Preface

Rigorous analysis is essential for making informed decisions about the construction of new electricity generation plants or transmission lines. This book provides a number of relevant models that constitute a framework for such investment analysis.

Since electricity generation and transmission assets last for many years, investment decisions are challenging because they involve high costs, are often made under high uncertainty, and generally require risk control on cost variability. Moreover, given the required investment level, wrong decisions may prove catastrophic from a financial viewpoint. Also, investment decisions are dynamic in nature since they are made by practitioners throughout a long-term planning horizon as uncertainty unfolds. As a result of the uncertainty involved, the required risk control, and the dynamic nature of investment decisions, appropriate mathematical models are complex and often need tailored solution techniques.

Within a market framework, distinct agents with different and often conflicting objectives are generally involved in making investment decisions, and thus a multiobjective equilibrium approach is desirable. Moreover, market power is common in electricity markets, and its representation entails nontrivial modeling features. Consequently, the resulting game-theoretic models are complex enough to require carefully crafted solution techniques.

By focusing on the application of the state-of-the-art mathematical tools for decision-making, this book aims to convey the principles of investment analysis in the electricity industry to students and practitioners alike. Initially, a social planning viewpoint is adopted, and generation expansion, transmission expansion, and generation plus transmission expansion problems are considered. Subsequently, a market perspective is taken, and generation investment equilibria are analyzed.

This book consists of seven chapters and five appendices. Chapter 1 provides an introduction to both electricity transmission and electricity generation expansion planning problems, emphasizing their long-term nature, the high degree of uncertainty involved, and the market framework in which electricity is produced, transported, distributed, and supplied in most parts of the world. Next, the chapter describes specific decision-making problems involving electricity transmission and/or generation facilities and introduces the computational tools needed to tackle these problems. It concludes by stating the scope of the book.

Chapter 2 is devoted to electricity transmission expansion planning adopting the viewpoint of a social planner. The rationale for this perspective is that the electricity transmission network is undoubtedly a natural monopoly. A simple deterministic model is first introduced to clarify the elements of this important decision-making problem, followed by a detailed robust adaptive model to cope with uncertainty in a secure yet economical manner.

Chapter 3 considers generation expansion planning also from a social planning viewpoint. The optimal outcome is intended to guide private investment in generation facilities. The chapter describes a number of increasingly complex models. The first model involves a single decision point, includes no network representation, and is deterministic. Subsequently, the single decision point is substituted by multiple decision points, the network is represented, and short-term (demand and renewable production variability within one year) and long-term (changes in demand and investment/operational costs across years) uncertainties are incorporated via stochastic programming.

Chapter 4 similarly adopts a social planning viewpoint and considers the joint generation and transmission expansion planning problem. Addressing the expansion of generation and transmission facilities together yields a transmission–generation coordinated solution that is optimal. The transmission component of this solution is to be built by the transmission operator, while its generation component serves as a guide for private investment in generation facilities. The chapter introduces models of increasing complexity: first, a deterministic single decision-point model, followed by a deterministic multiple decision-point model. Uncertainty is then introduced via stochastic programming, and finally, risk control (on total cost variability) is incorporated into this stochastic model.

Chapter 5 considers a market viewpoint and describes the decision-making problem of a private investor seeking to build electricity generation facilities from which to sell its output in the market for a profit. We assume that this investor has the capability to alter market outcomes, i.e., it has market power. This requires a complementarity or bilevel model, which generally entails high modeling and computational complexity. A single decision-point model is first introduced, followed by a multiple decision-point model. Short-term uncertainty pertaining to demand levels and renewable (solar- and wind-based) production is then introduced, but for simplicity, long-term uncertainty (change in investment/fuel cost and demand growth) is not considered. The chapter concludes by discussing computational techniques to tackle this type of large-scale complementarity problem.

Chapter 6 likewise takes a market viewpoint and considers a number of private investors competing in building power plants and in selling their generated electricity in the market for a profit. We assume that these investors are able to exert market power. The chapter describes models to identify the equilibria that are eventually reached by these competing investors. For simplicity, short-term uncertainty is represented, but long-term uncertainty is not. A number of solution methodologies to tackle these resulting equilibrium problems are discussed. Identifying equilibria is also of interest to the industry regulator in order to ascertain ways to improve market design and market rules.

Chapter 7 describes the real options methodology for identifying the timing, sizing, and technological characteristics of a specific investment project in generation or transmission facilities. The uncertainty unfolding over time is carefully represented to enable sequential decision analysis comprising features such as operational flexibility, modularity, and capacity choice. Risk control via utility functions is naturally embedded in the analysis.

Appendix A reviews the fundamentals of engineering economics. Appendix B provides an introduction to optimization under uncertainty. Appendix C reviews complementarity analysis, including equilibrium and hierarchical (bilevel) problems. Appendix D introduces the fundamentals of risk management. Appendix E provides an introduction to dynamic programming.

The material in this book can be arranged in different ways to address the needs of graduate teaching in a one-semester course. Chapters 1–4 and Appendices A, B, and D constitute the core of a capacity expansion planning course with no market focus. Chapters 1, 5, and 6 and Appendices A, B, C, and D include fundamental material for a market-focused capacity expansion planning course. Chapters 1 and 7 and Appendices A, D, and E constitute the basis for a real options course.

The book provides an appropriate blend of theoretical background and practical applications. This feature makes the book of interest to practitioners as well as to researchers and students in engineering, operations research, and business. Practical applications are developed up to working algorithms (coded in the GAMS environment) that can be readily used.

Reading this book provides a comprehensive understanding of current investment problems in electric energy systems, including the formulation of decision-making models for both generation and transmission expansion planning, the familiarization with efficient solution algorithms for such decision-making models, and insights into these investment problems through the detailed analysis of numerous illustrative examples.

This book opens the door to analyzing investment decisions in electricity generation and transmission facilities using the most advanced models available. Such models are explained in a tutorial and simple manner with illustrations provided by many worked examples. Hence, the concepts and insights can be accessible to practitioners and students.

To conclude, we would like to thank our colleagues and students for insightful observations, pertinent corrections, and helpful comments.

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