Electricity Markets

Theories and Applications

Jeremy Lin

Fernando H. Magnago

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To my parents
[Jeremy Lin]

and

To Gaby, Pris, and Andy
[Fernando H. Magnago]

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About the Authors

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Preface

Why did an electricity market emerge? How does it really work? What are the performance measures that we can use to tell that the electricity market under consideration is well functioning? These are the questions that will be explored in this book. The main purpose of this book is to introduce the fundamental theories and concepts that underpin the electricity markets which are based on three major disciplines: electrical power engineering, economics, and optimization methods.

This book is intended for first-year graduate students or senior-year undergraduate students as well as practitioners and professionals who would like to study the fundamental and advanced topics in electricity markets. The backgrounds of students or readers should not necessarily be restricted to the disciplines mentioned above. Emergence of markets in many engineering disciplines, such as electrical power engineering and telecommunication engineering, challenges us to draw upon the theories and concepts beyond the realm of such engineering disciplines. A good understanding of these fundamental concepts is necessary to further enhance the understanding of the complex operation of power system and electricity markets.

Representation of physical systems by mathematical equations is fairly common in many engineering disciplines. This book is no exception to this tradition. However, the authors try to have a level of mathematical sophistication so that the material is accessible to many students and practitioners as well as the important issues will be treated in a rather meaningful way.

The first chapter of the book will briefly describe the nature and characteristics of electric power system, and cover the basic drivers for the transformation of electricity industry in the United States and around the world. With that tremendous change brings challenges and complex issues. Understanding these complex issues requires both basic and advanced knowledge of electrical power engineering principles, microeconomic theories, and basic and advanced optimization methods. Therefore, fundamentals of electric power system are treated in Chapter 2, and relevant microeconomic theories are introduced in Chapter 3.

The key components of power system economic operation—unit commitment, economic dispatch, and optimal power flow—are covered in Chapters 4, 5, and

6. After having a solid understanding in the areas of how the power system is operated, students will be exposed to the fundamental elements of electricity markets to understand how electricity markets are designed and structured. For this reason, we will cover the design, structure, and operation of an electricity market in Chapter 7.

So, what is the outcome, intended or unintended, of the electricity market operation explained in the previous chapter? The topics that will be covered in Chapter 8 include market pricing, such as zonal pricing versus nodal pricing, market modeling, and simulation of electricity markets which have wide applications in the industry. With the emergence of any electricity market, the issue of market power and its mitigation, market performance, and other issues naturally appear. These issues are the inevitable results of a deliberate coalescence of economic theories and physical law-based electric power system. The fundamental approaches and methods used to evaluate an electricity market, particularly detecting and mitigating market power are broadly treated in Chapter 9. Students who have basic understanding of these topics will be in a better position to understand more complex issues that subsequently arise from the operation of electricity markets.

In Chapter 10, we will deal with one of the critical issues, that is, the system planning under the context of electricity market regime. We will provide reasons why there are new ways to solve the same problem, because the electric power system which has operating electricity markets has tremendous amount of economic data related to power system at its disposal. These new data will enable us to solve the same problem in new ways. Another emerging issue is the role that the electricity market will play under smart grid and microgrid environments. We will also provide some qualitative arguments related to those emerging, yet important, topics in the final chapter, Chapter 11.

While the book covers several topics related to electricity markets and the fundamental theories behind them, it is a challenge for an instructor to cover all the chapters in this book for a one-semester course. It is therefore necessary to make some choices as to cover which chapters that are deemed important for the students. The authors would also like to acknowledge that it is not possible to include all relevant references and sources for all the materials covered in this book. However, interested readers can explore more by tracking additional references which are outside of these given in the further reading section of each chapter.

The authors would like to express their sincere gratitude towards many colleagues at various organizations, academic and research institutions, and their former academic advisors. The authors particularly would like to thank Herminio Pinto from Nexant, and Diego Moitre and Juan Alemany from GASEP, Argentina. This book could not have been complete without previous discussions and research work done with them. The authors would also like to thank reviewers who made valuable comments and suggestions in the first manuscript which helped improve the final content of the book.

The book is dedicated to anyone who is and will be fascinated by the complex operation of electricity markets both in the United States and around the world.

Jeremy Lin
Fernando Hugo Magnago

Chapter 1

Introduction

This beginning chapter will provide a high-level overview of the topics related to the basic drivers and transformation of electricity industry around the world. With that tremendous change come challenges and complex issues. One of the key developments in this transformation is the development of electricity markets. This is the main topic of this book. In fact, the primary and paramount goal of an electric power system operation is to maintain a high level of reliability. Under a restructured environment, this goal of system reliability is achieved via a market mechanism. Understanding electricity markets requires both basic understanding and advanced knowledge of electrical power engineering principles, microeconomic theories, and optimization methods from the field of operations research. Therefore, the fundamentals of these topics will be covered in the first few chapters.

1.1 ELECTRIC POWER SYSTEM

Electricity is indispensable for a modern society. The marvels of a modern life that we enjoy today cannot be possible without electricity. The importance of electricity is without questions. So, how do we get electricity?

In general, electricity is generated from electric generating sources located far from the load centers, then transmitted over long distances using transmission lines, and distributed to the load customers which include factories, offices, and homes. The entire chain of this system is known as *electric power system*.

The electric power system as we know of today was developed more than a 100 years ago. It generally consists of generation, transmission, and distribution subsystems. The entire chain of business from generation to transmission and distribution to load customers for a particular service area is owned by a single entity, known as an *electric power company* or *electric utility company*. The electric power company

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is either owned and operated by a national government or can be a public company owned by investors, but operated by management and employees of the company. Therefore, electric power industry is an important part of a country's infrastructure.

For the last two decades, the electricity industry around the world has undergone a tremendous transformation. This transformation is from a traditional structure of an electric power industry typically owned by national governments or public investors (as in investor-owned utilities) towards a structure that is exposed to a competitive market environment. This transformation in electricity industry was preceded by similar transformations in other industries such as airlines, trucking, and natural gas industries. In the case of an electric utility owned by a national government, this transformation is in the form of privatization first, then the privatized company is exposed to an open, competitive market environment. This was the case for electricity industry restructuring in Argentina. In the case of an investor-owned utility as in the United States, the generation part of the business was separated from the wires part (transmission and distribution systems) of the same company. This generation business is either divested to an independent company or completely formed as a separate subsidiary of the original utility. This is equivalent to the functional unbundling of an existing vertically integrated company.

The key outcome of this entire industry transformation, which is generally known as *electricity industry restructuring*, is the development and establishment of electricity markets. This is achieved by breaking up generation services into a separate, more competitive segment of the industry while the transmission and distribution parts of the utility service largely remain a regulated monopoly service. Because of unbundling of services (generation vs. transmission and distribution), these services have to be priced separately on a customer's bill.

Generally, in an electricity market, generators (generator owners) compete among each other to have an opportunity to supply electricity to serve load customers at the other end of the wires. However, the transmission and distribution parts of the system (electric power system) are not open for competition because it is generally believed that the wires business is subject to a natural monopoly behavior. A firm with natural monopoly enjoys significant economies of scale. It has to be properly regulated due to potential market power issues.

Therefore, the competition among generators is one of the key developments when the electric power industry was restructured. As a consequence, the analysis of the strategic interactions among the competing generators becomes an important subject to explore. These topics will be covered in more detail in later chapters. Natural monopoly part of the system, that is, transmission and distribution system, is still regulated because it will create more inefficiencies in the system if more than one firm are allowed to compete for wires business. One way to effectively regulate the network system is to form an independent entity that would control and operate the network only with or without the ownership of these facilities. While such entities may carry different names, such as independent system operator (ISO), transmission system operator (TSO), or regional transmission organization (RTO), the key functions of these entities are essentially the same. The mandate of these entities is to operate and manage the network system in a fair, least-cost, and most-efficient manner so that generators can compete effectively on a level playing field. The primary goal of operating the network in such a manner is to increase the economic efficiency of the system, and thus increase the social welfare. However, there might be some variations among these system operators in the areas of ownership, non-profit or for-profit, financial and capital structures, and governance. The list here is not exhaustive, but just descriptive. These topics are beyond the scope of this book.

In the electricity market setting, electricity is treated as another commodity. However, electricity must be generated simultaneously with demand which constantly fluctuates. As a result, an additional capacity, called the reserve margin, must be available to compensate for planned and unplanned outages of generating plants as well as spikes in demand. In a sense, the unique characteristics of electricity provide challenges unlike any of the other industries that has been deregulated. Sometimes, some sort of intervention is needed to ensure adequate supply. There are some imperfections in the competitive wholesale market operations, so some kind of reforms or interventions are generally needed.

1.2 ELECTRICITY INDUSTRY RESTRUCTURING IN THE UNITED STATES

The electric power system in North America is divided into three large regions: *Eastern Interconnection*, *Western Interconnection*, and *ERCOT Interconnection*, where ERCOT stands for Electric Reliability Council of Texas, as shown in Figure 1.1. Each interconnection operates its own system with small ties to other interconnections. The nominal system frequency for the entire system, including all three interconnections, is 60 Hz.

1.2.1 Key Drivers for Electricity Industry Restructuring

It is generally believed that the following are the key reasons and drivers behind the electricity industry restructuring:

1. Technological changes
2. High electricity costs
3. Overall system inefficiencies
4. Higher environmental restrictions

Technological changes have been an important driver to allow the implementation of competitive schemes in an industry which had been historically considered as a natural monopoly. New technologies make it economical for competitors to provide

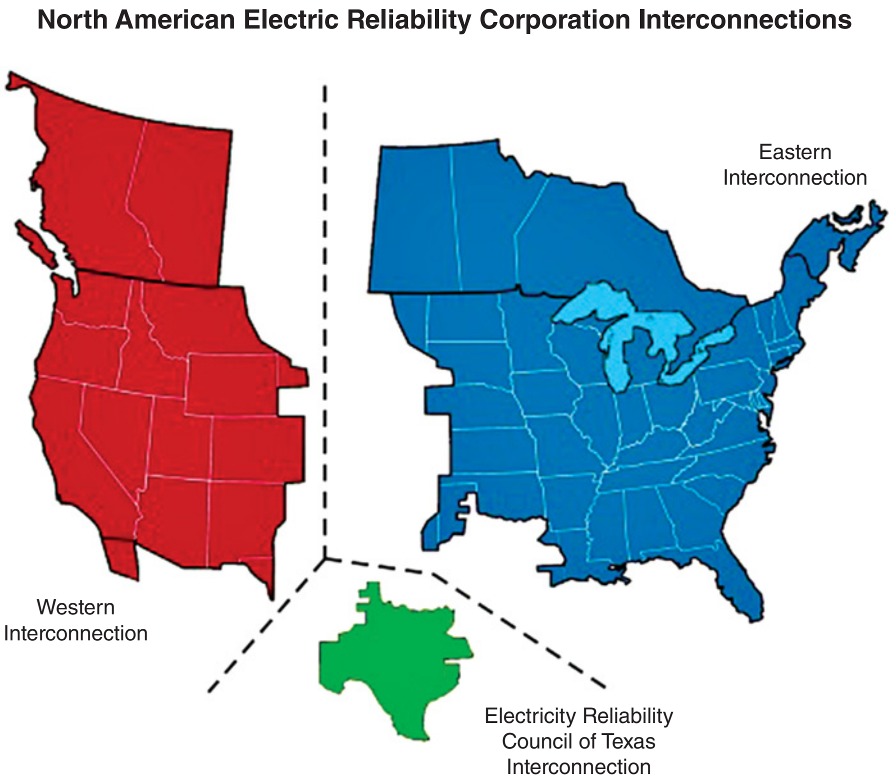

Figure 1.1 Electric Power System in North America.

electric generation services to electricity consumers, particularly industrial customers, which were traditionally served by incumbent utilities. Legal authority given to large industrial users to bypass the local utility provided more impetus to the industry restructuring.

In large part, the action was prompted by the burden of having a higher or the highest electricity costs in the country, which created hardships for residential consumers and handicapped many businesses from competing on a "level playing field" with companies located outside the region. For example, New England was one of the first regions of the country to restructure the industry. The persistently high cost of electricity which put the region at a competitive disadvantage was another driving force behind the push for further competition in the generation sector.

Another key driver in restructuring efforts was the environmental protection whose goal is to reduce atmospheric emissions from generating electricity. More rigorous air emission standards and regulations led to the construction of new natural gas-fired generating plants which, in turn, led to emission reduction and air-quality improvements. The new cleaner generators have displaced the older, inefficient, and polluting generating plants. Environmental protection rules, such as the Clean Air Act and subsequent federal rules along with the state's air quality regulations led to increased environmental benefits. The key pollutants that caused global environmental issues are sulfur dioxide (SO_2) which is responsible for acid rain, nitrogen oxide (NO_x) which produces smog, and carbon dioxide (CO_2) which is one of the key drivers of global warming.

The main objective of industry restructuring was to create a fair and reliable market for competition in generating electricity while ensuring equal access to transmission grids. The other objectives were to achieve lower electricity rates and enhance economic growth. Once established, the wholesale market treats electricity as a commodity with prices set not by regulators, but by market rules and the balance between supply and demand.

1.2.2 Pre-Federal Energy Regulatory Commission Order 2000

Traditionally, the majority of the electric utilities in the United States is formed as investor-owned utilities (IOUs). Some utilities are owned by the federal government and some are owned by municipalities and cooperatives. The vertically integrated utilities are granted franchise areas with the exclusive right to provide electric service. In exchange for this monopoly right, almost every aspect of their business was regulated by state's public utility commissions (PUCs) within their state boundaries. State PUCs set the operating standards for electric service, authorize the utilities to invest in new facilities such as power plants, transmission lines, or other equipments needed to meet their customer service obligations, and set the rates that customers pay for electricity service. Electric utilities are responsible for supplying electricity to load customers in their service territories.

The US Congress laid the groundwork for deregulating or restructuring wholesale electricity markets through provisions contained in the Public Utility Regulatory Policies Act of 1978 (PURPA). The Act mandated that regulated electric utilities provide a market for the output of non-utility generating (or power) plants that meet certain size, technology, and environmental criteria. Many state regulators required utilities to sign long-term power purchase contracts with small, independent PURPA generators at the utilities' then-avoided costs. Power plants that were built pursuant to PURPA represented the beginning of a new class of generators called independent power producers (IPP). Furthermore, pursuant to the state-mandated integrated resource planning processes, regulators required utilities to compare the cost of utility-built generation with that from IPP's generation and to take the least-cost alternative. This regulatory paradigm resulted in the maturation of the IPP industry across the country.

Thereafter, Congress passed the Energy Policy Act of 1992 which advanced the move to competition in wholesale markets. The Act gave Federal Energy Regulatory Commission (FERC) an authority to order utilities to provide transmission access to third parties in the wholesale electricity markets. This began the process of allowing open access to the existing transmission system to non-utility generators. This also created a condition in which there were increased competitions among generators owned by electric utilities and IPPs.

Subsequently, FERC issued Orders 888 and 889 in April 1996, which authorized open and equal access to all utilities' transmission lines for all electricity producers, thus facilitating wholesale and retail restructuring. These orders called for an accurate calculation and posting of available transfer capability (ATC) and implementation of the Open Access Same-Time Information System (OASIS), requiring transmission owners to open their transmission systems to third parties, giving equal access and fairness to use their transmission facilities to transfer power. In addition to asserting federal jurisdiction over all transmission, FERC Order 888 states that transmission-owning utilities must charge competing utilities the same fees to use their transmission system as they charge themselves. For the most part, FERC sets the transmission rates for wholesale transactions among transacting parties.

A few independent system operators (ISOs) were established to help achieve these and other objectives, although most transmission systems continued to be operated by the owning utilities. The wholesale portion of the US electric power industry has been shaped by FERC major orders dealing with electricity transmission: FERC Order 888–889, and subsequently Order 2000.

1.2.3 Post-Federal Energy Regulatory Commission Order 2000

Despite the push by FERC orders towards more open and fair access to the nation's transmission system, there were evidences that suggested that there were continued discrimination in the provision of transmission services by vertically integrated utilities against other users of their transmission system. This result may be impeding fully competitive electricity markets. That also implies that these orders failed to fully achieve what they were supposed to accomplish, that is, increased competitiveness of open electricity markets.

Frustrated by these outcomes, which are impediments to open competition, FERC later issued far-reaching "Order 2000" in December 1999 to push and expedite the development of efficient electricity markets by further calling for the formation of regional transmission organizations (RTOs) in various parts of the country. FERC Order 2000 requires FERC jurisdictional utilities to either file a plan by October 15, 2000, to establish an RTO whose function is to independently operate the transmission systems, or if a filing is not made, then each utility must explain why they are not making such a filing.

As envisioned by FERC, RTOs will implement and operate efficient electricity markets and also manage and operate the nation's transmission grid. FERC believes that RTOs, if established, will bring about the following benefits: increased efficiency, improved congestion management, accurate estimates of total transfer capability (TTC) and ATC, efficient planning of transmission and generation, increased coordination among states, and reduced transaction costs. All of these benefits will help promote competition and efficiency in wholesale electricity markets. The major role of RTOs is to provide fair and reasonable access to the transmission network nationwide. In consequence, electricity consumers would be expected to pay the lowest price possible for reliable service. FERC Order 2000 is a defining moment in the history of electric power system in the United States.

1.2.4 Regional Transmission Organization

RTOs, as called for by FERC, must have four minimum characteristics:

1. Independence
2. Scope and regional configuration
3. Operational authority
4. Short-term reliability

RTOs must also perform eight minimum functions:

1. Tariff administration and design
2. Congestion management
3. Parallel path flow
4. Ancillary services
5. OASIS and TTC/ATC
6. Market monitoring
7. Planning and expansion
8. Interregional coordination

Under Order 2000, the formation of RTOs is voluntary, and their organizational form is quite flexible. RTOs can take the form as not-for-profit ISOs or for-profit TransCo models. The focus is on "characteristics" and "functions." One of the salient characteristics is that the RTO must serve an appropriate region that must be of sufficient scope and regional configuration to permit the RTO to maintain reliability and effectively perform its required functions.

In general, RTO is a voluntarily formed entity that ensures comparable and nondiscriminatory access by electric generators to regional electric transmission systems.

RTOs are governed in a manner that renders them independent of the commercial interests of power suppliers who may also own transmission facilities in the region. The RTO assumes operational control of the use of transmission facilities, administers a system-wide transmission tariff applicable to all market participants, and maintains short-term system reliability.

Based on these characteristics, FERC proposed three RTOs in the Eastern Interconnect region: one in the Midwest, one in the Northeast, and one in the Southeast. In the Northeast, FERC tried to facilitate the process of merging three existing ISOs: PJM, New York ISO (NYISO), and ISO New England (ISO-NE), although these efforts were ultimately terminated without achieving an integrated Northeastern RTO. In terms of "scope and regional configuration" characteristics, FERC has not defined geographical boundaries for RTOs, leaving it to the transmission owners to determine appropriate consolidations that are sufficiently regional in size and scope. To date, the FERC-approved RTOs include Midcontinent ISO (MISO), PJM, Southwest Power Pool (SPP), California ISO (CAISO), NYISO, and ISO-NE in the United States. The transmission grid that the ERCOT ISO administers is located solely within the state of Texas and is not synchronously interconnected to the rest of the United States. The transmission of electric energy occurring wholly within ERCOT is not subject to the Commission's jurisdiction. The regional boundary map of RTOs/ISOs in the United States and Canada as of November 2015, is shown in Figure 1.2.

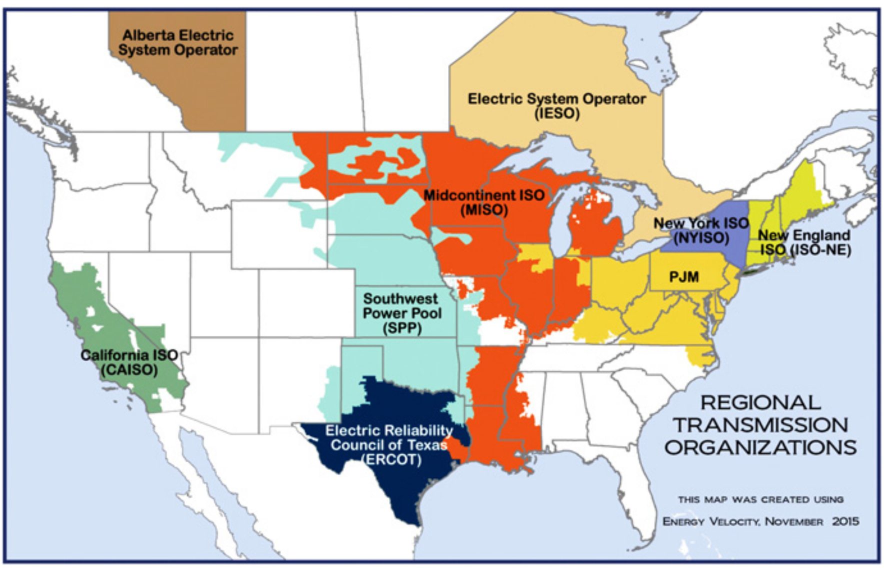

Figure 1.2 Map of Regional Transmission Organizations in North America. *Source:* http://www.ferc.gov/industries/electric/indus-act/rto.asp. Public domain.

1.2.5 Post-Regional Transmission Organization

In July 2002, FERC issued its Notice of Proposed Rulemaking on Standard Market Design (SMD NOPR), endorsing a market design that incorporates many of the best practices of the PJM and NYISO markets, such as *locational marginal pricing* (LMP) and *congestion revenue rights* (CRRs). An LMP scheme is currently used in PJM, NYISO, ISO-NE, and MISO markets. CRRs are also known as *financial transmission rights* (FTRs) in PJM and *transmission congestion contracts* (TCCs) in NYISO. The SMD policy includes far more implications for regional electricity markets than the previous RTO policy (Order 2000) on issues such as power rates, resource planning, and demand management.

FERC issued its NOPR on SMD to establish a uniform market structure and rules for emerging electricity markets. Any market participant who has to buy or sell electricity across two RTOs must currently follow two different tariffs, rules, and protocols. Inconsistent rules across the United States cause market inefficiency and raise costs for customers. FERC believes that SMD, if adopted, will create consistent market rules administered by fair and independent entities, no matter where the electricity is bought or sold. As a consequence, FERC expects SMD to lower costs to customers, to eliminate residual discrimination, to protect against potential market manipulation through market power mitigation measures and oversight, and to create incentives for investment in electric infrastructure, that is, transmission, generation, and demand-side resources with clear transmission policy and planning policies for grid expansion. The major requirements of FERC-proposed SMD are

1. Independent transmission provider (ITP)
2. Independent transmission companies (ITC)
3. Single transmission tariff
4. Long-term bilateral contract market
5. Day-ahead and real-time markets for energy and ancillary services
6. Regional transmission planning
7. LMP for congestion management
8. CRRs for tradable transmission rights
9. Market power monitoring and mitigation
10. Regional resource adequacy requirement
11. Role of states
12. Governance

However, on July 19, 2005, FERC issued an order terminating the SMD proceeding. This was partly due to the numerous criticisms about overreaching its federal authority over various issues such as power rates, demand forecasting, resource planning, and demand-side management.

In the next sections, electricity industry restructuring in some countries in Latin America, Europe, and Asia are presented.

1.3 ELECTRICITY INDUSTRY RESTRUCTURING IN LATIN AMERICA

Electricity industries in Latin America have undergone an enormous transformation in the 1990s. Basically, three electricity markets were developed in the region: the Central American market, the Andean market, and the Common Market of the Southern Cone. The Southern Cone market is the largest market including Chile, Argentina, and Brazil. The electricity industry restructuring in these markets are briefly described below. The electricity market in Mexico was only recently developed.

1.3.1 Chile

Chile is known as the pioneer of electricity industry reform. Before the restructuring in 1980s, the electric power industry in Chile has a vertically integrated structure which is centrally planned and heavily regulated. The centralized planning and operation were replaced by market-oriented approaches by deregulation and privatization. The objective of electric restructuring is to establish conditions for economic efficiency and to attract private investments.

Chilean Ministry of Energy has jurisdictional authority over the electricity sector. It is responsible for plans, policies, and standards regarding the development of the energy sector. In addition, it grants concessions for hydroelectric power plants, transmission lines, and distribution areas. Under the Ministry of Energy, the *Comisión Nacional de Energía* (CNE) is a technical agency responsible for studying prices, tariffs, technical standards, and setting tariffs according to the applicable regulations, and generating the electrical infrastructure work plan.

As part of the electricity industry restructuring in Chile, a wholesale electricity market in which the generation sector was opened for competition was developed. The business of transmission and distribution is still regulated due to their monopolistic characteristics. The transmission system is open for access by any legitimate market participants. Network costs are socially allocated. The distribution system is regulated based on some incentives.

In this market environment, at least large electricity consumers are exposed to unregulated market prices while the smaller consumers are protected from price volatility with some pass through of wholesale market prices. The so-called *Poolco* model in which generators compete under centralized generation dispatch was introduced. The market utilizes two-part pricing schemes: energy pricing and capacity pricing. In energy pricing, short-term marginal cost of energy is used as part of nodal pricing which considers both generation and transmission constraints. For capacity pricing, capacity payments are made to generators which make their capacities available in the yearly peak demand period (from May to September). The capacity payment depends on availability, start-time, and time to reach a full load energy production. The capacity price is defined by the regulator every 6 months based on the fixed cost of a typical gas-turbine generator.

In the energy market, financial (non-physical) bilateral contracts are also allowed. This is equivalent to the virtual bids which are eligible to participate in the electricity markets in the United States. The generation is centrally dispatched by *Centro de Despacho Económico de Carga* (CDEC). The economic dispatch is based on hourly marginal cost which is based on the variable costs of thermal generators. The variable cost of thermal generators are audited and hydro units are dispatched based on the cost of water estimated by CDEC. Economic transactions among generators are done based on marginal costs. It has entered into a second stage of reforms with public power purchase agreement (PPA) auctions in a private environment.

1.3.2 Argentina

Argentina began to reform its energy sector as part of a wider economic reform in the early 1990s. The long history of inefficient performance of state-owned utilities was one of the key drivers for the major transformation in the energy sector. The "Electricity and Natural Gas Acts" passed in the early 1990s paved the way for a new regulatory framework. Consequently, state-owned utilities were unbundled both horizontally and vertically as well as privatized. Wholesale markets for both electricity and natural gas were developed. The electricity industry is regulated by an authoritative regulatory body, *Ente Nacional Regulador de la Electricdad* (ENRE).

Private companies are allowed to participate in electricity generation which was open for competition while transmission and distribution parts of the system were still treated as regulated monopolies. The primary objectives of electricity restructuring in Argentina were to reduce electricity tariff, improve the quality of service, expand consumers' choices, and improve the economic efficiency. Due to the significant investments in the generation sector and some investments in transmission in the late 1990s, the Argentinean electricity market was one of the most competitive markets globally. The Argentinean model becomes a benchmark for measuring the success of electricity restructuring throughout the world.

To facilitate the development of a wholesale electricity market, an independent system operator (ISO), known as *Compañía Administradora del Mercado Mayorista Eléctrico S.A.* (CAMMESA) was established. CAMMESA is both a market operator and a market administrator. It provides open access to the market and transmission system to every market participant and establishes market rules. Its main roles entail delivery coordination, responsibility for wholesale price setting, and management of the economic transactions done by *Sistema Argentino De Interconexión* (SADI) which is the main transmission system.

The Argentinean electricity market comprises of both forward (contract) market and spot market. In the forward market, generators and distributors or large users can negotiate freely and sign contracts for electricity which set both prices and quantities for future delivery. In real-time, the electricity users with firm contracts are given priority in the event of shortages provided that the contracted generator is available. In the spot market, energy prices are set hourly on each system node based on the short-run marginal cost. Nodal energy prices also reflect marginal losses produced by generation/load and transmission congestion with local (zonal) pricing. The market does not have transmission rights, such as FTR. Ancillary services are both regulated and market based. For example, generators are obligated to provide frequency regulation (primary and secondary). But, they can trade their obligations among themselves. To provide voltage support, each market participant has to have a sufficient level of reactive power. Deviations from standard operating levels are penalized. Payments for black start services are based on regulated price. Transmission companies are not allowed to trade energy.

1.3.3 Brazil

Restructuring of electric power industry in Brazil followed a similar pattern as those in other Latin American countries. Before the restructuring, electric utilities are owned by the national government, which guarantees a certain level of rate of return. This leads to overinvestment and inefficiencies in the system. Electric utilities own all sectors of the business: generation, transmission, distribution, and retailing. Financial crisis in 1999 led to the payment default of sectoral liabilities and shortage in investment. Brazil started its power sector reform in 1996. The key objectives of this reform are to (1) ensure supply through continuity of expansion, (2) maintain and improve efficiency, (3) provide better service and competitive price setting, (4) provide more choices for consumers, and (5) reduce government debt through nongeneration of new debts and asset privatization.

The new rules, set forth in the restructured environment, were designed to introduce competition in generation and retailing sectors. However, the wires part (transmission and distribution) was still regulated with provisions for open access due to its monopolistic nature. As the result of restructuring, a wholesale energy market was developed, along with an establishment of an independent system operator, *Operador Nacional do Sistema Elétrico* (ONS), to facilitate the competition. A regulatory agency, *Agência Nacional de Energia Elétrica* (ANEEL), was also established and most distribution utilities were privatized. The wires part is subject to revenue cap and yardstick competition. For generators and retailers which are exposed to competition, the return on investment is based on their ability to manage risk under stable market rules.

Under its wholesale energy market regime, both generation and transmission resources are centrally dispatched on the least-cost basis by the system operator. There were no market rules or mechanisms that allow generators and load to offer and bid into the market based on price. Hydro units are dispatched based on their expected opportunity costs which are computed by a multistage stochastic optimization which models the detailed representation of hydro plant operation and inflow uncertainties. Bilateral contracts or other commercial arrangements are not considered in the centralized dispatch.

Market-clearing prices in the wholesale energy market are represented by short-run marginal costs calculated from the Lagrangian multipliers of the stochastic dispatch model. With any electricity market based on short-run marginal cost, the missing money problem is inevitable. In the missing money problem, a certain set of generators did not receive sufficient amount of revenues from the energy market to sustain their business viability. The revenue insufficiency for generators created by short-term spot price leads to an inability to provide sufficient incentives for new generation. In the Brazilian energy market, the prices are generally either volatile or very low due to the predominantly hydro system. The system marginal costs (spot prices) become low when there are surplus energy in the system, and become high when there is a very dry period or drought.

To encourage healthy entrance of new generation, a scheme based on mandatory bilateral contracts was introduced. First, all loads are required to be fully covered by power purchase agreements (PPAs). Second, these financial forward contracts must also be firmed up by actual generation capacity similar to firm energy from hydro plants. Therefore, such new contracts are used as a mandatory mechanism to secure energy supply for potentially growing load so as to facilitate the entry of new generators. To improve the long-term efficiency of the industry, those PPAs are also arranged through competitive auctions.

1.3.4 Mexico

The planned restructuring activity currently underway in Mexico is a prime example to show that more and more countries are interested in opening up their power industries to enjoy the economic benefits that can be potentially brought about by industry restructuring which encourages competition.

The new Law of the Electric Industry (*Ley de la Industria Eléctrica*), effective August 12, 2014, would allow the private sector to participate freely in the generation and sale of electricity while the electric grid will still be under the operational control of a state-owned agency. The new electric industry law will create a new wholesale electricity market (*Mercado Eléctrico Mayorista*) to be operated by the national energy control center, *Centro Nacional de Control de Energía* (CENACE), currently a unit within the federal commission, *Comisión Federal de Electricidad* (CFE). CENACE will also become the independent system operator for the entire grid. Mexican Ministry of Energy, *Secretaría de Energía de México* (SENER), and the regulatory authority, *Comisión Reguladora de Energía* (CRE) will have regulatory oversight and supervisory authority over the wholesale power market.

Under the new law, SENER crafted a draft regulation document on the guidelines for the electricity market, *Bases del Mercado Eléctrico*, and sent it to the Federal Commission for Regulatory Improvement (COFEMER) in February 2015. COFEMER is required to conduct a cost/benefit analysis of this new regulation. The guidelines establish the principles for the design and operation of the wholesale electricity market (WEM) including auction rules. All regulations before COFEMER are subject to public comment. After the review and decision by COFEMER, SENER will issue the final guidelines which will become a detailed plan for developing and operating an electricity market.

The key topics contained in the guidelines include staged implementation of the market, system reliability, market operation, operational planning, long-term markets, market monitoring, credit, and billings. The final guidelines will turn into the major protocols for the wholesale market operation. These protocols include (1) "Market Practice Manual" which will describe the principles for instructions and procedures for the administration, operation, and planning of the WEM, (2) "Operational Guidelines" which will include formulas and procedures that are contained in documents different from market practices manual, and (3) "Criteria and Procedures of Operation" which will include specifications, technical notes, and operating criteria required for the implementation of the constituent elements of the market rules in the design of software or daily operations. These protocols are collectively known as "Market Operational Provisions." The Guidelines and Market Operational Provisions together constitute the Market Rules which is equivalent to the tariffs issued by ISO/RTOs in the United States.

Components of WEM to be governed by the market rules include (1) day-ahead market and real-time market for energy and ancillary services, (2) capacity market, (3) market for clean energy certificates, (4) auctions for medium-term energy, (5) auctions for long-term capacity, clean energy, and clean energy certificates, and (6) auctions for financial transmission rights.

The key feature of Mexican WEM is the phased implementation of its various market components. For example, energy and ancillary services market will be implemented in two phases. Phase one will include day-ahead and real-time markets, as well as import/export transactions but exclude demand bidding and virtual bidding. Phase one market is slated to be tested in September 2015 and be fully operational on December 31, 2015. Phase two will include hour-ahead market, demand bidding by controllable resources, and virtual bidding subject to offer validation by market surveillance unit. Both testing and operation of phase two will occur in 2018. Capacity market will have two phases (phase one operational in November 2015 and phase two operational in November 2016).

The general characteristics of Mexican wholesale electricity market are as follows. CENACE will determine the economic dispatch for the entire system after receiving offers/bids from sellers/buyers. Then for each system node, it will calculate the market prices (equivalent to LMPs) which will include system energy price, congestion price, and incremental loss price. Some ancillary services, such as regulation reserves,