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Integrating Renewables in Electricity Markets

Operational Problems

Springer

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To our families.

Preface

Electric energy systems in the past included almost solely *deterministic* production facilities, such us coal- or gas-fired units, or nuclear power plants. If a unit of this type is not out-of-order, its functioning depends only on the will of its owner.

However, electric energy systems throughout the world are currently incorporating an increasing number of *stochastic* production facilities, such as solar- or wind-based units. The functioning of a stochastic unit that is not out-of-order depends not only on the will of its owner, but also on the availability of the primary energy source, i.e., solar intensity or wind level.

The control, operations, planning, economics, and regulation of an electric energy system that includes an important number of stochastic renewable production facilities are considerably different than those of a system without such stochastic facilities. This is the direct result of the variability and the limited predictability of the production levels of the stochastic units, which make it necessary to count on flexible backup energy resources to compensate for the variable and uncertain nature of the power output of these units.

This book focuses on operational issues in electric energy systems that comprise a significant number of stochastic renewable producers, and provides models and algorithms for the efficient and secure operation of such systems. These models and algorithms pertain to the market operator, the stochastic producers, and the demand.

To efficiently cope with the inherent uncertainty and variability in the production of stochastic renewable units, the algorithms provided mostly rely on techniques of optimization under uncertainty, in particular, stochastic programming and robust optimization.

This book consists of nine chapters and five appendices.

Chapter 1 motivates the subject matter of this book by introducing the organization of the pool-based electric energy market that is considered and providing an overview of the main problems addressed in the remaining chapters.

Chapter 2 introduces different types of models and forecasts to characterize the behavior of stochastic renewable electricity production facilities, such as solar- and wind-based units.

Chapter 3 provides tools to clear the day-ahead auction, the most important component of a pool-based electricity market. Both stochastic programming and robust optimization algorithms are proposed and illustrated.

Chapter 4 provides clearing tools for the real-time or balancing auction, another important component of every electricity market that includes a significant level of stochastic production capacity.

Chapter 5 describes a number of flexibility measures to facilitate the integration of stochastic renewable production facilities. Such measures involve both the supply and the demand sides.

Chapter 6 provides a detailed characterization of the impact of stochastic renewable production units on market outcomes, including production and prices.

Chapter 7 adopts the view of a stochastic renewable producer and considers the problem of how to sell effectively its production in a pool-based market. Both analytic and computation procedures are described in detail.

Chapter 8 considers different associations of stochastic and non-stochastic production units, forming a so-called virtual power plant, to increase their competitive edge in the market.

Chapter 9 takes the perspective of the demand and analyzes a number of price-response actions to enable a higher integration of renewable energy and an overall economic improvement in the operation of the system as a whole.

Appendix A provides the fundamentals of random variables and stochastic processes, Appendix B describes some basics of optimization theory, Appendices C and D provide introductions to stochastic programming and robust optimization, respectively, and Appendix E compiles GAMS codes for a number of illustrative examples considered throughout the book.

The material in this book can be arranged in different manners to address the needs of graduate teaching in electricity markets and in the integration of stochastic renewable production in electric energy systems.

Chapters 3–5 and Appendices C and D constitute the core of a course on market-clearing procedures from the perspective of a market operator.

Chapters 7 and 8 and Appendices B–D provide the basic material for a course on trading strategies for producers.

Chapters 2 and 6, and Appendix A include important material for a course on modeling and forecasting stochastic renewable production and their impact on electricity markets.

Chapter 9 and Appendices B–D can form part of a course on demand-side management.

GAMS codes in Appendix E help students to develop the appropriate skills to code and use algorithms of the type discussed throughout this book.

Stochastic renewable production facilities are here to stay for a number of important reasons, including global warming, the depletion of fossil fuels and, generally, the achievement of a sustainable planet. The penetration of stochastic production facilities in electric energy systems throughout the world will progressively increase, eventually making such systems fully renewable.

This book opens the door to develop operational tools for electric energy systems dominated by stochastic renewable production facilities. Such tools will evolve in a non-trivial manner as electric energy systems approach the fully renewable status. This constitutes a fascinating route ahead involving important intellectual and practical challenges, and, definitively, a way to contribute to the sustainability of planet Earth.

Lastly, we would be remiss if we were to conclude this preface without expressing our gratitude to a number of people and institutions. We are thankful to the Technical University of Denmark for providing us with an invaluable research environment and to the Danish Council for Strategic Research and DONG Energy for the financial support. More particularly, during the preparation of this book, the authors have been partly funded through projects ENSYMORA (no. 10-093904/DSF), iPower (DSR-SPIR program 10-095378), and 5s (no. 12-132636/DSF). We would also like to thank Fred Hillier and Camille Price for enthusiastically supporting the writing of this book, and to Neil Levine and Matt Amboy, from Springer US, for all their help throughout the writing process. Our special thanks go to our families, to whom we dedicate this book. We could have never made it through the arduous yet fulfilling adventure of writing a book without their constant support and encouragement.

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