ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

INVESTIGATION THE IMPACTS OF A DOMINANT FIRM'S BIDDING STRATEGIES ON MARKET-CLEARING PRICES IN A LIBERALISING ELECTRICITY MARKET

M.Sc. THESIS

Burak KARAMAN

Energy Science and Technology Division

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Thesis Advisor: Assoc. Prof. Dr. Sencer ECER

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

SERBESTLEŞME SÜRECİNDEKİ BİR ELEKTRİK PİYASASINDA FAALİYET GÖSTEREN PİYASA GÜCÜ BULUNAN BİR FİRMANIN PİYASA TAKAS FİYATLARI ÜZERİNDEKİ ETKİLERİNİN ARAŞTIRILMASI

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ARALIK 2015

Burak KARAMAN, a M.Sc. student of ITU Institute of Energy student ID 301121006 successfully defended the thesis entitled “INVESTIGATION THE IMPACTS OF A DOMINANT FIRM’S BIDDING STRATEGIES ON MARKET-CLEARING PRICES IN A LIBERALISING ELECTRICITY MARKET”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 09 December 2015
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Dedicated to my dear family and
in memory of my father İlyas KARAMAN,

FOREWORD

I am grateful to my thesis advisor Assoc. Prof. Dr. Sencer ECER for his valuable comments, continuous advice and well guidance in my survey. It was a pleasure to work with such a valuable instructor.
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December 2015 Burak KARAMAN
Mechanical Engineer

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ABBREVIATIONS

BSR : Balancing and Settlement Regulation
DAM : Day-Ahead Market
EIA : Energy Information Administration
EMRA : Energy Market Regulatory Authority
EPF : Electricity Price Forecasting
EPIAS : Turkish Independent Power Exchange
FMCP : Final Market-Clearing Price
F-BSR : Final Balancing and Settlement Regulation
HEPP : Hydroelectric Power Plant
IMCP : Initial Market-Clearing Price
IPP : Independent Power Producer
MCP : Market-Clearing Price
MCQ : Market-Clearing Quantity
MENR : Ministry of Energy and Natural Resources
NREL : National Renewables Energy Laboratory
OTC : Over-The-Counter
O&M : Operation and Maintenance
P : Price
PP : Power Plant
PMUM : State-Owned Market Operator
Q : Quantity
RD : Reduced Demand
TEIAS : State-Owned Transmission Company
T-BSR : Transitional Balancing and Settlement Regulation

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INVESTIGATION THE IMPACTS OF A DOMINANT FIRM'S BIDDING STRATEGIES ON MARKET-CLEARING PRICES IN A LIBERALISING ELECTRICITY MARKET

SUMMARY

For many years, electricity power industry has been controlled and managed by public utilities in many countries. Generation, transmission, distribution and retail of electricity were under the responsibility of government-owned companies. Over the last few decades, electricity industry are being liberalized and deregulated and has experienced significant changes.

Although countries have preferred different strategies and approaches in privatization program and deregulation of electricity markets, common goal of them is to have a sustainable, effective and well-functioning electricity market.

Few large firms are dominant in oligopoly market and these large firms may have tendency to use their market power typically by changing their offer quantities or prices. Interaction among such producers in the market also necessitates considering each effect of participants' offer strategies on market-clearing prices.

In the thesis, the impacts of dominant firm's bidding strategies on market-clearing prices is investigated. Day-ahead market is modeled under some assumptions. Supply and demand are taken from various sources to be able to run the simulation. Hypothetical power producers are set up to be able to show how the model works.

The model consists of two main parts, which are obtaining of reduced demand curve and formation of aggregated supply curve.

Three different cases are analyzed, which are uncoordinated simulation without manipulation, coordinated simulation with capacity withdrawal and coordinated simulation with intervention.

In first case, uncoordinated simulation is carried out. In this simulation, each power plant submits its offer individually based on its own marginal production cost. The results of first simulation give reference market-clearing prices, which are going to use by evaluating the effects of bidding strategies of dominant firm.

Second case is a coordinated simulation and power producers submit their offers by considering all their power plants, which they have. In this simulation active player's bidding strategies are taken into account by using game theory. It is aimed to investigate the impact of capacity withdrawal on market-clearing prices. In this circumstance, dominant firm tries to find out its optimum offer strategy by considering all their power plants and the strategies of other power producers.

In the third case, dominant firm is modeled as a firm trying to reduce market-clearing prices as low as possible by running all their power plants. Some power plants of the dominant firm run below their marginal costs. In this case, dominant firm submits its offers without considering its losses.

To have a well-designed market, privatization program should be carefully carried out to protect price increase/decrease or volatility arisen from market power. Privatization program should not serve to generate new dominant firm or contribute dominant firm's market power.

In conclusion, electricity prices should be determined in competitive market conditions without manipulation. Abuse of market power should be monitored and prevented.

SERBESTLEŞME SÜRECİNDEKİ BİR ELEKTRİK PİYASASINDA FAALİYET GÖSTEREN PİYASA GÜCÜ BULUNAN BİR FİRMANIN PİYASA TAKAS FİYATLARI ÜZERİNDEKİ ETKİSİNİN ARAŞTIRILMASI

ÖZET

Elektrik enerjisi ihtiyacının yeterli, kaliteli, kesintisiz, ucuz, çevreye uyumlu ve sürdürülebilir bir şekilde karşılanabilmesi, ülke enerji politikalarının temel gündemini oluşturmaktadır.

Elektrik enerjisinin erişilebilir ve rekabetçi fiyatlarla sunulması ülkelerin kalkınmasında büyük öneme sahiptir. Uygun elektrik fiyatları ülkelerin uluslararası pazarlardaki rekabet gücünü doğrudan etkilemektedir. Bu doğrultuda, ülkeler kaynakların daha etkin ve verimli kullanılmasına imkan tanıyan elektrik piyasa yapısını oluşturmaya çalışmışlardır. Teknolojik gelişmelerle birlikte değişen ölçek ekonomisi, artan elektrik talebini karşılayacak yeni üretim ve altyapı yatırımlarına duyulan ihtiyaç, serbestleşme sürecine zemin hazırlayan temel etmenler olmuştur.

Dünya genelindeki elektrik piyasaları incelendiğinde elektrik üretimi, iletimi, dağıtımı, satışı ve satış sonrası hizmetleri uzun yıllar boyunca kamu şirketleri tarafından dikey bütünleşik yapı içerisinde sunulmuştur. Serbestleşme süreciyle birlikte kar amacı olmayan, maliyet bazlı üretim yapan kamu şirketlerinden, fiyatların arz ve talebe göre piyasa koşullarında belirlendiği bir yapıya geçilmiştir.

Serbestleşme politikalarına bakıldığında ülkelerin farklı serbestleşme politikaları izlediği görülmektedir. Önce serbestleşme sürecini tamamlayıp daha sonra özelleştirme sürecin geçen ülkeler olduğu gibi, önce özelleştirme sürecini tamamlayıp daha sonra serbestleşme sürecini başlatan ülkeler de bulunmaktadır. Bazı ülkeler serbestleşme ve özelleştirme süreçlerini birlikte yürütürken, kimi ülkeler kamu şirketlerini özelleştirmeyerek piyasadaki varlıklarını haksız rekabeti önleyecek şekilde sürdürelebileceği bir piyasa yapısı tasarlamışlardır. İzlenen yöntem ve yaklaşım farklı olsa da, bütün ülkelerin ortak amacı etkin işleyen, sürdürülebilir bir elektrik piyasasına sahip olmaktır.

Elektrik piyasaları temel olarak organize ve organize olmayan piyasalar olmak üzere ikiye ayrılırlar. Toptan elektrik ticareti, türev ve spot piyasalarda gerçekleşmektedir. Organize spot piyasalar gün öncesi piyasası ve gün içi piyasalarından oluşmaktadır. Gün öncesi piyasaları, arz ve talebe göre birim elektrik fiyatlarının belirlendiği piyasalardır. Ayrıca ikili anlaşmaları tamamlayıcı piyasalar olarak da bilinirler. İkili anlaşmalar, piyasa işletmecisinin müdahalesi olmaksızın tarafların kendi arasında belli şartlar gözeterek yaptığı elektrik alım-satım sözleşmeleridir. Taraflar anlaşma fiyatını bildirmeksizin, anlaştıkları fiziki teslimata konu miktarı ve gerekli bilgileri piyasa işletmecisine bildirmekle yükümlüdür. İkili anlaşmalar fiziki teslimat şeklinde olabileceği gibi finansal uzlaşı şeklinde de olabilmektedir.

Tez çalışması kapsamında talep esnekliğinin bulunmadığı bir gün öncesi piyasasında, piyasa gücü bulunan bir firmanın piyasa takas fiyatları üzerindeki olası etkileri

incelenmiştir. Gün öncesi piyasasındaki fiyat oluşum mekanizması, bazı varsayımlar altında modellenmiştir. Model temel olarak; tahmini talep eğrisinin indirgenmesi ve toplanmış arz eğrisinin elde edilmesi olmak üzere iki ana kısımdan meydana gelmektedir.

Öncelikle talep eğrisinin nasıl indirgendiği açıklanmıştır. Her bir saat için ikili anlaşma hacmi, öngörülen talepten çıkartılarak gün öncesi piyasası işlem hacmi bulunur. Teknik yapıları itibariyle piyasada oluşacak fiyattan bağımsız olarak çalışması beklenen nükleer, jeotermal, rüzgar ve güneş enerjisi gibi santrallerin öngörülen üretim değerleri tahmini talepten çıkartılarak oyun hacmi bulunur. Rezervuarlı hidroelektrik santrallerini oyun hacmine dahil etmek mümkündür ancak yağış beklentisi, rezervuarındaki su miktarı ve gelecekte oluşacak piyasa takas fiyatlarının tahmin edilmesi ve bu bilgiler ışığında her bir hidroelektrik santralin üretim stratejisinin belirlemesi gerekmektedir. Yapılan tez çalışması kapsamında rezervuarlı hidroelektrik santrallerinin teklif stratejileri dikkate alınmayarak, bu santrallerin tahmini üretim değerleri kalan hacimden çıkartılmış ve indirgenmiş oyun hacmi bulunmuştur.

Çalışmanın ikinci kısımda indirgenmiş oyun hacmi içinde yarışan fosil yakıtlı santrallere ait toplanmış arz eğrisi elde edilmektedir. Bu kapsamdaki her bir firma üretim tekliflerini piyasa işletmecisine sunmaktadır. Daha sonra bu teklifler en düşükten başlayarak artan şekilde sıralanmasıyla toplanmış arz eğrisi elde edilir.

İzledikleri üretim stratejileri ile piyasa takas fiyatlarını değiştirebilme gücüne sahip firmalar aktif firmalar olarak adlandırılmaktadırlar. Aktif firmaların piyasa gücünü kullanarak karını maksimize edecek teklif stratejisini bulmaya çalıştıkları varsayılmıştır. Bu doğrultuda piyasa gücü bulunan bir firmanın piyasa takas fiyatları üzerindeki olası etkilerini gözlemleyebilmek için hayali üretim portföyüne sahip üreticiler oluşturulmuştur ve bu kapsamda üç farklı durum incelenmiştir.

İlk durumda, santrallerin değişken üretim maliyetleri referans alınarak oluşturulan üretim teklifleri piyasa işletmecisine sunulmasıyla elde edilen toplanmış arz eğrisi ile indirgenmiş talep eğrisinin kesişimi ile birlikte piyasa takas fiyatı ve üretim talimatı alacak santraller bulunur. Her bir santralin bağımsız birer oyuncu olarak ele alındığı, tam rekabet piyasası koşulunda oluşacak fiyatlar referans fiyatlar olarak alınmıştır.

İkinci durumda, oligopol piyasa yapısı gösteren bir elektrik piyasasında, piyasa gücü bulunan bir firmanın izlediği teklif stratejisinin piyasa takas fiyatları üzerindeki etkisi oyun teorisi ile araştırılmıştır. Firmalar miktar rekabetine girerek, karını maksimize edecek optimum teklif miktarını bulmaya çalışmaktadırlar. Piyasa gücü bulunan ve saatlik esnekliğine sahip santralleri olan firmalar, tüm olası durumları dikkate alarak normal şartlarda çalışma talimatı alacak bazı santraller için teklif vermeyerek piyasa takas fiyatının da meydana gelecek artış sonucu elde edeceği toplam kazancın, çalışmaması durumunda oluşacak toplam kaybından yüksek olması durumunda, bazı santral veya santralleri için teklif vermeyerek kar maksimizasyonu yapmaya çalışmaktadır. Ancak her firmanın piyasa takas fiyatını değiştirme gücü olmadığı gibi baz yük çalışan santrallerin de çalışma yapısı gereği saatlik devreye girme-çıkma esnekliği bulunmamaktadır.

Bir firmanın üretim teklifi, diğer firmaların tekliflerini dikkate alarak verebileceği en iyi teklif ise ve bu durum her bir firma için geçerliyse, oyun Nash dengesine ulaşmış demektir. Bir başka ifadeyle herhangi bir firma teklif stratejisini değiştirerek kar artışı sağlayamıyorsa ve bu durum her bir firma için geçerliyse, var olan denge noktası Nash dengesi olarak adlandırılmaktadır.

Son durumda ise piyasa gücü bulunan bir firmanın sahip olduğu santrallerden bazılarını marjinal üretim maliyetinin veya maliyetlerinin altında çalıştırarak piyasa takas fiyatlarını düşürmeyi amaçlayan üretim stratejisinin etkileri incelenmiştir.

Serbestleşme ve özelleştirme programlarının temel amaçlarından biri, tüketicilere elektriğin daha uygun fiyatlarla sunulmasıdır. Bu doğrultuda iyi tasarlanmış ve etkin işleyen bir elektrik piyasasında, elektrik fiyatları piyasa koşullarında arz ve talebe göre herhangi bir firmanın müdahalesi olmaksızın belirlenmelidir. Fiyatların piyasa koşullarında belirlenebilmesi için, serbestleşme ve özelleştirme süreçleri dikkatlice yürütülmelidir.

Özelleştirme programları sonucunda, piyasa gücü bulunan yeni firmaların oluşmamasına özen gösterilmelidir. Ayrıca bu süreç piyasa gücü bulunan firmaların gücüne de katkı sağlamamalıdır.

Serbestleşme ve özelleştirme süreçlerinin birlikte yürütüldüğü elektrik piyasalarında, istenilen sonuçların alınabilmesi için güçlü kamu şirketlerine karşı, özel sektör yatırımcılarını haksız rekabetten koruyan, adil rekabet ortamını güvence altına alan, şeffaf ve sürdürülebilir bir elektrik piyasa yapısına da ihtiyaç bulunmaktadır. Ayrıca, şeffaf bir elektrik piyasası, ihtiyaç duyulan elektrik üretimi ve altyapı yatırımlarının sürekliliğini güvence altına alarak enerji arz güvenliğine de katkı sağlayacaktır.

Yapılan tez çalışması kapsamında, birinci bölümde dünya genelindeki elektrik piyasalarındaki serbestleşme ve özelleştirme süreçlerine genel bir giriş yapılmıştır. İkinci bölümde ise elektrik piyasa yapıları ve toptan elektrik ticaretinden bahsedilmiştir. Üçüncü bölümde, modelin daha iyi anlaşılabilmesi için fiyat oluşum mekanizması ve modelde kullanılan elektrik piyasa yapısı detaylarıyla birlikte ele alınmıştır. Dördünce bölümde, arz ve talep verilerine yer verilmiştir. Beşinci bölümde ise serbest elektrik piyasasında faaliyet gösteren, piyasa gücü bulunan bir firmanın, bu gücü kullanarak piyasa takas fiyatları üzerindeki etkileri araştırılmış ve sonuçlarına yer verilmiştir.

1. INTRODUCTION

To meet electrical energy needs in a reliable, quality, continuous, inexpensive and sustainable way is the basis of energy policy agenda of the countries. Accessible and competitive electricity prices have great importance to contribute to the economic development of the countries. In particular, electricity prices directly affect country's competitiveness in international markets. In this regard, countries have been looking for market structures allowing use of resources in a more effective and efficient way [1,2].

For many years, electricity power industries were controlled and managed by public utilities in many countries. Generation, transmission, distribution and retail of electricity are under responsibility of governmental utilities. Such a system is described as a vertically integrated monopoly. Operation and maintenance of such systems are also carried out by these utilities. There are some advantages to have such a system. For example, it is easier to manage and control the system in order to provide quality power, which means stable voltage and frequency in electricity network. In addition, a vertically integrated monopoly supports stable market and risk free finance for new investments.

At the early stage of power industry, small and mid-scale power plants were not competitive when compared with large-scale power plants. Huge amounts of capital were required for constructing big power plants, which produce electricity more economically, nearly in half price in comparison with small scale ones. Due to efficiency increases in small-scale power plants such as natural gas and hydropower plants, unit production cost of small-scale power plants has decreased significantly and became more competitive against the older large-scale power plants. Lower initial investment costs for small and mid-scale natural gas fired power plants and hydropower plants made them more viable. Technological advancements in efficiency and material science led to high interest in investment of small and mid-scale power plants.

In the beginning of the 1990s, some developed countries started the liberalization process for the electricity power industry. There are many reasons that led to the deregulation of the electricity power system. One of main reasons was the change in the optimal scale in generation as articulated above. In addition, new investments for capacity expansion were required not only for constructing new power plants to meet growing demand but also refurbishment of existing old power plants. In addition, expansion and major maintenance of transmission and distribution systems were required. Consequently, some countries gave incentives and subsidies to encourage private investment for new power plants. Moreover, long-term power purchase agreements were made to protect Independent Power Producers (IPP) from unfair competition against to public generation companies. Besides all these, it was seen that to build and operate own power plant could be an economical way for energy-intensive industries in some cases. These developments accelerated the deregulation of electricity markets [3-5].

In electricity market reform, countries followed and implemented different privatization and liberalization strategies. Some countries preferred to complete liberalization program at first, and then the privatization program started. Nevertheless, some countries gave priority to privatization program and the liberalization program started afterwards. Some countries run these two programs together. Some countries designed a market structure in which public companies can continue their presence by preventing unfair competition. Although countries preferred and implemented different strategies and approaches, common goal of them was to have a sustainable, effective and well-functioning electricity market [3].

Opening generation to competition was the first step to change the structure of electricity markets. Competitive environment would serve to increase efficiency in generation of electricity, which induces lower electricity prices.

In order to get the intended result, the private sector should be protected against powerful public companies in electricity markets where liberalization and privatization processes are carried out together. Transparent, foreseeable and sustainable market structures protect investors from unfair competition.

In most countries, privatizations of distribution system have followed privatizations of generation to have a more deregulated electricity market. However, transmission systems were out the scope of privatization programs in many countries. Common thought was that transmission systems should be operated by independent system operators to maintain safety, sustainable and fairly market operation [5-7].

In oligopoly market, few large firms are dominant and these large firms may have a tendency to use their market power typically by changing their offer quantities or prices. Interaction among such producers in the electricity market necessitates considering each effect of participants' offer strategies on final market-clearing prices [8].

2. LITERATURE REVIEW

2.1 Restructuring Models of Wholesale Electricity Markets

Restructuring models of wholesale electricity markets can be divided into three main groups, which are power pool model, bilateral contracts model and hybrid model as seen in Figure 2.1.

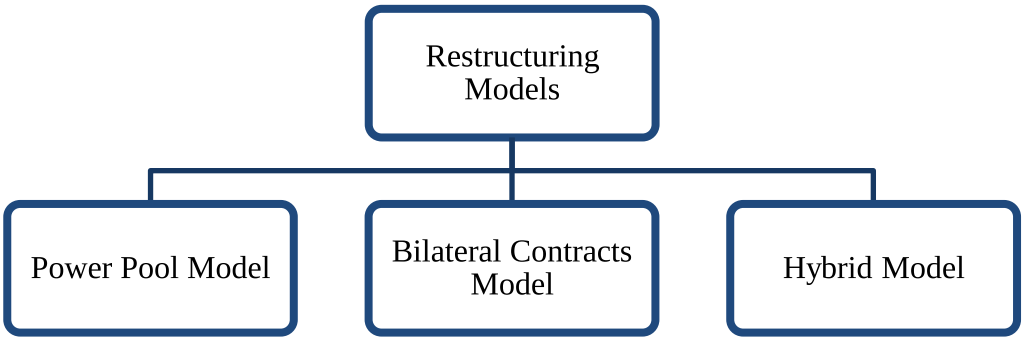

Figure 2.1 : Restructuring models of wholesale electricity markets [6].

2.1.1 Power pool model

Power pools are generally composed of generation companies, distribution companies, transmission companies, eligible consumers and power providers. Power producers have an obligation to participate in power pool. The main feature of power pools is the beginning of establishment of independent wholesale electricity market.

According to bidding procedures in this model, generation companies are forced to give more competitive offers to be under or equal market-clearing price to be able to run their power plants. New power plants with low generation cost are encouraged to enter market and power plants with relatively high generation costs are pushed out of the market. In this way, market efficiency increases.

2.1.2 Bilateral contracts model

In this model, producers are free to make a contract with eligible consumers. Prices and conditions are determined between parties in the commercial world, which enables to negotiate the price and conditions.

In bilateral contracts, market operator's duty is more restricted. The prices are set between parties and market operator does not have any rights to intervene in the agreed price and conditions. The market operator has to be informed of the delivery point, quantity and time but prices remain confidential.

2.1.3 Hybrid model

Third model is hybrid model, which is a kind of combination of power pool and bilateral contracts model. Hybrid model is more flexible and offers more options for producers and consumers. Some differences exist between the hybrid model and the previous two models. Main difference is that producers are free to enter power pool or power exchange.

This model presents many trading features in a competitive environment for both consumers and producers. In hybrid model, bilateral contracts could be physical or financial, short or long term, standardized or customizable periods [6].

2.2 Wholesale Electricity Markets

Electricity cannot be stored on a large scale in an economic way; hence, it should be consumed once it is produced. Physical link is also required between production and consumption areas. These features of electricity diversify it from other commodities. Being so, appropriate trading tools, considering special circumstances of electricity are required for powerful electricity market

Wholesale electricity markets can be grouped mainly into two categories: organized and unorganized electricity market as shown in Figure 2.2 [9-10].

In organized electricity markets, the trading procedures and market rules are regulated and standardized. Transactions are concluded through the clearing-house. Electricity can be traded in an organized market by means of physical delivery or financial settlement. Transactions can be short and long term.

In physical electricity trading, supply should be balanced against demand. However, in financial trading, there is no need for balancing. As a result, financial instruments offer more trading opportunities.

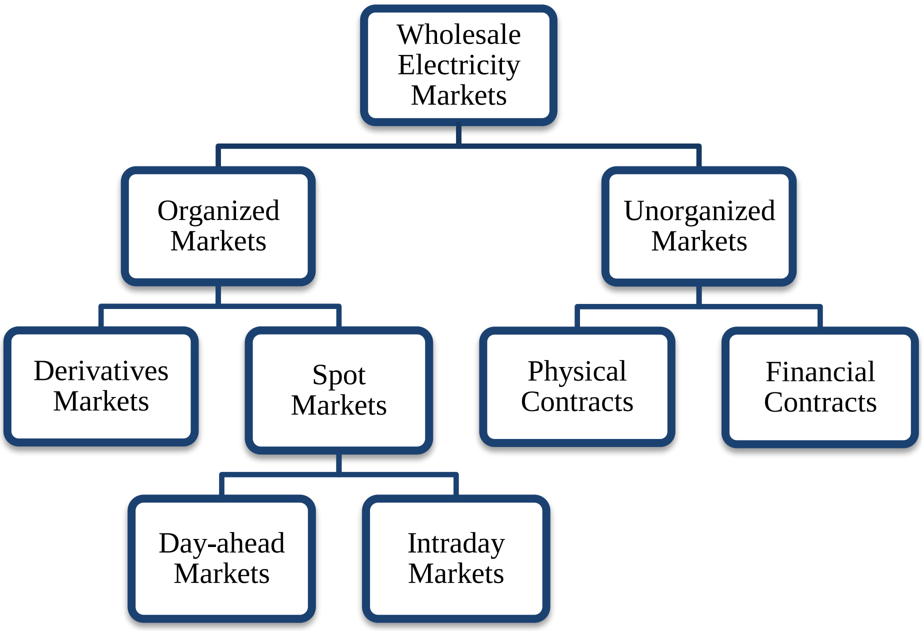

Figure 2.2 : Wholesale electricity markets [9-10].

Spot market consists of day-ahead market and intraday market. Day-ahead market is the main arena for electricity trading. Main responsibility of day-ahead market is to bring the system in balance for following day. When there is any variation between preplanned production/consumption and actual production/consumption, intraday market enables to reduce imbalances.

In unorganized markets also known as Over-The-Counter (OTC), contracts are not standardized. Transactions in OTC can be physical or financial. Transactions can be concluded directly between the parties or via broker/brokerage house.

The main difference between exchange and OTC is the standardization. On exchange, standardized products are traded. Except price and amount, the other features are standardized in an exchange. Transactions in OTC market are more flexible and customizable [10].

2.3 Market-Clearing Approaches in Day-Ahead Market

According to demand elasticity, power pools can mainly be classified as one-sided pool and double-sided pool.

If market operator obtains market-clearing prices in accordance with forecasted demand (zero elasticity), this type pool is called one-sided pool, in which demand is independent from prices. Figure 2.3 shows the one-sided pool.

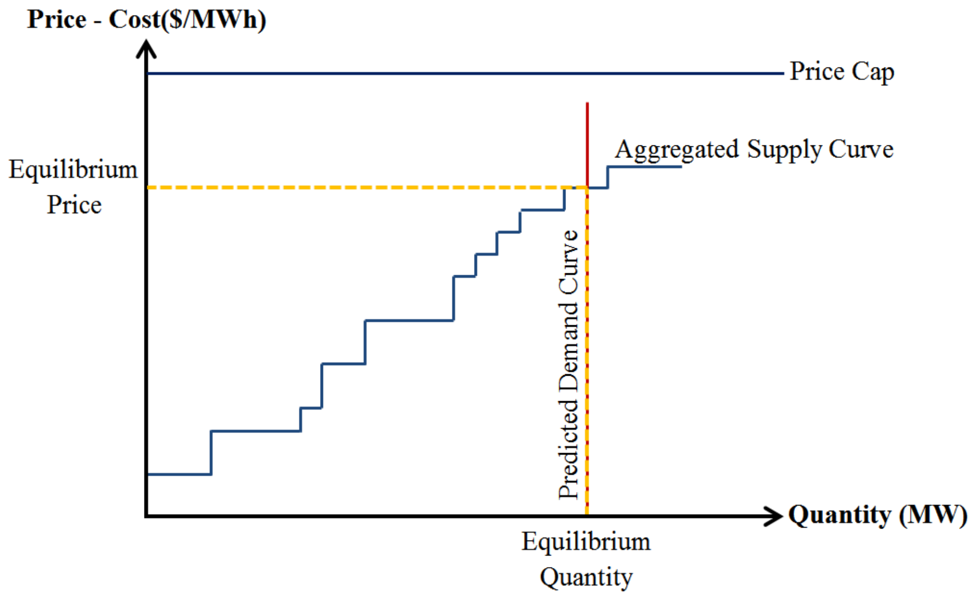

Figure 2.3 : Market-clearing in one-sided pool.

If market operator also considers price-quantity bids for demand to obtain market-clearing prices, this type pool is named two-sided pool. Aggregated supply curve is matched with aggregated demand curve to obtain market-clearing price. Eligible consumers are also included market-clearing process. Producers compete with each other to maximize their producer surplus and consumers compete with each other to maximize their consumer surplus in two sided pools. Figure 2.4 shows two-sided pool [11].

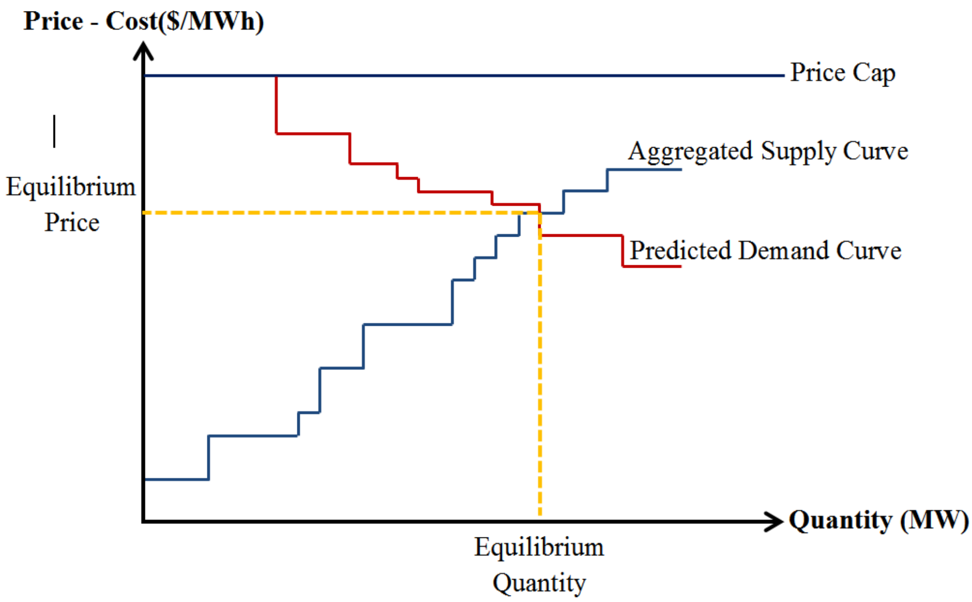

Figure 2.4 : Market-clearing in two-sided pool.

2.4 Turkish Electricity Market Reform at a Glance

Transition from state dominated vertically integrated structure to competitive electricity market has been started with electricity market law enacted in 2001. Energy Market Regulatory Authority (EMRA) was also established in order to perform the regulatory and supervisory functions in the market [12].

Turkish electricity market shows hybrid electricity market model and contains day-ahead market, intraday market, balancing market, derivative market and OTC market within itself.

Milestones of Turkish electricity market reforms are given in Figure 2.5.

Within 2011 day-ahead market started operations instead of day-ahead planning and it was operated by PMUM (State-Owned Market Operator). Future electricity contracts start to trade on exchange at the same year. Intraday market was introduced in 2015 in order to give market participant the opportunity for continuously trading in hourly intervals to reduce imbalance costs. EPIAS (Independent Power Exchange) is also established in 2015. After that, day-ahead and intraday market are operated by EPIAS instead of state-owned market in order to assure market transparency [12,14].

2.5 Electricity Price Forecasting Models

Electricity Price Forecasting (EPF) is very important for each participant and EPF is used for different purposes at different time intervals. Electricity price forecasting has become fundamental part of decision making not only for power producers but also for regulators and power providers.

A variety of methods have developed and suggested for electricity price forecasting for different periods. First of all, period and purpose should be defined in order get intended result.

Power producers want to foresee future electricity prices for determining bidding and trading strategy, participating in the day-ahead market and/or making bilateral contracts, budgeting activity, cash flow analysis, risk management, balance sheet, scheduling of maintenance in short and midterm, making new investment decisions or demolishing old power plants in long terms.

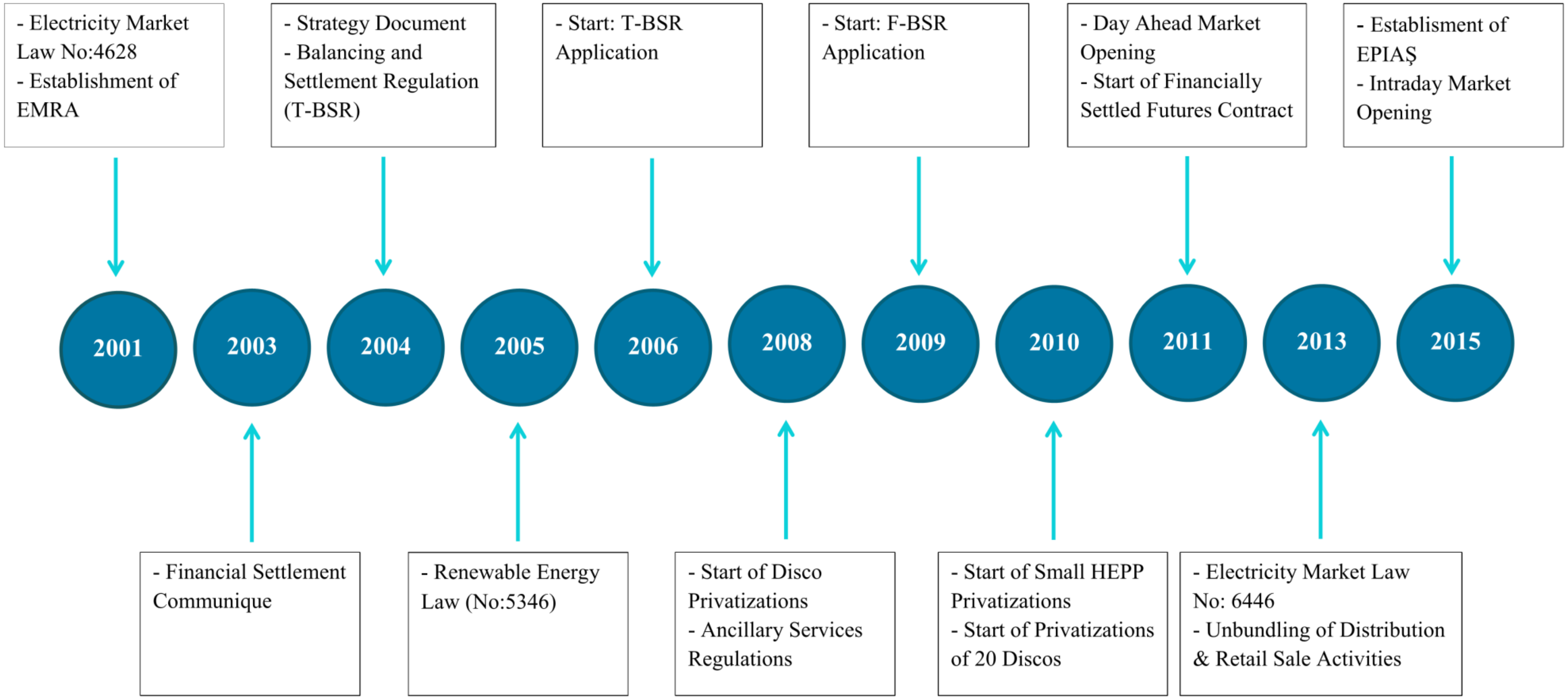

Figure 2.5 : Milestones of Turkish electricity market reform [13-14].

Regulators want to monitor the system, test the rules before implementation and make analyses for market behavior and incentives models in order to specify their boundaries.

Energy supplier and eligible consumers want to protect themself from price volatility and buy electricity from markets at a price as low as possible [15-17].

Electricity price forecasting can be categorized into three separate intervals: short-term, mid-term and long-term. If forecasting duration gets longer, the uncertainties also increases and that leads to get lower accuracy. Short-term analyses focus on bidding strategies and production schedules. Forecasting intervals for short-term can expand from one hour to one week. There are many articles about the short-term analyses. It is relatively easy to set up models because they do not have to take into account many uncertainties, which occur in the long-term. Medium-term models examine market behavior within the period of weeks or months. Such analyses are generally used to optimize hydro production schedule on a monthly basis. Long-run analyses concentrate to forecast electricity price with the yearly periods for investment decisions and regulation purposes.

There are different approaches in classification of electricity price forecasting methods. In Aggarwal's study, electricity price models are classified in three main groups namely simulation models, time series models and game theoretical models.

In simulation models, electricity market is modeled by considering electricity market structure and its dynamics. Some assumptions are made in accordance with the intended purpose to make easier to set up the model. Equilibrium price and quantity are obtained by using algorithms, which follow procedure and take into account pre-defined constraint. These methods simulate the actual dispatch of power plants and mimic electricity market. Transmission constraint can be taken into account but this makes the model more sophisticated [18].

Simulation models are based on generation cost. In short-term simulation, most articles consider only fuel cost. There are also some studies considering variable O&M cost. Some articles consider not only fuel cost but also start up and no load cost. When there is not enough price history or there is a variation in electricity generation capacity and portfolio, simulation models become more accurate for electricity price forecasting. Capacity variation could be an expansion with constructing new power plant or diminishing older ones. Simulation models are relatively difficult to set up because data of production cost for each power plant and market concentration are also required [19-21].

The second methods are time series models. These methods require enough historical data to be able to make reasonable predictions. The forecast accuracy depends on the quality of the data and incorporating fundamental factors, which have impact on electricity prices. Data should be carefully cleaned out before analysis. To be able to get realistic result, market structure and participant portfolio should also be stable.

Time series models are relatively easy to set up but their results can be unrealistic in some circumstances. Data in dynamics power market may change rapidly such as installed capacity and production portfolio, which directly affect market-clearing prices. Therefore, its result could not be realistic for long-term analyses in dynamic market.

Third model is game theoretical models. Some electricity markets show features of oligopolistic market. Participants interact with each other so bidding strategies of participants can also affect market-clearing prices [18].

In oligopoly market, few large firms are dominant and these large firms have tendency to use their market power by means of changing either their offer quantities or offer prices. Competition can capacity gaming or price gaming. Strategic interaction among producers in the electricity market necessitates considering the effect of participants' bidding strategies on market-clearing prices.

From a game theoretical perspective, electricity producers could be divided into two categories according to their capability to alter MCPs; the first category is competitive fringes, which act as price-takers and they cannot change market-clearing prices individually. The second group is named as dominant oligopolies, which can affect the market-clearing prices by changing their offer strategies. Dominant oligopolies are also known as active players and price makers. Game theory is convenient tool to analyze the effect of active player's bidding strategies on market-clearing prices [15,22].

2.6 Factors Affecting Electricity Prices

There are many factors affecting market-clearing prices. Some of them are related to demand side but most of them are related to supply side. There are also some factors apart from supply and demand side such as market power exercise, transmission constraint and power market design. These factors are grouped as supply side, demand side and other factors and given in Table 2.1 [23,24].

Table 2.1 : Factors affecting electricity prices.

Supply Side	Demand Side	Other Factors
Fuel Price	Electricity Price Tariff	Market Design
Plants Availability	Precipitation	Network Maintenance
Precipitation	Temperature	Transmission Constraint
Wind	Cloudiness	Historical Price Data
Sun Radiation	Day Type	Cross-Border Trading
Hydro storage	Holidays	Market Power Exercise
Feed in Tariff		
Power Purchase Agreement		
Bilateral Contracts		
Offer Strategy		

3. METHODOLOGY & MODEL

3.1 Daily Electricity Trading

Supply and demand are one of the most fundamental concepts of economics. How much good or service is produced and consumed and what price are determined by supply and demand. Intersection of the supply and demand curves gives equilibrium price and quantity. In similar way, electricity price is determined by intersection of aggregated supply curve and aggregated demand curve. Any variation of these curves directly affects market-clearing prices [25].

Daily physical electricity trading consists of bilateral contracts with physical delivery, day-ahead market, intraday market and balancing market. Daily electricity trading is modeled and it is shown in Figure 3.1.

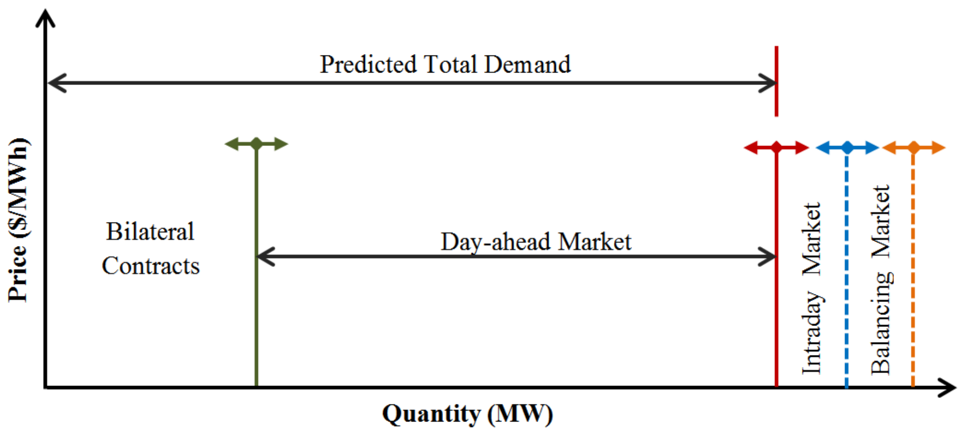

Figure 3.1 : Daily physical electricity trading.

Daily electricity demand mainly met by physical bilateral contracts and day-ahead market. Intraday and balancing markets mostly contribute to compensate imbalances.

A bilateral contract in an electricity market is an agreement between a buyer and a seller. Parties have to notify the agreed amounts and duration to the market operator for each hour in specified periods.

Day-ahead market is the main arena for electricity trading. Market participants submit their bids and offer electronically. Then, supply and demand curves are compared and the market-clearing price is calculated for each hour of the following day. Day-ahead market is a complementary market to bilateral contracts. Therefore, bilateral contracts volume is subtracted from predicted total demand to obtain day-ahead market volume. Only physical bilateral contracts are considered when day-ahead market volume is calculated. Electricity prices are set in day-ahead market, which is main arena for electricity trading. For this reason, the thesis focuses on the day-ahead market.

Intraday market provides market participants an opportunity to compensate their imbalances, which are differences between scheduled and actual production/ consumption. Imbalances could be positive or negative. For example, unplanned outage of one power plant causes negative imbalance or actual production of wind power plant may higher than estimated and that leads to positive imbalance. In intraday market, producers and consumers have opportunities to bring in balance their portfolio at least cost when they cause imbalances.

Balancing market's task is to compensate for imbalances and ensure that demand is equal to supply in real time. There is also an auction for balancing market but its main purpose is not trading.

3.2 Model

The model mimics day-ahead markets according to market structure and market clearing procedure. Market operator collects bids and offers from market participants for each hour in the following day. Last accepted offer sets the market-clearing price and all dispatched generator is paid the same price as what is paid to the last generating unit. This type auction is known as uniform pricing.

The model consists of two main parts, which are obtaining reduced demand curve and formation of aggregated supply curve. They are going to introduce respectively.

3.2.1 Reduced demand curve

In the model, demand is assumed inelastic and it is simply modeled as a vertical line. In some articles, demand is assumed perfectly inelastic, which means there is no quantity response to a price change. Inelastic demand corresponds to one-sided pool, in which profit maximization problems are generally examined [19,21]. However, some articles are written on double sided demand in which consumers bids are also taken into consideration and this model is generally used for social welfare[1] maximization [20,26,27]. There are also some articles, which are written on the demand elasticity [28,29].

Firstly, trading volumes in the day-ahead market should be determined for each hour. Net volume of bilateral contracts with physical delivery is subtracted from predicted total demand to find out day-ahead market volume. Framework of daily electricity trading is given in Figure 3.2.

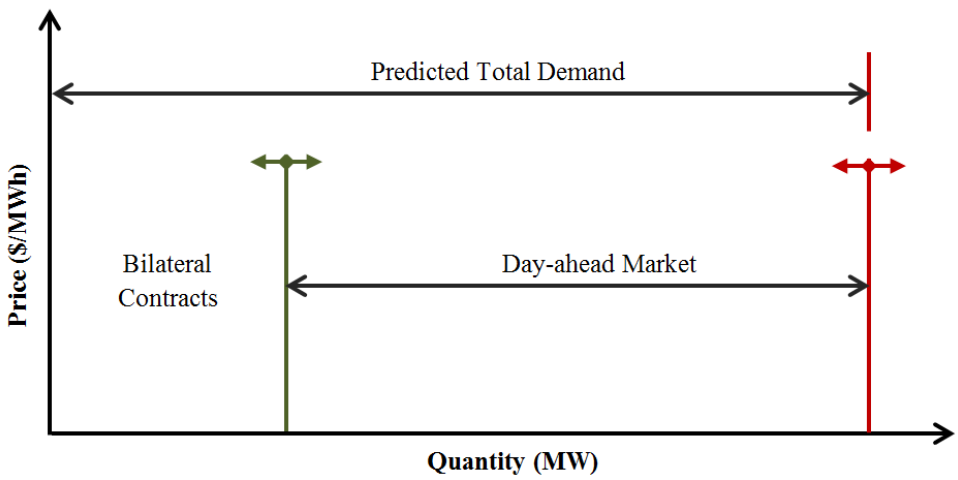

Figure 3.2 : Bilateral contracts and day-ahead market volumes.

Electricity production in day-ahead market typically can be categorized three main groups as “must-run power plants”, “hydropower plants with dam,” and “fossil-fueled power plants”. This thesis uses this typical composition to explain how to clear market. Fossil-fueled power plants usually determine market-clearing prices. Therefore, most articles consider only fossil-fueled power plants in capacity or price gaming volume [15,20,26]. Evaluating hydropower plants with dam in a game volume gives results that are more realistic but data of water volume in dams, expectation of rainfall and estimation of future MCPs should also be required. To get or predict these data accurately is not easy and other model is also required. Therefore, only a few studies take hydro power plant with dam in a game volume [19].

[1] Social welfare is defined as the area between the aggregated demand curve and aggregated offer curve.

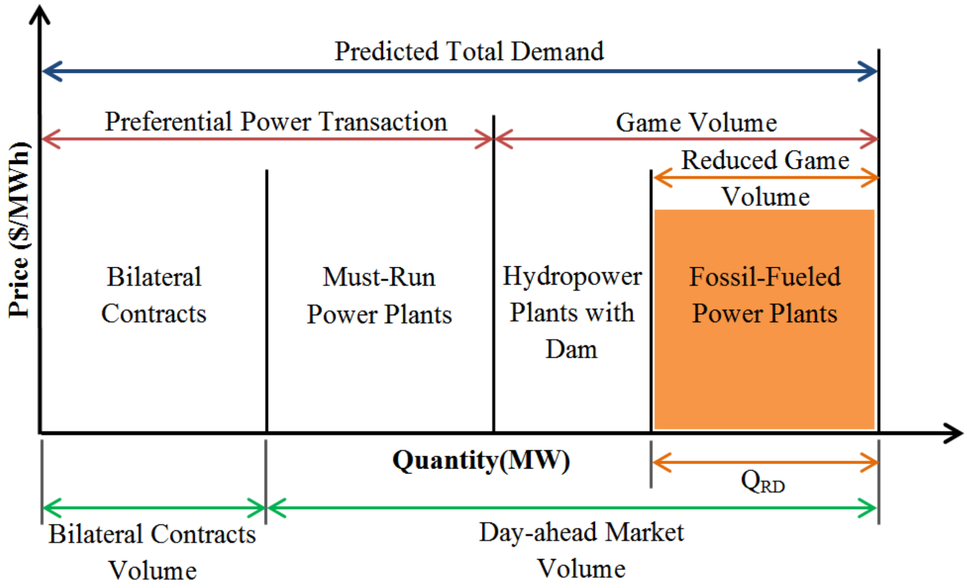

Figure 3.3 : Representation of biletaral contracts and DAM volumes.

Volume of bilateral contracts with physical delivery, production of must-run power plants and hydropower plants with dam indirectly affect market-clearing prices. Reduced game volume depends on aforementioned volumes. Any variation in these volumes also causes a change in reduced game volume. This can be apparently seen in Figure 3.3.

Production of must-run power plants is independent from market prices. Because of their working principles, these power plants do not have flexibilities for start-up or shot-down in short periods. Therefore, these power plants continue running regardless of market-clearing prices. Nuclear power plants, run-of-river hydro power plants, geothermal power plants, wind power plants, photovoltaic power plants can be grouped under must-run power plants.

Production of must-run power plants and hydroelectric power plants with dam is subtracted from day-ahead market volume to obtain reduced game volume. Only fossil-fueled power plants take part in reduced game volume.

On the other hand, fossil-fueled power plants cover all coal, natural gas and oil-fired power plants.

3.2.2 Aggregated supply curve

Demand is satisfied by a large number of power plants based on a variety of energy sources. Each firm has own offer price-quantity set based on marginal production cost of its power plants.

Once offers of fossil-fueled power plants are put in order from the lowest to the highest, aggregated supply curves are obtained. Intersection of aggregated supply curve and reduced demand curve gives market-clearing price, which is shown in Figure 3.4.

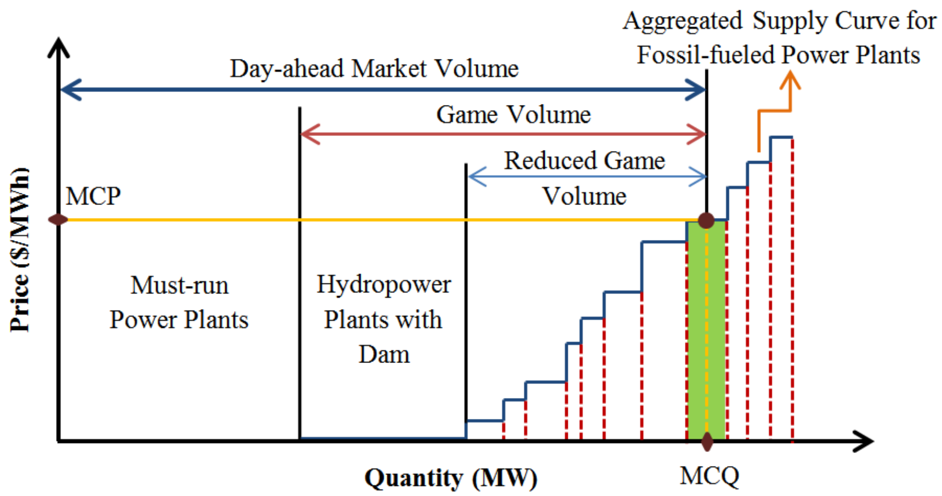

Figure 3.4 : Typical compositions of a day-ahead market.

The offer price of the last power plant, which is needed to meet the demand, determines the market-clearing price and it is called marginal power plant. MCQ and MCP indicate Market-Clearing Quantity and Market Clearing Price, respectively. Marginal power plant is highlighted in green (Figure 3.4).

Changes in electricity demand or production of renewable power plants lead to variations in reduced demand volume. Therefore, some fossil-fueled power plants have to turn on/off flexibility[2] to be able to meet these varying demands. However, some types of power plants do not have flexibility. These types of power plants were originally designed to run as base load.

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[2] The capability of technically possible and economically feasible switch on and off cycles is defined as flexibility.

Flexibility of a power plant plays an essential role for bidding strategies of this power plant. According to flexibility of unit commitment, fossil-fueled power plants are basically divided into two as hourly and daily flexible power plants. If a power plant has a capability to start up or shut down hourly, it is classified as hourly flexible power plants. If the unit commitment of a power plant is suitable for one start up or shut down in a day, it is categorized as daily flexible power plants.

For example, conventional coal or lignite fired power plants run to meet base load. Because of their running principles, their operations are not suitable for frequent start-up/shut-down. Therefore, they are not convenient for hourly bidding strategies.

To meet varying reduced demand, hydropower plants with dam, natural gas-fired power plant or fuel oil power plants are appropriate to run due to their flexible startup/shutdown capabilities. These types of power plants are suitable for hourly bidding strategies.

In our model, it is assumed that offer of each power plant is submitted at its own marginal production cost and only fuel and variable O&M cost are taken into consideration (Formula 3.1) [21].

$$\text{Marginal Production Cost} = \text{Fuel Cost} + \text{Variable O\&M Cost} \tag{3.1}$$

3.3 Market-Clearing Algorithm and Methodology

The market-clearing algorithm for auction in two-sided pool is given in Formula 3.2 [26,30,31]. Uniform price auction[3] is used for market-clearing. In this type auction, the market-clearing algorithm is as follows;

$$Max_{p_{jt}^{G},p_{dt}^{D}}\left[\sum_{d=1}^{N_D} p_{dt}^{D}\,\lambda_{dt}^{G-bid} - \sum_{j=1}^{N_J} p_{jt}^{G}\,\lambda_{jt}^{G-offer}\right] \tag{3.2}$$

p_{jt}^{G} : Power produced by power plant *j* in hour *t*

[3] There are two main auction types for clearing in electricity market, which are uniform price auction and discriminatory price auction. In uniform price auction, the last accepted offer determines the clearing price and all participants are paid that equilibrium price regardless of their actual offer. In discriminatory price auction, each participant is paid its offer price when its power plant runs.

p^{D}_{dt} : Power consumed by demand *d* in hour *t*

d : Demand blocks

N_D: Number of demand block in the auction

λ^{G-bid}_{dt} : Price bid by demand *d* in hour *t*

j : Power plants

N_J : Number of power plants in the auction

$\lambda^{G-offer}_{jt}$: Price offered by power plants *j* in hour *t*

The generation of power plants must meet the demand in each hour. It is shown in Formula 3.3. Total generated power in any given hour must equal total power consumed in that hour [30,31].

$$\sum_{d=1}^{N_D} p^{D}_{dt} = \sum_{j=1}^{N_J} p^{G}_{jt} \tag{3.3}$$

p^{G}_{jt} : Power produced by power plant *j* in hour *t*

p^{D}_{dt} : Power consumed by demand *d* in hour *t*

d : Demand blocks

N_D: Number of demand blocks in the auction

j : Power plants

N_J : Number of power plants in the auction

In this thesis, demand is assumed perfectly inelastic and only fossil-fueled power plants compete in reduced game volume. After that, market-clearing price are calculated based on only offers fossil-fueled power plants. Formula 3.4 shows how to clear market in one-sided pool. Based on Eq. (3.2), market-clearing algorithm is rewritten and modified as follow;

$$Min_{p^{G}_{jt}} \left[\sum_{j=1}^{N_J} p^{G}_{jt}\, \lambda^{G-offer}_{jt} \right] \tag{3.4}$$

Reduced demand should be met in each hour. The formula is given in formula 3.5.

$$Q_{RD} = \sum_{j=1}^{N_J} p_{jt}^{G} \quad (3.5)$$

Q_{RD}: Reduced demand

N_J : Number of fossil-fueled power plants in the auction

j : Fossil-fueled power plants

p_{jt}^{G} : Power produced by fossil-fueled power plants *j* in hour *t*

The following profit maximization formula is valid for both perfectly competitive fringes (price takers) and dominant firms (price makers) [26,30,31].

$$Max_{p_{jt}^{G},p_t^i} \sum_{t=1}^{N_T} \left[p_t^i \, \lambda_t^i(p_t^i) - \sum_{j \in \Gamma_i} C_j(p_{jt}^{G}) \right] \quad (3.6)$$

p_{jt}^{G} : Power produced by fossil-fueled power plant *j* in hour *t*

N_T : Number of time periods considered

t : Time periods considered in the time horizon

p_t^i : Power produced by the company *i* in hour *t*

$\lambda_t^i(p_t^i)$: Residual demand function of the company *i* in hour *t*, where $\lambda_t^i(p_t^i)$ states the corresponding market-clearing price as a function of the power generated by the company *i* in hour *t*, p_t^i

j : Fossil-fueled power plant

Γ_i : Fossil-fueled power plant/plants belonging to company i

$C_j(p_{jt}^{G})$: Marginal production cost for hour *t* of the fossil-fueled power plant *j*

Capacity gaming takes place in reduced game volume among fossil-fueled power plants participating in day-ahead market. Each firm tries to maximize its own profit. The optimized quantity for any producers is obtained by using formula 3.6. The solution of this formula gives optimal generation quantity for any producer whether it is a price maker or a price taker. Total gain of any producers is determined by subtracting the total production cost from total revenue [31].

Matching reduced demand curve and aggregated supply curve for fossil-fueled power plants participating in day-ahead market gives not only market-clearing price but also production schedule of power plants. Figure 3.5 shows how market-clearing occurs.

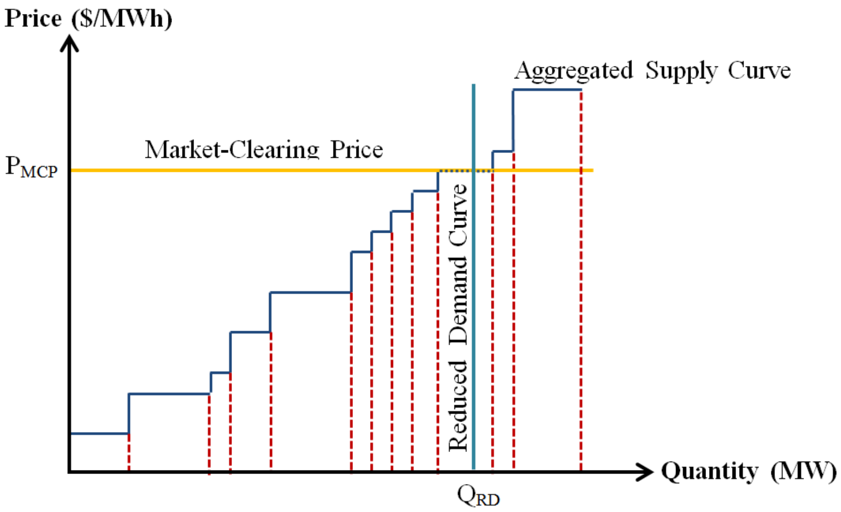

Figure 3.5 : Formation of market-clearing price in the model.

The area between offer block and market clearing price line gives the producer surplus[4] of related power plant, which is shown in Figure 3.6. Gain is also used to indicate producer surplus.

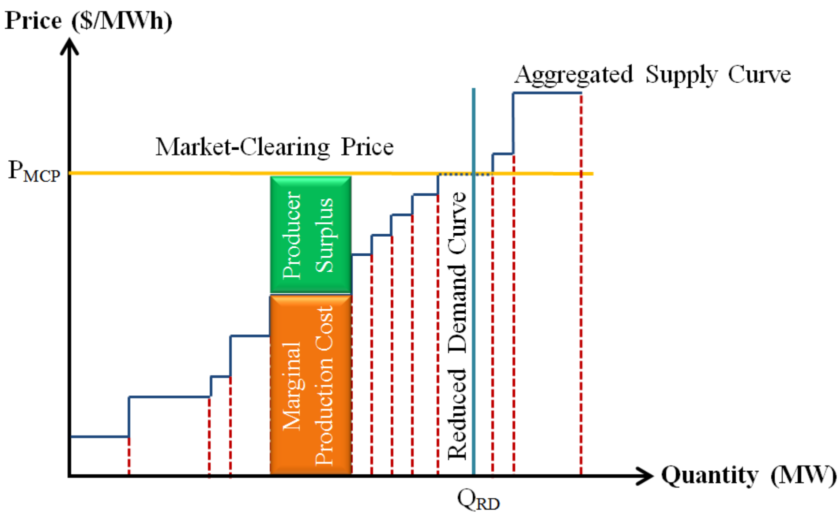

Figure 3.6 : Representation of marginal production cost and producer surplus.

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[4] Producer surplus is used to indicate profit more accurate because computing profits would require consideration of fixed costs as well.

In Figure 3.7, each block indicates a power plant and power plants belonging to the same firm are painted with the same color. There is only one multi-plant firm, which is represented by the blue color.

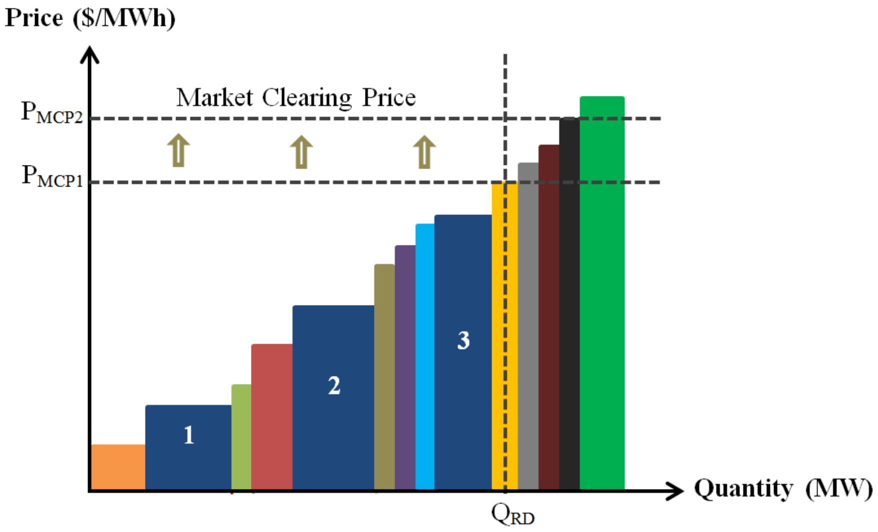

Figure 3.7 : Representation of capacity withdrawal effect on MCP.

If the blue firm does not submit any offer to market operator for its third power plant, the deficient demand will be met by grey, brown and black power plants instead of third blue power plant. Therefore, market-clearing price will rise from P_{MCP1} to P_{MCP2}. However, this increase does not mean that blue firm's gain will also increase. Only if the total gain is greater than total loss, blue firm will reduce the offered quantity. It is presented in Figure 3.8.

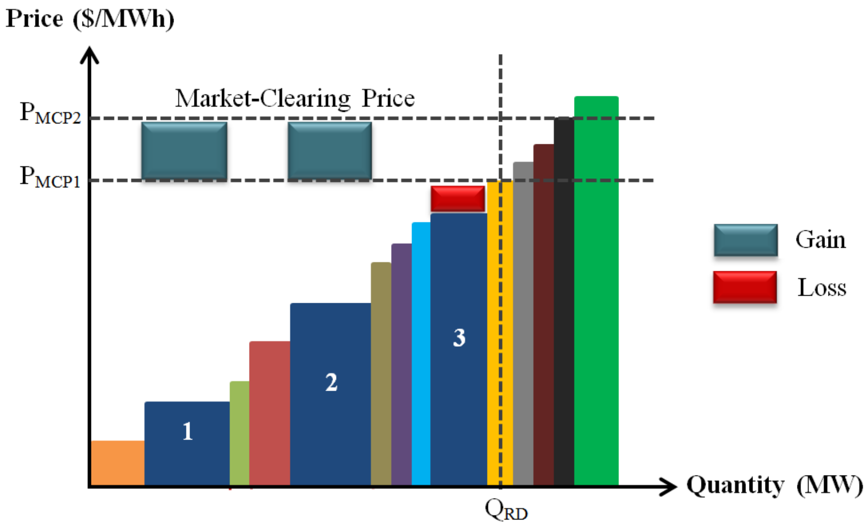

Figure 3.8 : Representation of additional gain/loss after capacity withdrawal.

Price maker can exercise its market power by means either of capacity withdrawal or price markups which are known as capacity gaming and price gaming, respectively [13].

In this thesis capacity withdrawal of dominant firm are examined. Only price makers have ability to change market-clearing price, so capacity gaming takes place among price makers, which try to find out optimal capacity to maximize their profit.

3.4 Game Theory and Nash Equilibrium

A game generally consists of following elements: players, actions and payoffs (utility). A game can be cooperative or non-cooperative, complete or incomplete information, sequential or simultaneous move, which are also known static and dynamic game as well, respectively. In cooperative games, players collaborate and take decisions for common objective. In non-cooperative games, players make decisions independently. Game with complete information, all players are perfectly informed of all other players' payoffs for all possible action and knowledge about other players is available to all players. Nevertheless, the players do not have common knowledge of competitor in incomplete information. In simultaneous game, all players move at same time. However, in sequential games players make moves at different times or in turn [32].

In game theory, outcome of player's strategy depends not only on his own actions but also the action of other players. Strategy of a player determines the action of a player will take. Strategies could be pure or mixed. In pure strategy, player selects an action and plays it. In mixed strategy, player chooses one of over available actions with probability distribution [26].

Surplus of a power producer depends on its own and other power producers actions. Given what all other players are doing, a strategy is a best response if and only if a player cannot gain more utility from switching to a different strategy. Nash equilibrium provides fundamental solution concept in game theory to predict the outcome of these strategic interactions. A game is in Nash equilibrium if and only if all players are playing best responses to what the other players are doing. In Nash equilibrium, which is also called strategic equilibrium, none of player has an incentive to change its strategy [31,33].

N indicates number of finite set of players {1,.., N}, s_i expresses strategy of player i, s expresses strategy vector, which covers strategies of all the players including strategy of player i $(s_1, \dots, s_i, \dots, s_N)$, u_i is the payoff function of player i shown as $u_i(s_1,\dots\dots,s_N)$, s_i' means any strategy of player i and s_{-i} represents strategy vector without strategy of player i $(s_1, \dots, s_{i-1}, s_{i+1}, \dots, s_N)$. It is useful to write the strategy vector s as (s_i, s_{-i}) [31,34].

For player i, s_i is a best response to s_{-i} if $u_i(s_i, s_{-i}) \geq u_i(s_i', s_{-i})$ for every strategy s_i' available to player i. A game is in Nash Equilibrium if and only if all players are playing best responses to what the other players are doing [31,34]. More formally,

$$u_i(s_i, s_{-i}) \geq u_i(s_i', s_{-i}) \qquad (\forall s_i' \epsilon\, S_i) \text{ and } \forall i\, \epsilon\, N \tag{3.7}$$

3.5 Assumptions

- Demand is assumed perfectly inelastic.
- Power plants and its capacity which is traded by bilateral contracts is declared.
- Estimated productions of must-run power plants and hydropower plants with dam are also known.
- Production costs of power plants consist of fuel and variable O&M cost.
- Capacity of a power plant is submitted as a whole.
- There is no outage of any power plant because of planned or unplanned maintenance. Each power plant is ready to run.
- Transmission constraint and congestion is not considered. Network modeling is disregarded.
- Startup cost, no load cost, other related costs arisen from electricity production and usage fees of transmission/ distribution systems are not taken into account.
- All producers are considered as rational and compete to obtain the maximum possible profits.
- Marginal production cost of each power plant is publicly available. And it is assumed that each power producer knows other player’s payoffs.

3.6 Market Simulation with Capacity Withdrawal

Volume of bilateral contracts with physical delivery, estimated production of must-run power plants and hydropower plants with dam are known for the following day in hourly interval. In these sights of information, reduced game volume can be calculated for each hour in a day. Volume of bilateral contracts with physical delivery is subtracted from predicted total demand to find out day-ahead market volume. In order to obtain reduced game volume, estimated production of must-run power plants and hydropower plants with dam removed from day-ahead market volume. Figure 3.9 shows clearly, how to reduce demands.

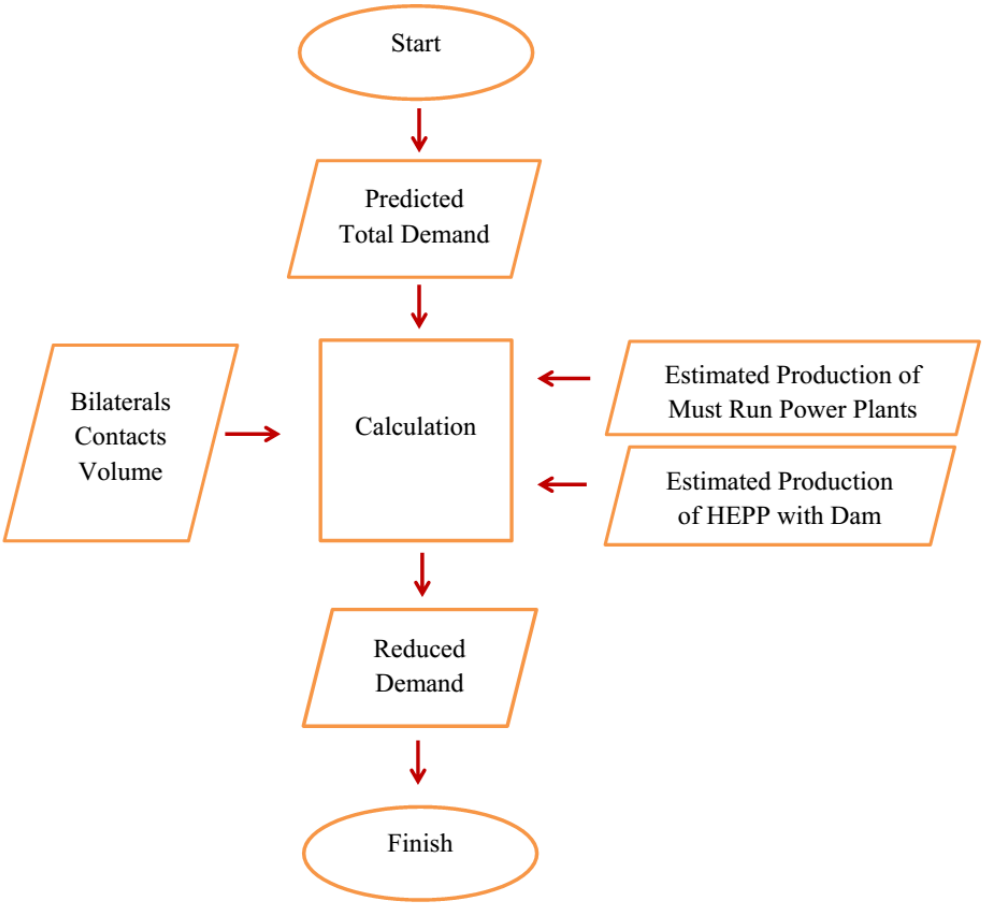

Figure 3.9 : Flowchart of reduced demand.

In reduced game volume, only fossil-fueled power plants compete with each other. Marginal production cost of each power plant is assumed publicly available. Each power producer having fossil-fueled power plants calculates initial market-clearing prices by using Formula 3.4 before submitting its offer to the market operator.

Once initial market-clearing prices are obtained, each power producer builds own residual demand curve[5] for each hour. This curve shows the effects of power producers on market clearing prices. For next iteration, optimal offer quantities are found out by using Formula 3.6.

Quantity optimization model is run per company. The iterative process is repeated until none of power producers is willing to change its offered quantity in order maximize its own profit. Once Nash equilibrium is reached, fossil-fueled power producers cannot improve its profit by independently changing its offer. When power producers find their optimum offer quantities, they submit their quantity-price pair to market operator. After that, final market-clearing prices are obtained.

Flow chart given in Appendix A.1 presents market-clearing procedure considering capacity gaming.

[5] Residual demand curve shows how market clearing prices change when a power producer change its offer quantity. It is obtained by subtracting all the offers of the competitors from the total demand.

4. DATA

This thesis focuses on the impact of a dominant firm's bidding strategies on market clearing prices. Therefore, modeling of supply-side of an actual electricity market and demand forecasting is not within the scope of this study. Supply and demand data are required to run the simulation. For this reason, data are taken from various sources to be able to run the simulation. Fuel and variable O&M cost are taken from the report "cost and performance assumptions for modeling electricity generation technologies" prepared by NREL, and "electricity market module report" prepared by EIA. Hypothetical producers are created in sight of these data. Firstly, raw data in these reports are gathered and then data are prepared for analyzing. Data for aggregated supply curve are shown in Table 4.1.

Table 4.1 : Data for aggregated supply curve [34,35-37].

Firms	Plant Name	Plant Type	Total Variable Cost ($/MWh)	Plant Capacity (MW)
Firm C	CIG1	IGCC	20,31	550
Firm M	MC1	Coal	20,47	600
Firm D	DIG1	IGCC	20,93	550
Firm A	AC1	Coal	22,35	1300
Firm B	BIG1	IGCC	22,56	550
Firm E	EC1	Coal	23,28	600
Firm F	FC1	Coal	23,33	600
Firm G	GC1	Coal	23,50	860
Firm A	AIG1	IGCC	24,48	600
Firm A	ACC1	Combined Cycle	36,29	250
Firm Y	YCC1	Combined Cycle	38,18	400
Firm I	ICC1	Combined Cycle	38,66	400
Firm A	ACC2	Combined Cycle	39,32	400
Firm S	SCC1	Combined Cycle	39,77	100
Firm Z	ZCC1	Combined Cycle	40,14	250
Firm L	LCC1	Combined Cycle	41,1	300
Firm A	ACC3	Combined Cycle	41,88	620
Firm K	KCC1	Combined Cycle	42,16	400
Firm A	ACC4	Combined Cycle	42,80	400
Firm O	OCC1	Combined Cycle	43,53	400
Firm P	PCC1	Combined Cycle	45,42	300
Firm N	NCC1	Combined Cycle	46,24	620
Firm R	RCT1	Combustion Turbine	52,12	160
Firm J	JCT1	Combustion Turbine	53,15	230
Firm T	TCT1	Combustion Turbine	54,52	230
Firm U	UCT1	Combustion Turbine	56,46	160
Firm A	ACT1	Combustion Turbine	57,56	230
Firm H	HCT1	Combustion Turbine	59,05	230

The aggregated supply curve is given in Figure 4.1. Each color represents a firm's power plant and dark blue colors indicate the power plants of Firm A.

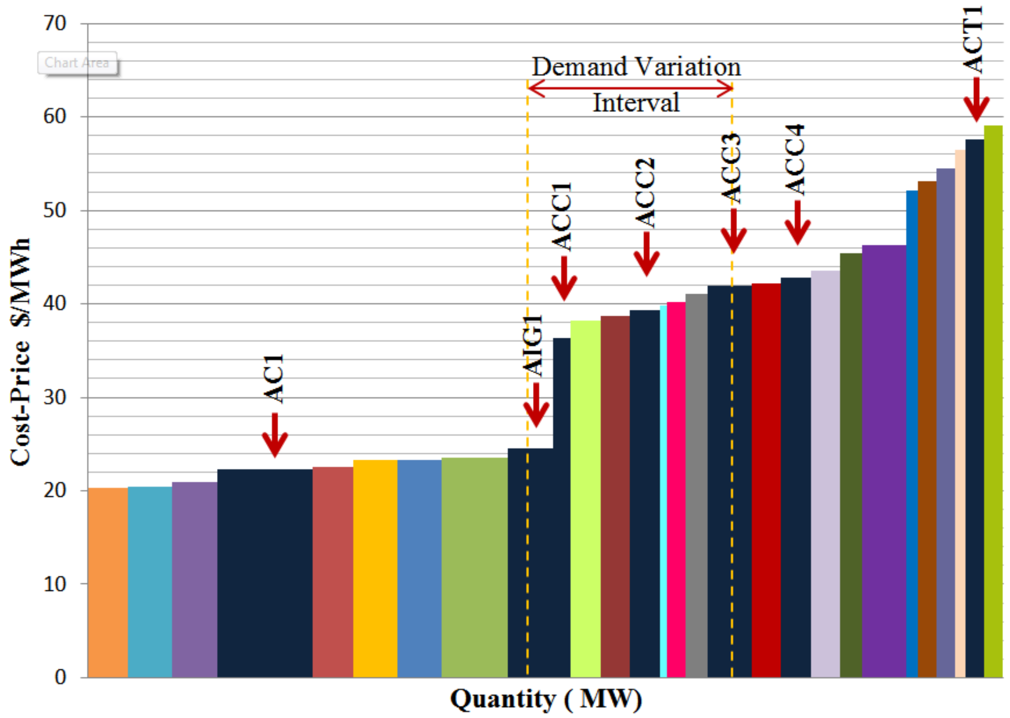

Figure 4.1 : Aggregated supply curve in the market.

In order to obtain reduced game volume, data of predicted total demand, net bilateral contracts volume with physical delivery, estimated production of must-run power plants and hydropower plants with reservoir are required. These data are taken from various reports such as PMUM, TEIAS and MENR for each hour in a day. With these arranged data, reduced game volume is obtained. Arranged data are given as hourly interval in Table 4.2.

Predicted demand is 692.356 MWh in the considered day. Net volume of bilateral contracts volume with physical delivery 462.849 MWh in that day and the rest of the demand is traded in day-ahead market in other words 33% of total electricity production are traded on day-ahead market.

Table 4.2 : Demand and generation data.

Hour	Predicted Total Demand(MWh)	Bilateral Contracts Volume(MWh)	DAM Volume (MWh)	Production of Must-run PP(MWh)	Production of HEPP with Dam(MWh)	Reduced Demand(MWh)
00:00	25.877	17.358	8.519	2.119	0	6.400
01:00	24.503	16.318	8.185	2.125	0	6.060
02:00	23.399	15.338	8.061	2.125	0	5.936
03:00	22.978	14.874	8.104	2.132	0	5.972
04:00	22.953	14.875	8.078	2.137	0	5.941
05:00	23.161	15.122	8.039	2.128	0	5.911
06:00	23.296	14.853	8.443	2.108	0	6.335
07:00	25.850	16.847	9.003	2.097	0	6.906
08:00	30.498	20.714	9.784	2.094	0	7.690
09:00	32.907	21.914	10.993	2.110	500	8.383
10:00	33.468	22.295	11.173	2.113	500	8.560
11:00	33.420	22.188	11.232	2.117	500	8.615
12:00	31.472	21.196	10.276	2.111	0	8.165
13:00	31.910	21.584	10.326	2.099	0	8.227
14:00	32.036	21.480	10.556	2.102	0	8.454
15:00	31.289	20.992	10.297	2.108	0	8.189
16:00	31.806	21.523	10.283	2.087	0	8.196
17:00	31.959	22.219	9.740	2.087	0	7.653
18:00	31.454	21.597	9.757	2.077	0	7.680
19:00	30.868	21.037	9.831	2.047	0	7.784
20:00	30.129	20.343	9.786	2.041	0	7.745
21:00	29.416	19.638	9.778	2.047	0	7.731
22:00	29.848	20.069	9.779	2.041	0	7.738
23:00	28.159	18.525	9.634	2.051	0	7.583
Toplam	692.656	462.899	229.657	50.303	1.500	177.854

5. RESULTS

The first case is the base simulation, in which each power plant submits its offer independently at its own marginal production cost without manipulation. Therefore, it is called as uncoordinated simulation. The results of this simulation provide reference market-clearing prices, which are going to use in comparison with the other two cases to be able to evaluate the effect of the dominant firm's bidding strategies. Simulation of Case I results are given in Table 5.1 for each hour.

Table 5.1 : Results of uncoordinated simulation (Case I **-** without manipulation).

Hour	Demand (MWh)	MCP ($/MWh)
00:00	6.400	38,66
01:00	6.060	38,18
02:00	5.936	38,18
03:00	5.972	38,18
04:00	5.941	38,18
05:00	5.911	36,29
06:00	6.335	38,66
07:00	6.906	39,32
08:00	7.690	41,10
09:00	8.383	42,16
10:00	8.560	42,16
11:00	8.615	42,16
12:00	8.165	41,88
13:00	8.227	41,88
14:00	8.454	42,16
15:00	8.189	41,88
16:00	8.196	41,88
17:00	7.653	41,10
18:00	7.630	41,10
19:00	7.784	41,88
20:00	7.745	41,88
21:00	7.731	41,10
22:00	7.738	41,10
23:00	7.583	41,10
Average	7.409	40,51

In the second case, given the same aggregated supply curve as above, multi-plant firm submits its offers by considering all their power plants. So, this simulation is known as coordinated simulation, in which firms compete with each other rather than power plants. Firms submit their offers by considering all their power plants.

Bidding strategy of price makers has capability to affect market-clearing prices. Multi-plant firm may manipulate by exerting its market power to maximize its surplus. Therefore, in the second simulation, the effect of capacity withdrawal is investigated.

In this simulation, firm A is the only price maker and all the other firms are price takers. Table 5.2 presents simulation results of Case II. IMCP and FMCP express Initial Market-Clearing Price and Final Market-Clearing Price, respectively. Capacity withdrawal of firm A leads to an increase in market-clearing prices overall 5,10% in daily basis and its surplus increases approximately 9,80%.

Results of capacity withdrawal of Firm A are shown in Table 5.3. Its initial and final offer capacity and running power plants are given hourly basis in the same table.

The results show that the effect of firm A on market-clearing price increases when reduced demand goes up. Actually, this results from the marginal plant, which takes place in somewhere close price gap. In addition, more power plants of firm A run and it gives more opportunity for capacity gaming. Market-clearing price reaches maximum value at 14:00. The reason is that firm A does not submit any offer for its two power plants (ACC2 and ACC3) which is going to run with regards to base case.

There are totally twenty-eight fossil-fueled power plants in the reduced game volume. Eight of them are base load power plants. In other words, they do not have hourly on/off flexibility. If their marginal production cost is below the average daily market-clearing price, they are going to run anyway. These power plants are not suitable for hourly bidding strategies. Therefore, they are excluded from capacity gaming volume.

Firm A, which is only price maker in the auction, has seven power plants. Nevertheless, two of them (AC1 and AIG1) are base load power plants. These two power plants do not have on/off flexibility in hourly basis. Therefore, only five power plants are suitable for hourly bidding strategies.

Except firm A, all the other firms are price takers. Price takers have to choose from two possible strategies, which are on or off. In other words, they are going to decide whether their power plants run or not.

Set of strategies of a price taker S_i={s_{i1}, s_{i2}}={on, off}={1,0}

Table 5.2 : Results of coordinated simulation and firm A's surpluses (Case II - capacity gaming).

Hour	Demand(MWh)	IMCP($/MWh)	FMCP($/MWh)	Price Increase(%)	Initial Surplus($)	Final Surplus($)	Surplus Increase(%)
00:00	6.400	38,66	38,66	0,00%	27.791	27.791	0,00%
01:00	6.060	38,18	38,18	0,00%	26.838	26.838	0,00%
02:00	5.936	38,18	38,18	0,00%	26.838	26.838	0,00%
03:00	5.972	38,18	38,18	0,00%	26.838	26.838	0,00%
04:00	5.941	38,18	38,18	0,00%	26.838	26.838	0,00%
05:00	5.911	36,29	38,18	5,21%	23.087	26.372	14,23%
06:00	6.335	38,66	38,66	0,00%	27.791	27.791	0,00%
07:00	6.906	39,32	41,10	4,53%	29.101	31.447	8,06%
08:00	7.690	41,10	43,53	5,91%	33.337	35.669	6,99%
09:00	8.383	42,16	45,42	7,72%	36.031	41.356	14,78%
10:00	8.560	42,16	45,42	7,72%	36.031	43.607	21,03%
11:00	8.615	42,16	45,42	7,72%	36.031	43.607	21,03%
12:00	8.165	41,88	45,42	8,44%	35.193	41.201	17,07%
13:00	8.227	41,88	45,42	8,44%	35.193	41.201	17,07%
14:00	8.454	42,16	46,24	9,69%	36.031	42.846	18,91%
15:00	8.189	41,88	45,42	8,44%	35.193	41.201	17,07%
16:00	8.196	41,88	45,42	8,44%	35.193	41.201	17,07%
17:00	7.653	41,10	43,53	5,91%	33.337	35.669	6,99%
18:00	7.630	41,10	43,53	5,91%	33.337	35.669	6,99%
19:00	7.784	41,88	43,53	3,94%	35.193	37.455	6,43%
20:00	7.745	41,88	43,53	3,94%	35.193	37.455	6,43%
21:00	7.731	41,10	43,53	5,91%	33.337	35.669	6,99%
22:00	7.738	41,10	43,53	5,91%	33.337	35.669	6,99%
23:00	7.583	41,10	43,53	5,91%	33.337	35.669	6,99%
Average	7.408	40,51	42,57	5,10%	32.101	35.246	9,80%

Table 5.3 : Firm A's initial and final offers (Case II - capacity gaming).

Hour	Demand (MWh)	Initial Offer Capacity(MW)	Final Offer Capacity(MW)	Offer Change(%)	Initial Running Power Plants	Final Running Power Plants
00:00	6.400	1.985	1.985	0,00%	AC1, AIG1, ACC1	AC1, AIG1, ACC1
01:00	6.060	1.985	1.985	0,00%	AC1, AIG1, ACC1	AC1, AIG1, ACC1
02:00	5.936	1.985	1.985	0,00%	AC1, AIG1, ACC1	AC1, AIG1, ACC1
03:00	5.972	1.985	1.985	0,00%	AC1, AIG1, ACC1	AC1, AIG1, ACC1
04:00	5.941	1.985	1.985	0,00%	AC1, AIG1, ACC1	AC1, AIG1, ACC1
05:00	5.911	1.981	1.738	12,25%	AC1, AIG1, ACC1	AC1, AIG1
06:00	6.335	1.985	1.985	0,00%	AC1, AIG1, ACC1	AC1, AIG1, ACC1
07:00	6.906	2.187	1.738	20,51%	AC1, AIG1, ACC1, ACC2	AC1, AIG1
08:00	7.690	2.380	1.738	26,96%	AC1, AIG1, ACC1, ACC2	AC1, AIG1
09:00	8.383	2.992	2.133	28,70%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC2
10:00	8.560	2.992	2.380	20,45%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1,ACC1,ACC2
11:00	8.615	2.992	2.380	20,45%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1,ACC1,ACC2
12:00	8.165	2.805	1.985	29,23%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
13:00	8.227	2.867	1.985	30,76%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
14:00	8.454	2.992	1.985	33,65%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
15:00	8.189	2.829	1.985	29,83%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
16:00	8.196	2.836	1.985	30,00%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
17:00	7.653	2.380	1.738	26,96%	AC1, AIG1, ACC1, ACC2	AC1, AIG1
18:00	7.630	2.380	1.738	26,96%	AC1, AIG1, ACC1, ACC2	AC1, AIG1
19:00	7.784	2.424	1.985	18,10%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
20:00	7.745	2.385	1.985	16,76%	AC1, AIG1, ACC1, ACC2, ACC3	AC1, AIG1, ACC1
21:00	7.731	2.380	1.738	26,96%	AC1, AIG1, ACC1, ACC2	AC1, AIG1
22:00	7.738	2.380	1.738	26,96%	AC1, AIG1, ACC1, ACC2	AC1, AIG1
23:00	7.583	2.380	1.738	26,96%	AC1, AIG1, ACC1, ACC2	AC1, AIG1

Each price takers will employ the following strategy, “run if the marginal production cost is equal or below market clearing price, otherwise don’t run”. Being so, it is expected that each price taker chooses to run be able to maximize its utility.

Market-clearing auction at 07:00 is chosen to show how to work the model. Normally, four plants of firm A, which are AC1, AIG1, ACC1, ACC2, are going to run according to uncoordinated simulation (Case I) at that hour. AC1 and AIG1 are base load power plants so they do not have hourly flexibility. Only ACC1 and ACC2 have hourly flexibility. Then firm A attempts to find optimal offer strategy.

In order to find the best response of firm A, given that every other firm is employing the following strategy “run if the marginal production cost is equal or below market clearing price, otherwise don’t run”, all the different combinations of firm A’s strategies are analyzed. Firm A has 2^2=4 different strategies (ACC1 on/off, ACC2 on/off) and its strategy set is as follows;

$S_A=\{s_{A1}, s_{A2}, s_{A3}, s_{A4}\}$={(on, on),(on, off),(off, on),(off, off)}

Firm A’s utilities and best response are given in Table 5.4. All the other players are price takers. Each price takers has only one power plant so they decide to run or not. Best response of a price taker is to run when it has a run order. Strategy 4 is the best response of firm A. “A game is in Nash equilibrium if and only if all players are playing best responses to what the other players are doing”. The sign " * " is used in Table 5.4 to indicate Nash equilibrium for related hour.

In the third case, given the same aggregated supply curve as above, the dominant firm is modeled as a firm trying to reduce market-clearing prices as low as possible. In this simulation, dominant firm’s target is not increasing its surplus. Its goal is to reduce market-clearing price. Therefore, the firm increases its production without concerning its loss and some power plants of this firm run below their marginal production cost.

The dominant firm may intend to keep electricity prices in certain level with specific intention. In third case, the effect of firm A’s bidding strategies is investigated. Firm A intervenes the MCP by increasing its production without concerning its loss. Therefore, firm A offers all available power plants to be able to decrease electricity prices.

Table 5.4 : Firm A's best response and Nash equilibrium at 07:00.

Firms	Power Plant	Hourly Flexibility	Base Case	s1	s2	s3	s4
Firm C	CIG1	No	On	1	1	1	1
Firm M	MC1	No	On	1	1	1	1
Firm D	DIG1	No	On	1	1	1	1
Firm A	AC1	No	On	1	1	1	1
Firm B	BIG1	No	On	1	1	1	1
Firm E	EC1	No	On	1	1	1	1
Firm F	FC1	No	On	1	1	1	1
Firm G	GC1	No	On	1	1	1	1
Firm A	AIG1	No	On	1	1	1	1
Firm A	ACC1	Yes	On	1	1	0	0
Firm Y	YCC1	Yes	On	1	1	1	1
Firm I	ICC1	Yes	On	1	1	1	1
Firm A	ACC2	Yes	On	1	0	1	0
Firm S	SCC1	Yes	Off	0	1	1	1
Firm Z	ZCC1	Yes	Off	0	1	0	1
Firm L	LCC1	Yes	Off	0	0	0	1
Firm A	ACC3	Yes	Off	0	0	0	0
Firm K	KCC1	Yes	Off	0	0	0	0
Firm A	ACC4	Yes	Off	0	0	0	0
Firm O	OCC1	Yes	Off	0	0	0	0
Firm P	PCC1	Yes	Off	0	0	0	0
Firm N	NCC1	Yes	Off	0	0	0	0
Firm R	RCT1	Yes	Off	0	0	0	0
Firm J	JCT1	Yes	Off	0	0	0	0
Firm T	TCT1	Yes	Off	0	0	0	0
Firm U	UCT1	Yes	Off	0	0	0	0
Firm A	ACT1	Yes	Off	0	0	0	0
Firm H	HCT1	Yes	Off	0	0	0	0
Market-Clearing Price				$39,32	$40,14	$39,37	$41,40
Utility of Firm A				$29.101	$30.737	$29.313	$31.447*

Simulation results of Case III are given in Table 5.5, which includes IMCP and FMCP. The effect of firm A is more obvious when the reduced demand gets lower.

Figure 5.1 is given to be able to compare three different cases with each other. It also demonstrates the effects of firm A's bidding strategies in different cases.

Finally, Table 5.6 presents market-clearing prices and price change resulting from firm A's bidding strategies for each hour in different cases.

Table 5.5 : Results of coordinated simulation with intervention (Case III).

Hour	Demand (MWh)	Reduced Demand (MWh)	IMCP ($/MWh)	FMCP ($/MWh)	Price Change(%)
00:00	6.400	2.787	38,66	23,33	-39,65%
01:00	6.060	2.447	38,18	23,28	-39,03%
02:00	5.936	2.323	38,18	23,28	-39,03%
03:00	5.972	2.359	38,18	23,28	-39,03%
04:00	5.941	2.328	38,18	23,28	-39,03%
05:00	5.911	2.298	36,29	23,28	-35,85%
06:00	6.335	2.722	38,66	23,33	-39,65%
07:00	6.906	3.293	39,32	23,50	-40,23%
08:00	7.690	4.077	41,10	38,18	-7,10%
09:00	8.383	4.770	42,16	39,77	-5,67%
10:00	8.560	4.947	42,16	40,14	-4,78%
11:00	8.615	5.002	42,16	40,14	-4,78%
12:00	8.165	4.552	41,88	38,66	-7,69%
13:00	8.227	4.614	41,88	38,66	-7,69%
14:00	8.454	4.841	42,16	40,14	-4,78%
15:00	8.189	4.576	41,88	38,66	-7,69%
16:00	8.196	4.583	41,88	38,66	-7,69%
17:00	7.653	4.040	41,10	38,18	-7,10%
18:00	7.630	4.067	41,10	38,18	-7,10%
19:00	7.784	4.171	41,88	38,18	-8,83%
20:00	7.745	4.132	41,88	38,18	-8,83%
21:00	7.731	4.118	41,10	38,18	-7,10%
22:00	7.738	4.125	41,10	38,18	-7,10%
23:00	7.583	3.970	41,10	38,18	-7,10%
Average	7.409	3.798	40,51	33,62	-17,01%

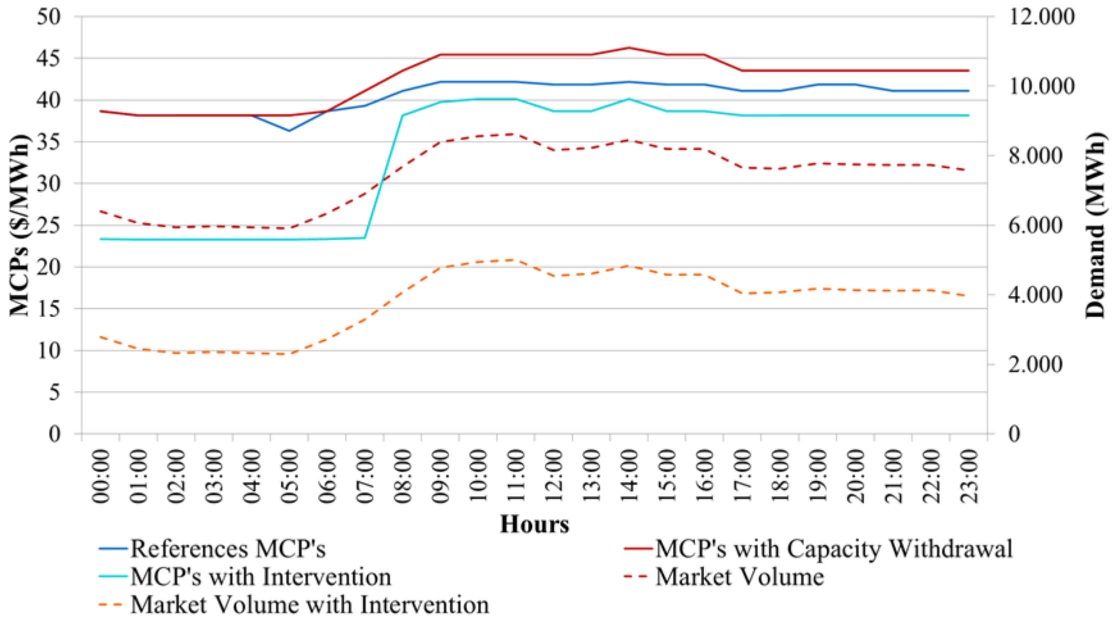

Figure 5.1 : MCPs in the three different cases.

Table 5.6 : Comparison of three different simulations results.

Hour	Uncoordinated Simulation with No Manipulation (Case I)		Coordinated Simulation with Capacity Withdrawal (Case II)		Coordinated Simulation with Intervention (Case III)	
	MCP ($/MWh)	Price Change (%)	MCP ($/MWh)	Price Change (%)	MCP ($/MWh)	Price Change (%)
00:00	38,66	0,00%	38,66	0,00%	23,33	-39,65%
01:00	38,18	0,00%	38,18	0,00%	23,28	-39,03%
02:00	38,18	0,00%	38,18	0,00%	23,28	-39,03%
03:00	38,18	0,00%	38,18	0,00%	23,28	-39,03%
04:00	38,18	0,00%	38,18	0,00%	23,28	-39,03%
05:00	36,29	0,00%	38,18	5,21%	23,28	-35,85%
06:00	38,66	0,00%	38,66	0,00%	23,33	-39,65%
07:00	39,32	0,00%	41,10	4,53%	23,50	-40,23%
08:00	41,10	0,00%	43,53	5,91%	38,18	-7,10%
09:00	42,16	0,00%	45,42	7,72%	39,77	-5,67%
10:00	42,16	0,00%	45,42	7,72%	40,14	-4,78%
11:00	42,16	0,00%	45,42	7,72%	40,14	-4,78%
12:00	41,88	0,00%	45,42	8,44%	38,66	-7,69%
13:00	41,88	0,00%	45,42	8,44%	38,66	-7,69%
14:00	42,16	0,00%	46,24	9,69%	40,14	-4,78%
15:00	41,88	0,00%	45,42	8,44%	38,66	-7,69%
16:00	41,88	0,00%	45,42	8,44%	38,66	-7,69%
17:00	41,10	0,00%	43,53	5,91%	38,18	-7,10%
18:00	41,10	0,00%	43,53	5,91%	38,18	-7,10%
19:00	41,88	0,00%	43,53	3,94%	38,18	-8,83%
20:00	41,88	0,00%	43,53	3,94%	38,18	-8,83%
21:00	41,10	0,00%	43,53	5,91%	38,18	-7,10%
22:00	41,10	0,00%	43,53	5,91%	38,18	-7,10%
23:00	41,10	0,00%	43,53	5,91%	38,18	-7,10%
Average	40,51	0,00%	42,57	5,10%	33,62	-17,61%

6. CONCLUSIONS AND RECOMMENDATIONS

Hypothetical power producers are set up to show how the model works. Therefore, simulation results may not be significant but the outputs are important.

This model can be applied in actual electricity market with some realistic assumptions. The model can be used either for monitoring electricity market by a market operator to detect market power exercise or for profit maximization by a price maker. Simulators can be built to meet the needs of regulation authority or to find out optimum offer strategies of market players.

Deregulation and privatization programs are intended to achieve more efficient electricity markets, which lead to lower electricity prices. To have a well-designed market, privatization program should be carefully carried out to protect price increase/decrease or volatility arisen from market power. Privatization program should not serve to generate new dominant firm or contribute dominant firm’s market power.

Transparency is important as well as for well-functioning electricity market and contributes fairly price formation. Transparent, foreseeable and sustainable market structures protect investors from unfair competition and ensure security of supply for new investments needed in the long term. Transparent electricity markets support reference electricity prices, which is important to give better sight for investment decisions. Because foreseeable future prices are one of the main input in investment decisions. A transparent electricity market will also contribute to the security of energy supply by ensuring the continuity of the investment with a better sight.

Consequently, electricity prices should be determined in competitive market conditions without manipulation. Abuse of market power should be monitored and prevented.

7. FURTHER STUDY

The model can be applied to actual electricity market. However, results of the simulation may deviate from actual circumstance because some assumptions are made during modeling of electricity market. These assumptions directly affect the success of the results. The model can be improved and constraint can be taken into consideration with more realistic assumption to obtain better results.

In this study, the game is non-cooperative, simultaneous and complete information. All firms are established as price takers except firm A and each power producer offers its whole capacity for a power plant or withdraws it as a whole. In other words, power producers decide to run their power plants or not. Therefore, each power producer uses only an offer strategy and each player knows which strategies the other players play. In the second simulation, pure strategy Nash equilibrium exists.

Price makers can be more than one in the game and interaction of these players should also be considered. In addition, it is assumed that each producer submits its whole capacity at marginal production cost of its power plant which is running its optimum efficiency point. In reality, power plants run in a power range. Therefore, they can be modeled more realistic. For example, offer of a power plant can be modeled by considering its technical limitation of generation (such as minimum generation limit, maximum generation limit, minimum stable generation etc.), capability of power plant (such as ramp-up and ramp-down rate, ramp-up and ramp-down times etc.) and other related variable cost such as start-up and no load cost etc. Moreover, once the offer quantity of a power plant changes, its marginal production cost also varies. For this reason, supply function equilibrium approach can be used.

When there are more than one price makers in the game, these interactions may lead to multiple Nash equilibrium. It is also required to finds all the equilibrium for a range of strategies of the power producers.

Availability of information is also important. It is assumed that the game is complete information. When there is lack of information or the case with multiple Nash equilibrium, power producers make their decision under uncertainty. Moreover, power producers may also have a higher tolerance to risk than other power producers. So probability and risk analysis can be made to be able to have result that is more sensible.

Transmission constraint disregarded in the model. Capability of exerting market power in the electricity market is not simply a market share issue when transmission constraints are taken into account. In other words, market power does not always directly arise from the market share but critically from the capability to change market-clearing prices. As such, a firm, which has relatively lower installed capacity compared to a dominant firm, could also affect the MCPs when transmission capacity constraint are taken into consideration.

Finally, hydropower plants with dam are not included in capacity gaming volume. To to include hydropower plants with dam in game volume give results that are more reasonable. Their effects can also be investigated or analyzed in the further studies.

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APPENDICES

APPENDIX A.1

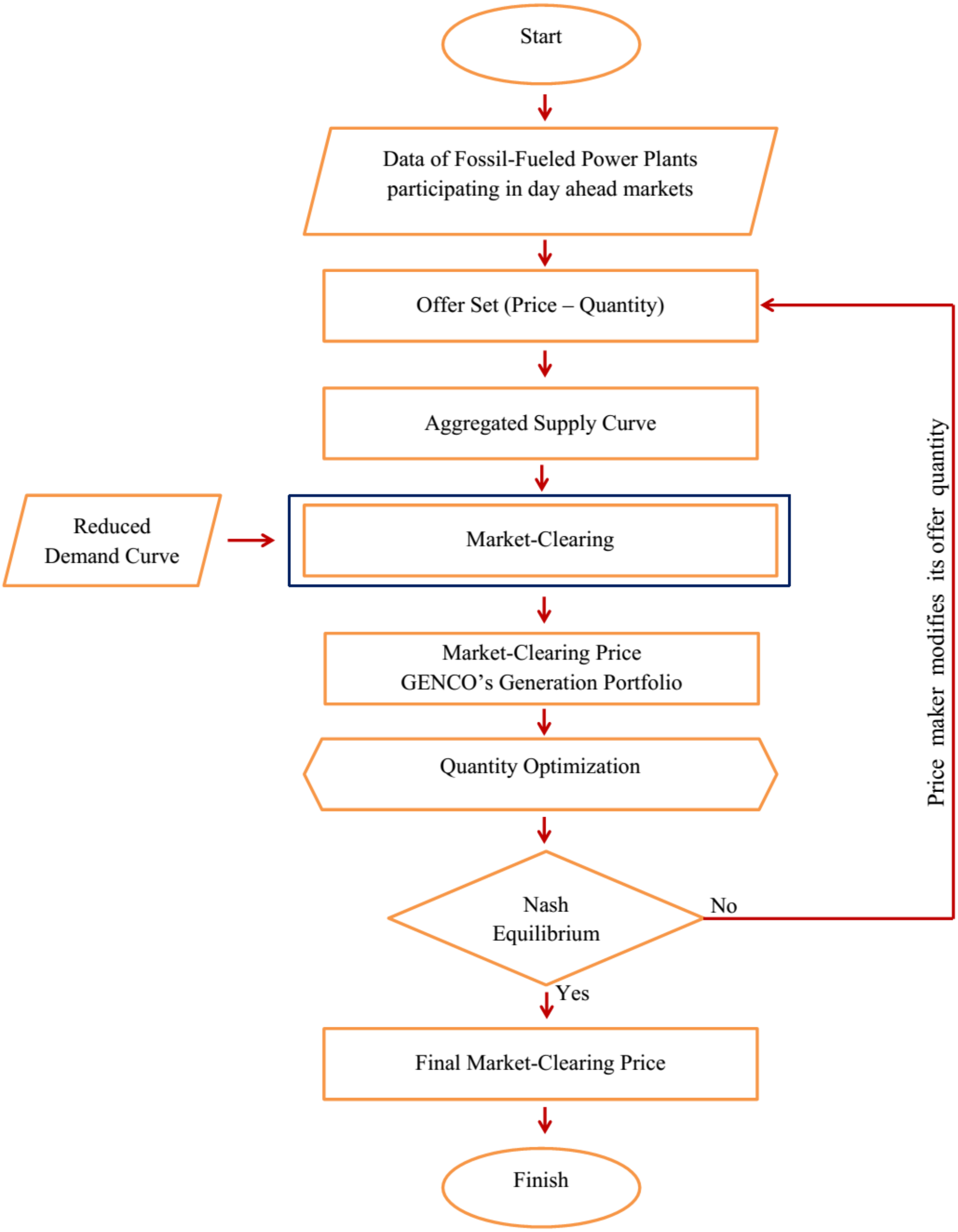

Figure A.1 : Flowchart of market-clearing process with capacity gaming.

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