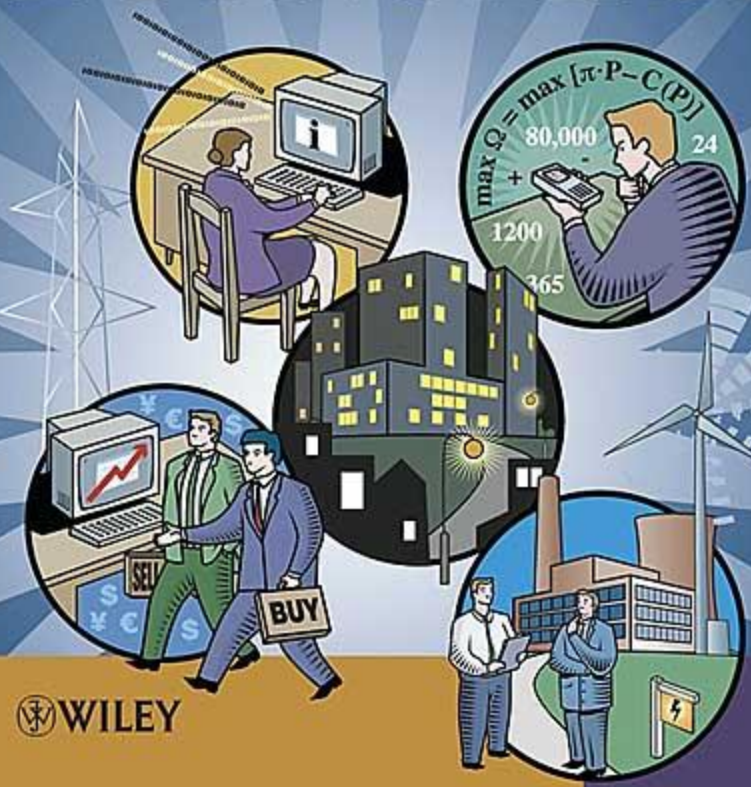
FUNDAMENTALS OF
POWER SYSTEM ECONOMICS



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DANIEL S. KIRSCHEN | GORAN STRBAC

Fundamentals of Power System Economics

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Daniel Kirschen
Goran Strbac
University of Manchester Institute of Science & Technology (UMIST), UK

John Wiley & Sons, Ltd

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester,
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For Penny and Philippe
For Dragana, Jelena and Anna

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Preface

For about a hundred years, the electricity supply industry was in the hands of vertically integrated monopoly utilities. During that time, engineers treated the management of this industry as a set of challenging optimization problems. Over the years, these optimization problems grew in size, complexity and scope. New algorithms were developed, and ever more powerful computers were deployed to refine the planning and the operation of the power systems. With the introduction of competition in the electricity supply industry, a single organization is no longer in charge. Multiple actors with divergent or competing interests must interact to deliver electrical energy and keep the lights on. Conventional optimization problems are often no longer relevant. Instead, dozens of new questions are being asked about a physical system that has not changed. To deliver the promised benefits of competition, old issues must be addressed in radically new ways. To stay in business, new companies must maximize the value of the service they provide. Understanding the physics of the system is no longer enough. We must understand how the economics affect the physics and how the physics constrain the economics.

An environment with many independent participants evolves very rapidly. Over the last two decades, hundreds of technical papers, thousands of reports and a few books have been written to discuss these new issues and to propose solutions. The objective of this book is not to summarize or repeat what is in these documents. Instead, we have chosen to concentrate on delivering a clear and in-depth explanation of the fundamental issues. Our aim is to give the readers a solid understanding of the basics and help them develop innovative solutions to problems that vary in subtle ways from country to country, from market to market and from company to company. Therefore, we do not discuss the organization of specific markets. Neither do we attempt to describe all the solution techniques that have been proposed.

The plan of this book is simple. After introducing the participants in a restructured electricity supply industry, we discuss the concepts from microeconomics that are essential for the understanding of electricity markets. We then move on to the analysis of the operation of power systems in a competitive environment. To keep matters simple, we begin by ignoring the transmission network and we consider the operation of pure energy markets. We then discuss power system security and the effects that networks have on electricity prices. Finally, in the last two chapters, we address the issue of investments in power generation and transmission equipment in a competitive environment.

The typical reader we had in mind while writing this book was a first-year graduate student or a final-year undergraduate student specializing in power engineering. We have assumed that these students know the physical structure of power systems, understand the purpose and principles of a power flow calculation and are familiar with basic optimization theory. We believe that this book will also be valuable to engineers who are working on deregulation or competition issues and who want to acquire a broader perspective on these questions. Finally, this book might also be useful to economists and other professionals who want to understand the engineering perspective on these multidisciplinary issues.

Except when a specific source is cited, we have made no attempt to use or produce realistic numbers in the problems and examples. We have used $ as a unit for money because it is probably the best-known symbol for a currency. We could have used €, £ or ¥ instead without any change in meaning.

Some of our examples refer to the fictitious countries of Syldavia and Borduria, which are the product of the fertile imagination of the Belgian cartoonist Hergé, creator of the character Tintin.

This book stems from our research and teaching activities in power system economics at UMIST. We are grateful to our colleagues Ron Allan and Nick Jenkins for fostering an environment in which this work was able to flourish. We also thank Fiona Woolf for fascinating interdisciplinary discussions on transmission expansion.

A few of our students spent considerable time proofreading drafts of this book and checking answers to the problems. In particular, we thank Tan Yun Tiam, Miguel Ortega Vazquez, Su Chua Liang, Mmeli Fipaza, Irene Charalambous, Li Zhang, Jaime Maldonado Moniet, Danny Pudjianto and Joseph Mutale. Any remaining errors are our sole responsibility.

1
Introduction

1.1 Why Competition?

For most of the twentieth century, when consumers wanted to buy electrical energy, they had no choice. They had to buy it from the utility that held the monopoly for the supply of electricity in the area where these consumers were located. Some of these utilities were vertically integrated, which means that they generated the electrical energy, transmitted it from the power plants to the load centers and distributed it to individual consumers. In other cases, the utility from which consumers purchased electricity was responsible only for its sale and distribution in a local area. This distribution utility in turn had to purchase electrical energy from a generation and transmission utility that had a monopoly over a wider geographical area. In some parts of the world, these utilities were regulated private companies, while in others they were public companies or government agencies. Irrespective of ownership and the level of vertical integration, geographical monopolies were the norm.

Electric utilities operating under this model made truly remarkable contributions to economic activity and quality of life. Most people living in the industrialized world have access to an electricity distribution network. For several decades, the amount of energy delivered by these networks doubled about every eight years. At the same time, advances in engineering improved the reliability of the electricity supply to the point that in many parts of the world the average consumer is deprived of electricity for less than two minutes per year. These achievements were made possible by ceaseless technological advances. Among these, let us mention only the development and erection of transmission lines operating at over 1 000 000 V and spanning thousands of kilometers, the construction of power plants capable of generating more than 1000 MW and the online control of the networks connecting these plants to the consumers through these lines. Some readers will undoubtedly feel that on the basis of this record, it may have been premature to write the first paragraph of this book in the past tense.

In the 1980s, some economists started arguing that this model had run its course. They said that the monopoly status of the electric utilities removed the incentive to operate efficiently and encouraged unnecessary investments. They also argued that the cost of the mistakes that private utilities made should not be passed on to the consumers. Public utilities, on the other hand, were often too closely linked to the government. Politics could then interfere with good economics. For example, some

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public utilities were treated as cash cows, and others were prevented from setting rates at a level that reflected costs or were deprived of the capital that they needed for essential investments.

These economists suggested that prices would be lower and that the economy as a whole would benefit if the supply of electricity became the object of market discipline rather than monopoly regulation or government policy. This proposal was made in the context of a general deregulation of western economies that had started in the late seventies. Before attention turned toward electricity, this movement had already affected airlines, transportation and the supply of gas. In all these sectors, regulated market or monopolies had been deemed the most efficient mean of delivering the "products" to the consumers. It was felt that their special characteristics made them unsuitable for trading on free markets. Advocates of deregulation argued that the special characteristics of these products were not insurmountable obstacles and that they could and should be treated like all other commodities. If companies were allowed to compete freely for the provision of electricity, the efficiency gains arising from this competition would ultimately benefit the consumers. In addition, competing companies would probably choose different technologies. It was therefore less likely that the consumers would be saddled with the consequences of unwise investments.

If electricity truly were a simple commodity[1], kilowatt-hours could be stacked on a shelf – like kilograms of flour or television sets – ready to be used as soon as the consumer turns on the light or starts the industrial process. Despite recent technological advances in electricity storage and microgeneration, this concept is not yet technically or commercially feasible. The reliable and continuous delivery of significant amounts of electrical energy still requires large generating plants connected to the consumer through transmission and distribution networks.

In this book, we will explore how the production and trading of electrical energy can be separated conceptually from the operation of this power system. The kilowatt-hours can then be treated as a commodity and traded on a deregulated market.

1.2 Dramatis Personae

Before we delve into the analysis of electricity markets, it is useful to introduce the types of companies and organizations that play a role in these markets. In the following chapters, we will, of course, discuss in much more detail the function and motivation of each of these participants. Since markets have evolved at different rates and in somewhat different directions in each country or region, not all these entities will be found in each market. In some cases, one company or organization may perform more than one of the functions described below.

Vertically integrated utilities own generating plants as well as a transmission and distribution network. In a traditional regulated environment, such a company has a monopoly for the supply of electricity over a given geographical area. Following the liberalization of the electricity market, its generation and network activities are likely to be separated.

[1]This book would also not have been written.

Generating companies (gencos) produce and sell electrical energy. They may also sell services such as regulation, voltage control and reserve that the system operator needs to maintain the quality and security of the electricity supply. A generating company can own a single plant or a portfolio of plants of different technologies. Generating companies that coexist with vertically integrated utilities are sometimes called *independent power producers* (IPP).

Distribution companies (discos) own and operate distribution networks. In a traditional environment, they have a monopoly for the sale of electrical energy to all consumers connected to their network. In a fully deregulated environment, the sale of energy to consumers is decoupled from the operation, maintenance and development of the distribution network. Retailers then compete to perform this energy sale activity. One of these retailers may be a subsidiary of the local distribution company.

Retailers buy electrical energy on the wholesale market and resell it to consumers who do not wish, or are not allowed, to participate in this wholesale market. Retailers do not have to own any power generation, transmission or distribution assets. Some retailers are subsidiaries of generation or distribution companies. All the customers of a retailer do not have to be connected to the network of the same distribution company.

A market operator (MO) typically runs a computer system that matches the bids and offers that buyers and sellers of electrical energy have submitted. It also takes care of the settlement of the accepted bids and offers. This means that it forwards payments from buyers to sellers following delivery of the energy. The independent system operator (ISO) is usually responsible for running the market of last resort, that is, the market in which load and generation are balanced in real time. Markets that close some time ahead of real time are typically run by independent for-profit market operators.

The independent system operator (ISO) has the primary responsibility of maintaining the security of the power system. It is called independent because in a competitive environment, the system must be operated in a manner that does not favor or penalize one market participant over another. An ISO would normally own only the computing and communications assets required to monitor and control the power system. An ISO usually combines its system operation responsibility with the role of the operator of the market of last resort.

Transmission companies (transco) own transmission assets such as lines, cables, transformers and reactive compensation devices. They operate this equipment according to the instructions of the independent system operator. Transmission companies are sometimes subsidiaries of companies that also own generating plants. An *independent transmission company* (ITC) is a transmission company that does not own generating plants and also acts as an independent system operator.

The regulator is the governmental body responsible for ensuring the fair and efficient operation of the electricity sector. It determines or approves the rules of the electricity market and investigates suspected cases of abuse of market power. The regulator also sets the prices for the products and services that are provided by monopolies.

Small consumers buy electrical energy from a retailer and lease a connection to the power system from their local distribution company. Their participation in the electricity market usually amounts to no more than choosing one retailer among others when they have this option.

Large consumers, on the other hand, will often take an active role in electricity markets by buying their electrical energy directly through the market. Some of them may offer their ability to control their load as a resource that the ISO can use to control the system. The largest consumers are sometimes connected directly to the transmission system.

1.3 Models of Competition

Hunt and Shuttleworth (1996) propose four models to chart the evolution of the electricity supply industry from a regulated monopoly to full competition.

1.3.1 Model 1: Monopoly

The first model, which is shown in Figure 1.1, corresponds to the traditional monopoly utility. Submodel (a) corresponds to the case where the utility integrates the generation, transmission and distribution of electricity. In submodel (b), generation and transmission are handled by one utility, which sells the energy to local monopoly distribution companies. This model does not preclude bilateral energy trades between utilities operating in different geographical areas. As illustrated in Figure 1.1, these trades take place at the wholesale level.

1.3.2 Model 2: Purchasing agency

Figure 1.2(a) shows a possible first step toward the introduction of competition in the electricity supply industry. The integrated utility no longer owns all the generation

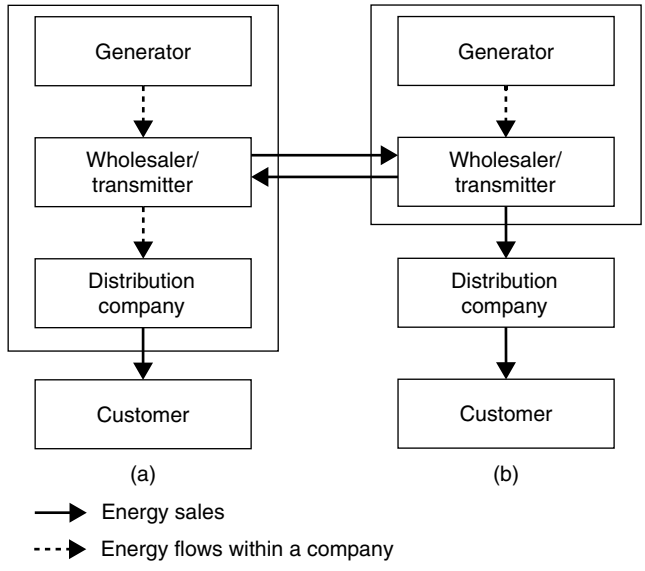

Figure 1.1 Monopoly model of electricity market based on (Hunt and Shuttleworth, 1996). In submodel (a), the utility is completely vertically integrated, while in submodel (b), the distribution is handled by one or more separate companies

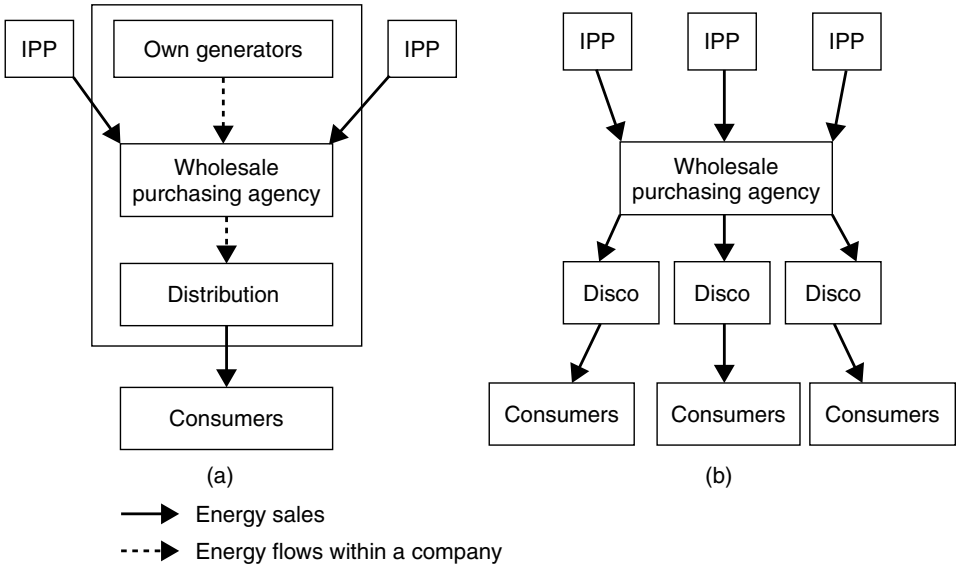

Figure 1.2 Purchasing agency model of electricity market based on (Hunt and Shuttleworth, 1996). (a) integrated version; (b) disaggregated version

capacity. Independent power producers (IPP) are connected to the network and sell their output to the utility that acts as a purchasing agent. Figure 1.2(b) shows a further evolution of this model where the utility no longer owns any generation capacity and purchases all its energy from the IPPs. The distribution and retail activities are also disaggregated. Discos then purchase the energy consumed by their customers from the wholesale purchasing agency. The rates set by the purchasing agency must be regulated because it has monopoly power over the discos and monopsony power toward the IPPs. This model therefore does not discover a cost-reflective price in the same way that a free market does (see Chapter 2). However, it has the advantage of introducing some competition between generators without the expense of setting up a competitive market as in the more complex models that we describe next.

1.3.3 Model 3: Wholesale competition

In this model, which is shown in Figure 1.3, no central organization is responsible for the provision of electrical energy. Instead, discos purchase the electrical energy consumed by their customers directly from generating companies. These transactions take place in a wholesale electricity market. The largest consumers are often allowed to purchase electrical energy directly on the wholesale market. As we will see in Chapter 3, this wholesale market can take the form of a pool or of bilateral transactions. At the wholesale level, the only functions that remain centralized are the operation of the spot market, and the operation of the transmission network. At the retail level, the system remains centralized because each disco not only operates the distribution network in its area but also purchases electrical energy on behalf of the consumers located in its service territory.

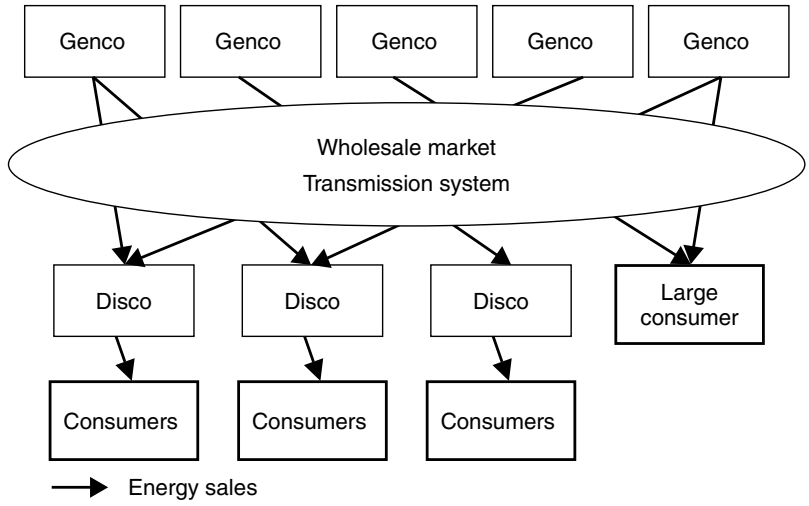

Figure 1.3 Wholesale competition model of electricity market based on (Hunt and Shuttleworth, 1996)

This model creates considerably more competition for the generating companies because the wholesale price is determined by the interplay of supply and demand. On the other hand, the retail price of electrical energy must remain regulated because small consumers cannot choose a competing supplier if they feel that the price is too high. This leaves the distribution companies exposed to sudden large increases in the wholesale price of energy.

1.3.4 Model 4: Retail competition

Figure 1.4 illustrates the ultimate form of competitive electricity market in which all consumers can choose their supplier. Because of the transaction costs, only the largest consumers choose to purchase energy directly on the wholesale market. Most small and medium consumers purchase it from retailers, who in turn buy it in the wholesale market. In this model, the "wires" activities of the distribution companies are normally separated from their retail activities because they no longer have a local monopoly for the supply of electrical energy in the area covered by their network. In this model, The only remaining monopoly functions are thus the provision and operation of the transmission and distribution networks.

Once sufficiently competitive markets have been established, the retail price no longer has to be regulated because small consumers can change retailer when they are offered a better price. As we will see in Chapter 2, from an economics perspective this model is the most satisfactory because energy prices are set through market interactions. Implementing this model, however, requires considerable amounts of metering, communication and data processing.

The cost of the transmission and distribution networks is still charged to all their users. This is done on a regulated basis because these networks remain monopolies.

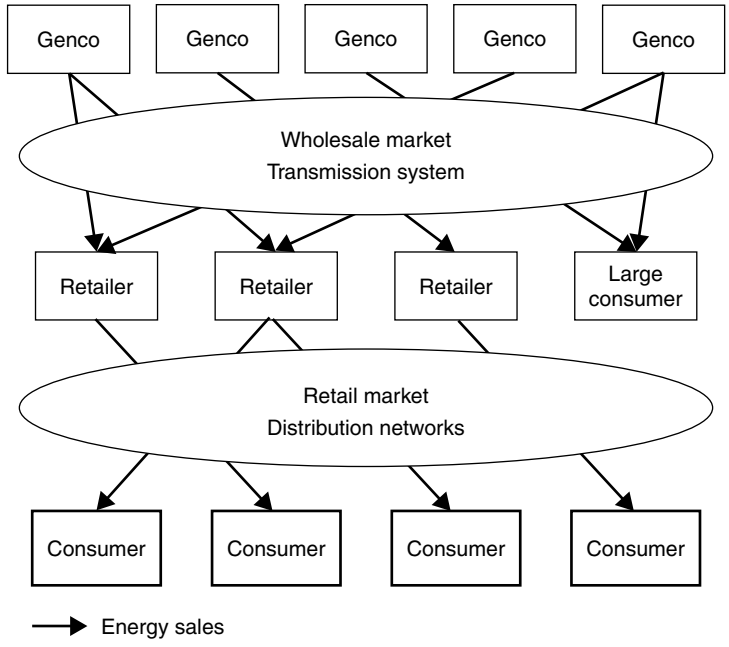

Figure 1.4 Retail competition model of electricity market based on (Hunt and Shuttleworth, 1996)

1.3.5 Competition and privatization

In many countries, the introduction of competition in the supply of electricity has been accompanied by the privatization of some or all components of the industry. Privatization is the process by which publicly owned utilities are sold by the government to private investors. These utilities then become private, for-profit companies. Privatization is not, however, a prerequisite for the introduction of competition. None of the four models of competition described above implies a certain form of ownership. Public utilities can, and in many instances do, compete with private companies.

1.4 Open Questions

In the monopoly utility model, all technical decisions regarding the operation and the development of the power system are taken within a single organization. In the short term, this means that, at least in theory, the operation of all the components of the system can be coordinated to achieve least cost operation. For example, the maintenance of the transmission system can be scheduled jointly with the maintenance of the generation units to minimize the effects of congestion. Similarly, the long-term development of the system can be planned to ensure that the transmission capacity and topology match the generation capacity and location.

Introducing competition implies renouncing centralized control and coordinated planning. A single integrated utility is replaced by a constellation of independent companies. Each of these decides independently what it will do to maximize its private

objectives. When the idea of competitive electricity markets was first mooted, it was rejected by many on the grounds that such a disaggregated system could not keep the lights on. There is now ample evidence to demonstrate that separating the operation of generation from that of the transmission system does not necessarily reduce the reliability of the overall system.

What is considerably more difficult to prove is that a disaggregated, competitive system operates more efficiently than a centralized one. While it is clear that the profit motive encourages generating companies to take better care of their plants, it remains to be proven that this improvement in availability (and possibly efficiency) is sufficient to compensate for the loss of coordination between the plants.

In terms of long-term development, the argument in favor of competition is that central planners always get their forecast wrong. In particular, monopoly utilities have a tendency to overestimate the amount of generation capacity that will be needed. Their captive consumers are then obliged to pay for unnecessary investments. With the introduction of competition, it is hoped that the sum of the independent investment decisions of several profit-seeking companies will match the actual evolution of the demand more closely than the recommendations of a single planning department. In addition, underutilized investments by a company operating in a free market represent a risk for its owners and not its customers. Experience from around the world suggests that investors are willing to accept this risk. However, it remains to be seen if the growth in generation capacity smoothly matches the increase in demand or goes through "boom-and-bust" cycles.

Vertically integrated utilities can plan the development of their transmission network to suit the construction of new generating plants. In a competitive environment, the transmission company does not know years in advance where and when generating companies will build new plants. This uncertainty makes the transmission planning process much more difficult. Conversely, generating companies are not guaranteed that transmission capacity will remain available for the output of their plants. Other companies may indeed build new plants in the vicinity and compete for the available transmission capacity.

The transmission and distribution networks have so far been treated as natural monopolies. Having two separate and competing sets of transmission lines or distribution feeders clearly does not make sense. From both the economic and the reliability points of view, all lines, feeders and other components should be connected to the same system. On the other hand, some economists and some entrepreneurs have begun to argue that not all these components must be owned by the same company. They believe that new investments could be driven by investors who expand a network to satisfy specific needs for power transmission or distribution that they have identified. Taken individually, such opportunities could be lucrative for the investors. However, they must take place within a framework that maximizes the overall benefits derived by all users of the network. Such a framework remains to be developed.

1.5 Further Reading

Hunt S, Shuttleworth G, *Competition and Choice in Electricity*, Wiley, Chichester, 1996.

1.6 Problems

1.1 Using the classification proposed by Hunt and Shuttleworth, determine the level of competition that exists in your region or country or in another area for which you have access to sufficient information. Discuss any difference that you observe between the basic model and the electricity market implementation in this area.

1.2 Identify the companies that participate in the electricity market in the area that you chose for Problem 1.1. Map the basic functions defined in this chapter with these companies and discuss any difference that you observe. Identify clearly the companies that enjoy a monopoly status in some or all their activities.

1.3 Identify the regulatory agencies that oversee the electricity supply industry in the area that you chose for Problem 1.1.

1.4 Identify the organizations that fulfill the functions of market operator and system operator in the area that you chose for Problem 1.1.

1.5 The reasons invoked for implementing a competitive electricity market or a certain model of electricity market depend on local circumstances. Identify and discuss the reasons that were invoked in the region that you chose for Problem 1.1.