-regulation requirement is met. The marginal price, P is equal to the offer price of the last selected generator. Accepted offer volume of the generator g, Q_g is calculated for all the generators that submit offer by the following rules:

1) If the offer price of generator is lower than the offer price of the last selected generator, then the accepted offer volume is equal to actual offer volume

2) If generator is last selected one, then the accepted offer volume is equal to the remaining up-regulation requirement.
3) If the offer price of generator is higher than the offer price of the last selected generator, then the accepted offer volume is equal to zero.

If there is an energy surplus in the system and it is required to down-regulate some of the generators, then bids are ranked in decreasing order. System Operator selects the bids starting with the one with the highest price until the down-regulation requirement is met. The marginal price, P is equal to the bid price of the last selected generator. Accepted bid volume of the generator g, Q_g is calculated for all the generators that submit bid by the following rules:

1) If the bid price of generator is higher than the bid price of the last selected generator, then the accepted bid volume is equal to actual bid volume
2) If generator is last selected one, then the accepted bid volume is equal to the remaining down-regulation requirement.
3) If the bid price of generator is lower than the bid price of the last selected generator, then the accepted bid volume is equal to zero.

5.2.5. Nash Equilibrium

The concept of Nash Equilibrium is utilized in order to determine the equilibrium strategies. As explained by Carmichael (2005), “in a Nash Equilibrium the players in a game choose strategies that are best response to each other. However, no player’s Nash Equilibrium strategy is necessarily best response to any of the other strategies of the other players.” In a Nash Equilibrium none of the players has an incentive to change their equilibrium strategies. In other words, it is not possible to attain a pay-off better than the equilibrium pay-offs by changing the strategy unilaterally.

Maximum energy surplus case is modeled as the first market scenario. Maximum down-regulation volume occurred on 14.12.2008 between 6:00-7:00 hours and the corresponding down-regulation volume is 6272 MW. Therefore data regarding this time point is utilized in order to model the maximum energy surplus market scenario. Three players were formed from the clusters regarding 14.12.2008 between 6:00-7:00 hours. Each player has 3 strategies, namely high price, normal price and low price. In order to represent the real market conditions, realized demand of 6272 MW down-regulation, is utilized. For each of the strategy combinations merit orders are prepared and system marginal prices are calculated as shown in Appendix A. Based on the calculated system marginal prices, pay-off of each player for each strategy combination is calculated according to Formula 5. Corresponding pay-off matrices are exhibited in Table 7.

Table 7 – Pay-off matrices for the date 14.12.2008 and hours 6:00-7:00

Player 1 = k1		player 3								
		k1			k2			k3		
player 2	k1	-26,159	-100,115	-3,671	-26,159	-100,115	-3,671	-26,159	-100,115	-3,671
	k2	-23,781	-91,014	-3,338	-23,781	-91,014	-3,338	-23,781	-91,014	-3,338
	k3	**-21,403**	**-81,912**	**-3,004**	**-21,403**	**-81,912**	**-3,004**	**-21,403**	**-81,912**	**-3,004**

Player 1 = k2		player 3								
		k1			k2			k3		
player 2	k1	-26,159	-100,115	-3,671	-26,159	-100,115	-3,671	-26,159	-100,115	-3,671
	k2	-23,781	-91,014	-3,338	-23,781	-91,014	-3,338	-23,781	-91,014	-3,338
	k3	**-21,403**	**-81,912**	**-3,004**	**-21,403**	**-81,912**	**-3,004**	**-21,403**	**-81,912**	**-3,004**

Player 1 = k3		player 3								
		k1			k2			k3		
player 2	k1	-26,159	-100,115	-3,671	-26,159	-100,115	-3,671	-26,159	-100,115	-3,671
	k2	-23,781	-91,014	-3,338	-23,781	-91,014	-3,338	-23,781	-91,014	-3,338
	k3	**-21,403**	**-81,912**	**-3,004**	**-21,403**	**-81,912**	**-3,004**	**-21,403**	**-81,912**	**-3,004**

Pay-offs are negative because dispatched generators buy electricity energy equal to the down-regulation instruction volume from the balancing mechanism instead of generating that volume at that hour. The cost of the electricity that they buy from the balancing mechanism is less than their marginal costs. Therefore players would prefer to buy electricity from balancing mechanism at any price lower than their bid price, instead of no transaction. In other words, players would prefer to have a negative pay-off, instead of zero. Also, players would prefer to pay less for the transactions in balancing mechanism. Namely, pay-offs closer to zero are more preferable for players, except the zero pay-off.

As seen in pay-off matrices, Nash Equilibrium occurs for multiple combinations of strategies. The only determining strategy is the strategy of Player 2. Regardless of the strategies of Player 1 and Player 3, Nash Equilibrium occurs when Player 2 plays the strategy k_3 namely the low price strategy for bids. Nine Nash Equilibrium points, [strategy of player 1, strategy of player 2, strategy of player 3] are:

$NE_1 = [k_1, k_3, k_1]$ $NE_2 = [k_1, k_3, k_2]$ $NE_3 = [k_1, k_3, k_3]$

$NE_4 = [k_2, k_3, k_1]$ $NE_5 = [k_2, k_3, k_2]$ $NE_6 = [k_2, k_3, k_3]$

$NE_7 = [k_3, k_3, k_1]$ $NE_8 = [k_3, k_3, k_2]$ $NE_9 = [k_3, k_3, k_3]$

It can be concluded that when energy surplus is maximum, Nash Equilibrium occurs when the dominant player, Player 2, plays the low price strategy regardless of the strategies of other players. This way, all the players can buy cheap electricity energy from the balancing mechanism and a complete win-win situation could be achieved for all the players.

Maximum energy deficit case is modeled as the second market scenario. Maximum up-regulation volume occurred on 27.04.2008 between 10:00-11:00 hours and the corresponding up-regulation volume is 7986 MW. Therefore data regarding this time point is utilized in order to model the maximum energy deficit market scenario. Three players were formed from the clusters regarding 27.04.2008 between 10:00-11:00 hours. Each player has 3 strategies, namely high price, normal price and low price. In order to represent the real market conditions, realized demand of 7986 MW up-regulation, is utilized. For each of the strategy combinations merit orders are prepared and system marginal prices are calculated as shown in Appendix A. Based on the calculated system marginal prices, pay-off of each player for each strategy combination is calculated according to Formula 5. Corresponding pay-off matrices are exhibited in Table 8.

Table 8 – Pay-off matrices for the date 27.04.2008 and hours 10:00-11:00

Player 1 = k1		player 3								
		k1			k2			k3		
player 2	k1	0	2,525	1,678,158	0	2,296	1,525,598	0	0	1,375,105
	k2	0	2,525	1,678,158	0	2,296	1,525,598	0	2,066	1,373,038
	k3	0	2,525	1,678,158	0	2,296	1,525,598	0	2,066	1,373,038

Player 1 = k2		player 3								
		k1			k2			k3		
player 2	k1	0	2,525	1,678,158	0	2,296	1,525,598	0	0	1,375,105
	k2	0	2,525	1,678,158	0	2,296	1,525,598	0	2,066	1,373,038
	k3	0	2,525	1,678,158	0	2,296	1,525,598	0	2,066	1,373,038

Player 1 = k3		player 3								
		k1			k2			k3		
player 2	k1	0	2,525	1,678,158	0	2,296	1,525,598	0	0	1,375,105
	k2	0	2,525	1,678,158	0	2,296	1,525,598	0	2,066	1,373,038
	k3	0	2,525	1,678,158	0	2,296	1,525,598	0	2,066	1,373,038

Dispatched generators sell electricity energy equal to the up-regulation instruction volume to the balancing mechanism. Therefore players would prefer to have higher pay-off. In other words, players would prefer to earn more revenue through the transactions in balancing mechanism.

As seen in pay-off matrices, Nash Equilibrium occurs for multiple combinations of strategies. The only determining strategy is the strategy of Player 3. Regardless of the strategies of Player 1 and Player 2, Nash Equilibrium occurs when Player 3 plays the strategy k_1, namely high price strategy for offers. Corresponding nine Nash Equilibrium points, [strategy of player 1, strategy of player 2, strategy of player 3] are:

$NE_1 = [k_1, k_1, k_1]$ $NE_2 = [k_1, k_2, k_1]$ $NE_3 = [k_1, k_3, k_1]$

$NE_4 = [k_2, k_1, k_1]$ $NE_5 = [k_2, k_2, k_1]$ $NE_6 = [k_2, k_3, k_1]$

$NE_7 = [k_3, k_1, k_1]$ $NE_8 = [k_3, k_2, k_1]$ $NE_9 = [k_3, k_3, k_1]$

It can be concluded that when energy deficit is maximum, Nash Equilibrium occurs when the player with maximum offer volume, Player 3, plays the high price strategy regardless of the strategies of other players. This way, Player 2 and Player 3 can sell electricity energy to the balancing mechanism at a high price and a win-win situation could be achieved. As Player 1 does not have free capacity for up-regulation, it cannot gain revenue through balancing mechanism, regardless of its and other player's strategies.

Average amount of energy surplus case is modeled as the third market scenario. Average of the down-regulation volumes in 2008 is 1597 MW. On 23.03.2008 between 7:00-8:00 hours 1560 MW down-regulation occurred and this volume is the closest to the average of the down-regulation volumes in 2008. Therefore data regarding this time point is utilized in order to model the average amount of energy surplus market scenario. Three players were formed from the clusters regarding 23.03.2008 between 7:00-8:00 hours. Each player has 3 strategies, namely high price, normal price and low price. In order to represent the real market conditions, realized demand of 1560 MW down-regulation, is utilized. For each of the strategy combinations merit orders are prepared and system marginal prices are calculated as shown in Appendix A. Based on the calculated system marginal prices, pay-off of each player for each strategy combination is calculated according to Formula 5. Corresponding pay-off matrices are exhibited in Table 9.

Table 9 – Pay-off matrices for the date 23.03.2008 and hours 7:00-8:00

Player 1 = k1		player 3								
		k1			k2			k3		
player 2	k1	-66,004	-9,684	0	-66,004	-9,684	0	-66,004	-9,684	0
	k2	-60,003	-8,804	0	-60,003	-8,804	0	-60,003	-8,804	0
	k3	**-54,003**	**-7,923**	**0**	**-54,003**	**-7,923**	**0**	**-54,003**	**-7,923**	**0**

Player 1 = k2		player 3								
		k1			k2			k3		
player 2	k1	-66,004	-9,684	0	-66,004	-9,684	0	-66,004	-9,684	0
	k2	-60,003	-8,804	0	-60,003	-8,804	0	-60,003	-8,804	0
	k3	**-54,003**	**-7,923**	**0**	**-54,003**	**-7,923**	**0**	**-54,003**	**-7,923**	**0**

Player 1 = k3		player 3								
		k1			k2			k3		
player 2	k1	-66,004	-9,684	0	-66,004	-9,684	0	-66,004	-9,684	0
	k2	-60,003	-8,804	0	-60,003	-8,804	0	-60,003	-8,804	0
	k3	**-54,003**	**-7,923**	**0**	**-54,003**	**-7,923**	**0**	**-54,003**	**-7,923**	**0**

Due to the same reasons explained above, pay-offs are negative and players would prefer to have pay-offs closer to zero, except the zero pay-off.

As seen in pay-off matrices, Nash Equilibrium occurs for multiple combinations of strategies. The only determining strategy is the strategy of Player 2. Regardless of the strategies of Player 1 and Player 3, Nash Equilibrium occurs when Player 2 plays the strategy k_3, namely low price strategy for bids. Nine Nash Equilibrium points, [strategy of player 1, strategy of player 2, strategy of player 3] are:

$NE_1 = [k_1, k_3, k_1]$ $NE_2 = [k_1, k_3, k_2]$ $NE_3 = [k_1, k_3, k_3]$

$NE_4 = [k_2, k_3, k_1]$ $NE_5 = [k_2, k_3, k_2]$ $NE_6 = [k_2, k_3, k_3]$

$NE_7 = [k_3, k_3, k_1]$ $NE_8 = [k_3, k_3, k_2]$ $NE_9 = [k_3, k_3, k_3]$

It can be concluded that when there is average amount of energy surplus, Nash Equilibrium occurs when the dominant player, Player 2, plays the low price strategy regardless of the strategies of other players. This way, Player 1 and Player 2 can buy cheap electricity energy from the balancing mechanism. Under any strategy combination Player 3 can buy electricity energy from the balancing mechanism due to considerably lower bid prices compared to other players.

Average amount of energy deficit case is modeled as the fourth market scenario. Average of the up-regulation volumes in 2008 is 2643 MW. On 13.07.2008 between 11:00-12:00 hours exactly 2643 MW up-regulation occurred. Therefore data regarding this time point is utilized in order to model the average amount of energy deficit market scenario. Three players were formed from the clusters regarding 13.07.2008 between 11:00-12:00 hours. Each player has 3 strategies, namely high price, normal price and low price. In order to represent the real market conditions, realized demand of 2643 MW up-regulation, is utilized. For each of the strategy combinations merit orders are prepared and system marginal prices are calculated as shown in Appendix A. Based on the calculated system marginal prices, pay-off of each player for each strategy combination is calculated according to Formula 5. Corresponding pay-off matrices are exhibited in Table 10.

Table 10 – Pay-off matrices for the date 13.07.2008 and hours 11:00-12:00

Player 1 = k1		player 3								
		k1			k2			k3		
player 2	k1	0	606,121	0	0	578,602	27,520	0	578,602	27,520
	k2	0	551,019	0	0	551,019	0	0	526,002	25,018
	k3	0	495,918	0	0	495,918	0	0	495,918	0

Player 1 = k2		player 3								
		k1			k2			k3		
player 2	k1	327,668	278,408	0	327,668	250,888	27,520	327,668	250,888	27,520
	k2	0	551,019	0	0	551,019	0	0	526,002	25,018
	k3	0	495,918	0	0	495,918	0	0	495,918	0

Player 1 = k3		player 3								
		k1			k2			k3		
player 2	k1	558,673	0	0	558,673	0	0	533,308	0	25,365
	k2	297,880	253,098	0	297,880	253,098	0	297,880	228,080	25,018
	k3	**0**	**495,918**	**0**	**0**	**495,918**	**0**	**0**	**495,918**	**0**

Because of the same reasons explained above, players would prefer to have higher pay-off and earn more revenue through the transactions in balancing mechanism.

As seen in pay-off matrices, Nash Equilibrium occurs for three combinations of strategies. Nash Equilibrium occurs when Player 1 and Player 2 play the strategy k_3 regardless of the strategy of Player 3. Namely, both Player 1 and Player 2 play the low price strategy for offers regardless of the strategy of Player 3. By this way, Player 2 sells cheap electricity energy to the system due to the high level of competition under average level of up-regulation demand. Corresponding three Nash Equilibrium points, [strategy of player 1, strategy of player 2, strategy of player 3] are:

$NE_1 = [k_3, k_3, k_1]$ $NE_2 = [k_3, k_3, k_2]$ $NE_3 = [k_3, k_3, k_3]$

It can be concluded that when there is average amount of energy deficit, Nash Equilibrium occurs when the player with maximum offer volume, Player 2, plays the low price strategy in order to meet the whole demand alone and second big player, Player 1, also plays the low price strategy for a chance to capture some of the demand. This way, Player 2 guarantees a higher ranking in the merit order and can sell energy to the balancing mechanism at the level of his offer price.

CHAPTER 6

RESULTS AND RECOMMENDATIONS

According to the data analyzed for Turkish Electricity Market on 14.12.2008 between 6:00-7:00 hours, on 27.04.2008 between 10:00-11:00 hours, on 23.03.2008 between 7:00-8:00 hours and on 13.07.2008 between 11:00-12:00 hours, following observations and recommendations can be stated;

- For the maximum energy surplus case, Nash Equilibrium occurs when the player with the maximum down-regulation capacity plays the low price strategy for bids regardless of the strategies of other players. When high level of energy surplus is expected, dominant player is advised to submit bids with lower price for these hours. Hence, all the players can buy cheap electricity energy from the balancing mechanism.
- For the maximum energy deficit case, Nash Equilibrium occurs when the player with the maximum up-regulation capacity plays the high price strategy for offers regardless of the strategies of other players. When high level of energy deficit is expected, dominant player is advised to submit offers with higher price for these hours. Hence, all the players that have extra capacity can sell electricity energy to the balancing mechanism at a high price.
- For the average amount of energy surplus case, Nash Equilibrium occurs when the player with the maximum down-regulation capacity plays the low price strategy for bids regardless of the strategies of other players. When average amount of energy surplus is expected, dominant player is advised

to submit bids with lower price for these hours. Hence, all the players can buy cheap electricity energy from the balancing mechanism.

- For the average amount of energy deficit case, Nash Equilibrium occurs when the players with more up-regulation capacity play the low price strategy for bids regardless of the strategies of other players. When average amount of energy deficit case is expected and there is a competitive environment, dominant players are advised to submit offers with lower price for these hours. By this strategy of dominant players, only the players that submit offers with lowest prices would sell electricity energy to the balancing mechanism.

In short, when there is not enough competition in the market, dominant player is advised to submit bids with lower price for energy surplus cases and offers with higher price for energy deficit cases. However, when there is competition in the market, players are advised to submit offers with lower price in order to take a share of the limited demand for up-regulation. Therefore, it can be concluded that the suggested methodology produces reasonable results.

It is recommended to replicate the methodology with more clusters corresponding to more players so that the level of competition might be increased and strategies of players might be evaluated better. Also, extending this study to more time points may provide a better understanding of the mechanism.

Electricity Market Balancing and Settlement Regulation (2009), which will substantially change the current balancing and settlement mechanism, is published in Official Gazette on 14.04.2009 and financial operation of the aforementioned regulation will begin on 01.10.2009. It is expected that together with the ongoing privatization and deregulation process, improved market mechanism and rules will increase the level of competition in Turkish Electricity Market. Therefore, it is recommended to repeat a similar study as soon as sufficient market data is accumulated pursuant to Electricity Market Balancing and Settlement Regulation (2009).

The cluster analysis is utilized only to form the players for game within the scope of this thesis. However, results of cluster analysis include valuable market data regarding the patterns, abnormal bids, cooperation, collusions and seasonal effects. Bernard, Lesieutre, Oh, Thomas, and Donde (2006) suggest another clustering algorithm to identify generators that may already be exercising some market power to their advantage. Such cluster analysis can produce significant clues for supervising authority to accurately and timely detect abnormal biddings, tacit collusions and abuse of dominant position. Therefore cluster analysis should also be considered from this point of view in order to investigate these prohibited actions in Turkish Electricity Market. Within the context of this thesis individual offer and bid data, owners of the offers and bids are not revealed. However, for such cluster analysis strictly confidential bidding data has to be analyzed under the supervision of Electricity Market Regulatory Authority (EMRA).

There are various studies regarding the investigation of gaming opportunities in electricity markets. For instance Bialek (2002) derives a range of indices including a modification of the Herfindahl–Hirschman Index to quantify the incentives to game the uniform-price spot market. Akçollu (2003) examines the effectiveness and sustainability of competition in Turkish Electricity Market. Complemented with the above cluster analysis such indices and analysis may display Turkish Electricity Market's vulnerability to gaming.

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APPENDIX A

DETAILS OF PAY-OFF CALCULATION

Offer or bid prices of players for different strategies are shown at the top of each table. For each of the strategy combinations (a total of 3x3x3=27 combinations) merit orders are prepared either for up-regulation or down-regulation based on these offer and bid prices. Corresponding strategy combination is specified on up-left corner of each merit order. In every merit order each player has two offers or bids. According to merit orders required volume of bids or offers are selected and system marginal prices are determined equal to the offer or bid price of last selected offer or bid. Selected offers and bids are shown in bold characters.

Table 11 - Pay-off calculation for 14.12.2008 between 6:00-7:00 hours

Demand: 6272 MW for Down-Regulation

	Price			
	k1	k2	k3	Quantitiy
Player 1	77.20	70.18	63.16	232
Player 1	123.77	112.52	101.27	1,031
Player 2	20.72	18.83	16.95	12,774
Player 2	55.25	50.23	45.20	2,134
Player 3	41.82	38.02	34.22	177
Player 3	53.10	48.27	43.44	0

k1k1k1	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 2	**55.25**	**2,134**
Player 3	**53.10**	**0**
Player 3	**41.82**	**177**
Player 2	**20.72**	**12,774**

k1k1k2	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 2	**55.25**	**2,134**
Player 3	**48.27**	**0**
Player 3	**38.02**	**177**
Player 2	**20.72**	**12,774**

k1k1k3	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 2	**55.25**	**2,134**
Player 3	**43.44**	**0**
Player 3	**34.22**	**177**
Player 2	**20.72**	**12,774**

k1k2k1	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 3	**53.10**	**0**
Player 2	**50.23**	**2,134**
Player 3	**41.82**	**177**
Player 2	**18.83**	**12,774**

k1k2k2	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 2	**50.23**	**2,134**
Player 3	**48.27**	**0**
Player 3	**38.02**	**177**
Player 2	**18.83**	**12,774**

k1k2k3	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 2	**50.23**	**2,134**
Player 3	**43.44**	**0**
Player 3	**34.22**	**177**
Player 2	**18.83**	**12,774**

k1k3k1	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 3	**53.10**	**0**
Player 2	**45.20**	**2,134**
Player 3	**41.82**	**177**
Player 2	**16.95**	**12,774**

k1k3k2	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 3	**48.27**	**0**
Player 2	**45.20**	**2,134**
Player 3	**38.02**	**177**
Player 2	**16.95**	**12,774**

k1k3k3	Price	Quantity
Player 1	**123.77**	**1,031**
Player 1	**77.20**	**232**
Player 2	**45.20**	**2,134**
Player 3	**43.44**	**0**
Player 3	**34.22**	**177**
Player 2	**16.95**	**12,774**

Table 11 (continued)

k2k1k1	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 2	55.25	2,134
Player 3	53.10	0
Player 3	41.82	177
Player 2	20.72	12,774

k2k1k2	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 2	55.25	2,134
Player 3	48.27	0
Player 3	38.02	177
Player 2	20.72	12,774

k2k1k3	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 2	55.25	2,134
Player 3	43.44	0
Player 3	34.22	177
Player 2	20.72	12,774

k2k2k1	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 3	53.10	0
Player 2	50.23	2,134
Player 3	41.82	177
Player 2	18.83	12,774

k2k2k2	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 2	50.23	2,134
Player 3	48.27	0
Player 3	38.02	177
Player 2	18.83	12,774

k2k2k3	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 2	50.23	2,134
Player 3	43.44	0
Player 3	34.22	177
Player 2	18.83	12,774

k2k3k1	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 3	53.10	0
Player 2	45.20	2,134
Player 3	41.82	177
Player 2	16.95	12,774

k2k3k2	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 3	48.27	0
Player 2	45.20	2,134
Player 3	38.02	177
Player 2	16.95	12,774

k2k3k3	Price	Quantity
Player 1	112.52	1,031
Player 1	70.18	232
Player 2	45.20	2,134
Player 3	43.44	0
Player 3	34.22	177
Player 2	16.95	12,774

k3k1k1	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 2	55.25	2,134
Player 3	53.10	0
Player 3	41.82	177
Player 2	20.72	12,774

k3k1k2	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 2	55.25	2,134
Player 3	48.27	0
Player 3	38.02	177
Player 2	20.72	12,774

k3k1k3	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 2	55.25	2,134
Player 3	43.44	0
Player 3	34.22	177
Player 2	20.72	12,774

k3k2k1	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 3	53.10	0
Player 2	50.23	2,134
Player 3	41.82	177
Player 2	18.83	12,774

k3k2k2	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 2	50.23	2,134
Player 3	48.27	0
Player 3	38.02	177
Player 2	18.83	12,774

k3k2k3	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 2	50.23	2,134
Player 3	43.44	0
Player 3	34.22	177
Player 2	18.83	12,774

k3k3k1	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 3	53.10	0
Player 2	45.20	2,134
Player 3	41.82	177
Player 2	16.95	12,774

k3k3k2	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 3	48.27	0
Player 2	45.20	2,134
Player 3	38.02	177
Player 2	16.95	12,774

k3k3k3	Price	Quantity
Player 1	101.27	1,031
Player 1	63.16	232
Player 2	45.20	2,134
Player 3	43.44	0
Player 3	34.22	177
Player 2	16.95	12,774

Table 12 - Pay-off calculation for 27.04.2008 between 10:00-11:00 hours

Demand: 7986 MW for Up-Regulation

	Price			
	k1	k2	k3	Quantitiy
Player 1	212.56	193.24	173.91	0
Player 1	235.88	214.43	192.99	0
Player 2	163.82	148.93	134.03	0
Player 2	172.29	156.63	140.97	12
Player 3	199.81	181.65	163.48	2,936
Player 3	210.45	191.32	172.19	7,656

k1k1k1	Price	Quantity
Player 2	**163.82**	**0**
Player 2	**172.29**	**12**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k1k2	Price	Quantity
Player 2	**163.82**	**0**
Player 2	**172.29**	**12**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k1k3	Price	Quantity
Player 3	**163.48**	**2,936**
Player 2	**163.82**	**0**
Player 3	**172.19**	**7,656**
Player 2	172.29	12
Player 1	212.56	0
Player 1	235.88	0

k1k2k1	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k2k2	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k2k3	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 3	**163.48**	**2,936**
Player 3	**172.19**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k3k1	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k3k2	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k1k3k3	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 3	**163.48**	**2,936**
Player 3	**172.19**	**7,656**
Player 1	212.56	0
Player 1	235.88	0

k2k1k1	Price	Quantity
Player 2	**163.82**	**0**
Player 2	**172.29**	**12**
Player 1	**193.24**	**0**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**
Player 1	214.43	0

k2k1k2	Price	Quantity
Player 2	**163.82**	**0**
Player 2	**172.29**	**12**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	193.24	0
Player 1	214.43	0

k2k1k3	Price	Quantity
Player 3	**163.48**	**2,936**
Player 2	**163.82**	**0**
Player 3	**172.19**	**7,656**
Player 2	172.29	12
Player 1	193.24	0
Player 1	214.43	0

k2k2k1	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 1	**193.24**	**0**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**
Player 1	214.43	0

k2k2k2	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	193.24	0
Player 1	214.43	0

k2k2k3	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 3	**163.48**	**2,936**
Player 3	**172.19**	**7,656**
Player 1	193.24	0
Player 1	214.43	0

k2k3k1	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 1	**193.24**	**0**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**
Player 1	214.43	0

k2k3k2	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	193.24	0
Player 1	214.43	0

k2k3k3	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 3	**163.48**	**2,936**
Player 3	**172.19**	**7,656**
Player 1	193.24	0
Player 1	214.43	0

Table 12(continued)

k3k1k1	Price	Quantity
Player 2	**163.82**	**0**
Player 2	**172.29**	**12**
Player 1	**173.91**	**0**
Player 1	**192.99**	**0**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**

k3k1k2	Price	Quantity
Player 2	**163.82**	**0**
Player 2	**172.29**	**12**
Player 1	**173.91**	**0**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	192.99	0

k3k1k3	Price	Quantity
Player 3	**163.48**	**2,936**
Player 2	**163.82**	**0**
Player 3	**172.19**	**7,656**
Player 2	172.29	12
Player 1	173.91	0
Player 1	192.99	0

k3k2k1	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 1	**173.91**	**0**
Player 1	**192.99**	**0**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**

k3k2k2	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 1	**173.91**	**0**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	192.99	0

k3k2k3	Price	Quantity
Player 2	**148.93**	**0**
Player 2	**156.63**	**12**
Player 3	**163.48**	**2,936**
Player 3	**172.19**	**7,656**
Player 1	173.91	0
Player 1	192.99	0

k3k3k1	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 1	**173.91**	**0**
Player 1	**192.99**	**0**
Player 3	**199.81**	**2,936**
Player 3	**210.45**	**7,656**

k3k3k2	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 1	**173.91**	**0**
Player 3	**181.65**	**2,936**
Player 3	**191.32**	**7,656**
Player 1	192.99	0

k3k3k3	Price	Quantity
Player 2	**134.03**	**0**
Player 2	**140.97**	**12**
Player 3	**163.48**	**2,936**
Player 3	**172.19**	**7,656**
Player 1	173.91	0
Player 1	192.99	0

Table 13 - Pay-off calculation for 23.03.2008 between 7:00-8:00 hours

Demand: 1560 MW for Down-Regulation

	Price			
	k1	k2	k3	Quantitiy
Player 1	63.01	57.28	51.55	482
Player 1	102.19	92.90	83.61	879
Player 2	21.05	19.14	17.23	12,593
Player 2	48.52	44.11	39.70	1,728
Player 3	35.67	32.43	29.19	80
Player 3	41.34	37.58	33.82	0

k1k1k1	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**48.52**	**1,728**
Player 3	41.34	0
Player 3	35.67	80
Player 2	21.05	12,593

k1k1k2	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**48.52**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	21.05	12,593

k1k1k3	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**48.52**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	21.05	12,593

k1k2k1	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**44.11**	**1,728**
Player 3	41.34	0
Player 3	35.67	80
Player 2	19.14	12,593

k1k2k2	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**44.11**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	19.14	12,593

k1k2k3	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**44.11**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	19.14	12,593

k1k3k1	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 3	**41.34**	**0**
Player 2	**39.70**	**1,728**
Player 3	35.67	80
Player 2	17.23	12,593

k1k3k2	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**39.70**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	17.23	12,593

k1k3k3	Price	Quantity
Player 1	**102.19**	**879**
Player 1	**63.01**	**482**
Player 2	**39.70**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	17.23	12,593

k2k1k1	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**48.52**	**1,728**
Player 3	41.34	0
Player 3	35.67	80
Player 2	21.05	12,593

k2k1k2	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**48.52**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	21.05	12,593

k2k1k3	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**48.52**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	21.05	12,593

k2k2k1	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**44.11**	**1,728**
Player 3	41.34	0
Player 3	35.67	80
Player 2	19.14	12,593

k2k2k2	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**44.11**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	19.14	12,593

k2k2k3	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**44.11**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	19.14	12,593

k2k3k1	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 3	**41.34**	**0**
Player 2	**39.70**	**1,728**
Player 3	35.67	80
Player 2	17.23	12,593

k2k3k2	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**39.70**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	17.23	12,593

k2k3k3	Price	Quantity
Player 1	**92.90**	**879**
Player 1	**57.28**	**482**
Player 2	**39.70**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	17.23	12,593

Table 13 (continued)

k3k1k1	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**48.52**	**1,728**
Player 3	41.34	0
Player 3	35.67	80
Player 2	21.05	12,593

k3k1k2	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**48.52**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	21.05	12,593

k3k1k3	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**48.52**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	21.05	12,593

k3k2k1	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**44.11**	**1,728**
Player 3	41.34	0
Player 3	35.67	80
Player 2	19.14	12,593

k3k2k2	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**44.11**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	19.14	12,593

k3k2k3	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**44.11**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	19.14	12,593

k3k3k1	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 3	**41.34**	**0**
Player 2	**39.70**	**1,728**
Player 3	35.67	80
Player 2	17.23	12,593

k3k3k2	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**39.70**	**1,728**
Player 3	37.58	0
Player 3	32.43	80
Player 2	17.23	12,593

k3k3k3	Price	Quantity
Player 1	**83.61**	**879**
Player 1	**51.55**	**482**
Player 2	**39.70**	**1,728**
Player 3	33.82	0
Player 3	29.19	80
Player 2	17.23	12,593

Table 14 - Pay-off calculation for 13.07.2008 between 11:00-12:00 hours

Demand: 2643 MW for Up-Regulation

	Price			
	k1	k2	k3	Quantitiy
Player 1	236.10	214.63	193.17	1,429
Player 1	258.35	234.86	211.38	2,243
Player 2	224.33	203.93	183.54	0
Player 2	229.33	208.48	187.63	4,828
Player 3	242.54	220.49	198.44	0
Player 3	245.63	223.30	200.97	120

k1k1k1	Price	Quantity
Player 2	**224.33**	**0**
Player 2	**229.33**	**4,828**
Player 1	236.10	1,429
Player 3	242.54	0
Player 3	245.63	120
Player 1	258.35	2,243

k1k1k2	Price	Quantity
Player 3	**220.49**	**0**
Player 3	**223.30**	**120**
Player 2	**224.33**	**0**
Player 2	**229.33**	**4,828**
Player 1	236.10	1,429
Player 1	258.35	2,243

k1k1k3	Price	Quantity
Player 3	**198.44**	**0**
Player 3	**200.97**	**120**
Player 2	**224.33**	**0**
Player 2	**229.33**	**4,828**
Player 1	236.10	1,429
Player 1	258.35	2,243

k1k2k1	Price	Quantity
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	236.10	1,429
Player 3	242.54	0
Player 3	245.63	120
Player 1	258.35	2,243

k1k2k2	Price	Quantity
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 3	220.49	0
Player 3	223.30	120
Player 1	236.10	1,429
Player 1	258.35	2,243

k1k2k3	Price	Quantity
Player 3	**198.44**	**0**
Player 3	**200.97**	**120**
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	236.10	1,429
Player 1	258.35	2,243

k1k3k1	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 1	236.10	1,429
Player 3	242.54	0
Player 3	245.63	120
Player 1	258.35	2,243

k1k3k2	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 3	220.49	0
Player 3	223.30	120
Player 1	236.10	1,429
Player 1	258.35	2,243

k1k3k3	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 3	198.44	0
Player 3	200.97	120
Player 1	236.10	1,429
Player 1	258.35	2,243

k2k1k1	Price	Quantity
Player 1	**214.63**	**1,429**
Player 2	**224.33**	**0**
Player 2	**229.33**	**4,828**
Player 1	234.86	2,243
Player 3	242.54	0
Player 3	245.63	120

k2k1k2	Price	Quantity
Player 1	**214.63**	**1,429**
Player 3	**220.49**	**0**
Player 3	**223.30**	**120**
Player 2	**224.33**	**0**
Player 2	**229.33**	**4,828**
Player 1	234.86	2,243

k2k1k3	Price	Quantity
Player 3	**198.44**	**0**
Player 3	**200.97**	**120**
Player 1	**214.63**	**1,429**
Player 2	**224.33**	**0**
Player 2	**229.33**	**4,828**
Player 1	234.86	2,243

k2k2k1	Price	Quantity
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	214.63	1,429
Player 1	234.86	2,243
Player 3	242.54	0
Player 3	245.63	120

k2k2k2	Price	Quantity
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	214.63	1,429
Player 3	220.49	0
Player 3	223.30	120
Player 1	234.86	2,243

k2k2k3	Price	Quantity
Player 3	**198.44**	**0**
Player 3	**200.97**	**120**
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	214.63	1,429
Player 1	234.86	2,243

k2k3k1	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 1	214.63	1,429
Player 1	234.86	2,243
Player 3	242.54	0
Player 3	245.63	120

k2k3k2	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 1	214.63	1,429
Player 3	220.49	0
Player 3	223.30	120
Player 1	234.86	2,243

k2k3k3	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 3	198.44	0
Player 3	200.97	120
Player 1	214.63	1,429
Player 1	234.86	2,243

Table 14 (continued)

k3k1k1	Price	Quantity
Player 1	**193.17**	**1,429**
Player 1	**211.38**	**2,243**
Player 2	224.33	0
Player 2	229.33	4,828
Player 3	242.54	0
Player 3	245.63	120

k3k1k2	Price	Quantity
Player 1	**193.17**	**1,429**
Player 1	**211.38**	**2,243**
Player 3	220.49	0
Player 3	223.30	120
Player 2	224.33	0
Player 2	229.33	4,828

k3k1k3	Price	Quantity
Player 1	**193.17**	**1,429**
Player 3	**198.44**	**0**
Player 3	**200.97**	**120**
Player 1	**211.38**	**2,243**
Player 2	224.33	0
Player 2	229.33	4,828

k3k2k1	Price	Quantity
Player 1	**193.17**	**1,429**
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	211.38	2,243
Player 3	242.54	0
Player 3	245.63	120

k3k2k2	Price	Quantity
Player 1	**193.17**	**1,429**
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	211.38	2,243
Player 3	220.49	0
Player 3	223.30	120

k3k2k3	Price	Quantity
Player 1	**193.17**	**1,429**
Player 3	**198.44**	**0**
Player 3	**200.97**	**120**
Player 2	**203.93**	**0**
Player 2	**208.48**	**4,828**
Player 1	211.38	2,243

k3k3k1	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 1	193.17	1,429
Player 1	211.38	2,243
Player 3	242.54	0
Player 3	245.63	120

k3k3k2	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 1	193.17	1,429
Player 1	211.38	2,243
Player 3	220.49	0
Player 3	223.30	120

k3k3k3	Price	Quantity
Player 2	**183.54**	**0**
Player 2	**187.63**	**4,828**
Player 1	193.17	1,429
Player 3	198.44	0
Player 3	200.97	120
Player 1	211.38	2,243