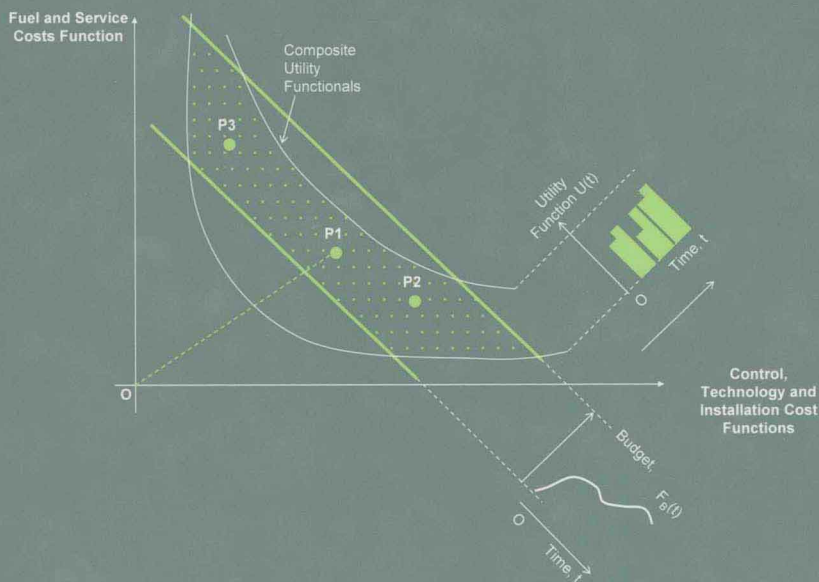


Economic Market Design and Planning *for* Electric Power Systems



JAMES MOMOH • LAMINE MILI

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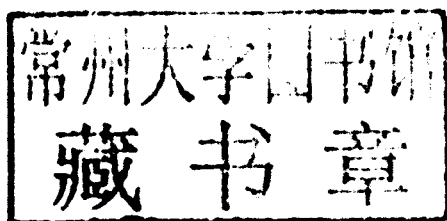

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ECONOMIC MARKET DESIGN AND PLANNING FOR ELECTRIC POWER SYSTEMS

Edited by

**JAMES MOMOH
LAMINE MILI**



Mohamed E. El-Hawary, *Series Editor*



Celebrating 125 Years
of Engineering the Future



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PREFACE

This is a textbook of a two-book series based on interdisciplinary research activities carried out by researchers in power engineering, economics and systems engineering as envisioned by the NSF-ONR EPNES initiative. This initiative has funded researchers, university professors, and graduate students engaged in interdisciplinary work in all the aforementioned areas. Both textbooks are written by experts in economics, social sciences, and electric power systems. They shall appeal to a broad audience made up of policy makers, executives and engineers of electric utilities, university faculty members and graduate students as well as researchers working in cross-cutting areas related to electric power systems, economics, and social sciences.

While the companion textbook of the two series addresses the operation and control of electric energy processing systems, this textbook focuses on the economic, social and security aspects of the operation and planning of restructured electric power systems. Specifically, various metrics are proposed to assess the resiliency of a power system in terms of survivability, security, efficiency, sustainability, and affordability in a competitive environment.

This textbook meets the need for power engineering education on market economics and risk-based power systems planning. It proposes a multidisciplinary research-based curriculum that prepares engineers, economists, and social scientists to plan and operate power systems in a secure and efficient manner in a competitive environment. It recognizes the importance of the design of robust power networks to achieve sustainable economic growth on a global scale. To our best knowledge, there is no textbook that combines all these fields. The purpose of this textbook is to provide a working knowledge as well as cutting-edge areas in electric power systems theories and applications.

This textbook is organized in ten chapters as follows:

- Chapter 1, which is authored by J. Momoh, introduces the EPNES initiative.
- Chapter 2, which is authored by A. Garcia, L. Mili, and J. Momoh, provides a comprehensive overview of the economic structure of present and future electricity markets from the combined perspectives of economics and electrical engineering.
- Chapter 3, which is authored by E. E. Sauma and S. S. Oren, advocates the use of a multistage game model for transmission expansion as a new planning paradigm that incorporates the effects of strategic interaction between generation and transmission investments and the impact of transmission on spot energy prices.
- Chapter 4, which is authored by P. B. Luh, Y. Chen, J. H. Yan, G. A. Stern, W. E. Blankson, and F. Zhao, deals with payment cost minimization with

demand bids and partial capacity cost compensations for day-ahead electricity auctions.

- Chapter 5, which is authored by R. Mookherjee, B. F. Hobbs, T. L. Friesz, and M. A. Rigdon, puts forward a dynamic game theoretic model of oligopolistic competition in spatially distributed electric power markets having a 24-hour planning horizon.
- Chapter 6, which is authored by G. Deltas and C. Hadjicostis, investigates the interaction between system availability/reliability, economic restructuring, and regulating constraints.
- Chapter 7, which is authored by J. A. Momoh, P. Fanara Jr., H. Kurban, and L. J. Iwarere, introduces economic, technical, modeling and performance indices for reliability measures across boundary disciplines.
- Chapter 8, which is authored by L. Mili and K. Dooley, investigates the decision making processes associated with the risk assessment and management of bulk power transmission systems under a unified methodological framework of security and survivability objectives.
- Chapter 9, which is authored by J. McCalley, R. Kumar, V. Ajjarapu, O. Volij, H. Liu, L. Jin, and W. Shang, introduces models for power transmission system enhancement by integrating economic analysis of the transmission cost to accommodate an informed business decision. Finally,
- Chapter 10, which is authored by J. Momoh, elaborates on next generation optimization for electric power systems.

We are grateful to Katherine Drew from ONR for providing financial and moral support of this initiative, Ed Zivi from ONR for providing the benchmarks, colleagues from ONR and NSF for providing a fostering environment to this work to grow and flourish. We thank former NSF Division Directors, Dr. Rajinder Khosla and Dr. Vasu Varadan, who provided seed funding for this initiative. We also thank Dr. Paul Werbos and Dr. Kishen Baheti from NSF for facilitating interdisciplinary discussions on power systems reliability and education. We are thankful to NSF-DUE program directors, Prof. Rogers from the NSF Division of Undergraduate Education and Dr. Bruce Hamilton of NSF BES Division, and.

We acknowledge graduate students from Howard University and Virginia Tech for helping us to put together this book.

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CONTENTS

<i>PREFACE</i>	xi
<i>CONTRIBUTORS</i>	xiii

1	<i>A FRAMEWORK FOR INTERDISCIPLINARY RESEARCH AND EDUCATION</i>	1
----------	--	----------

<i>James Momoh</i>	
1.1	Introduction 1
1.2	Power System Challenges 3
1.2.1	The Power System Modeling and Computational Challenge 4
1.2.2	Modeling and Computational Techniques 5
1.2.3	New Curriculum that Incorporates the Disciplines of Systems Theory, Economic and Environmental Science for the Electric Power Network 5
1.3	Solution of the EPNES Architecture 5
1.3.1	Modular Description of the EPNES Architecture 5
1.3.2	Some Expectations of Studies Using EPNES Benchmark Test Beds 7
1.4	Implementation Strategies for EPNES 8
1.4.1	Performance Measures 8
1.4.2	Definition of Objectives 8
1.4.3	Selected Objective Functions and Pictorial Illustrations 9
1.5	Test Beds for EPNES 13
1.5.1	Power System Model for the Navy 13
1.5.2	Civil Testbed—179-Bus WSCC Benchmark Power System 15
1.6	Examples of Funded Research Work in Response to the EPNES Solicitation 16
1.6.1	Funded Research by Topical Areas/Groups under the EPNES Award 16
1.6.2	EPNES Award Distribution 17
1.7	Future Directions of EPNES 18
1.8	Conclusions 18
Acknowledgments 19	
Bibliography 19	

2	<i>MODELING ELECTRICITY MARKETS: A BRIEF INTRODUCTION</i>	21
----------	--	-----------

<i>Alfredo Garcia, Lamine Mili, and James Momoh</i>	
2.1	Introduction 21
2.2	The Basic Structure of a Market for Electricity 22

2.2.1	Consumer Surplus	23
2.2.2	Congestion Rents	24
2.2.3	Market Power	24
2.2.4	Architecture of Electricity Markets	25
2.3	Modeling Strategic Behavior	26
2.3.1	Brief Literature Review	26
2.3.2	Price-Based Models	27
2.3.3	Quality-Based Models	30
2.4	The Locational Marginal Pricing System of PJM	32
2.4.1	Introduction	32
2.4.2	Congestion Charges and Financial Transmission Rights	33
2.4.3	Example of a 3-Bus System	34
2.5	LMP Calculation Using Adaptive Dynamic Programming	39
2.5.1	Overview of the Static LMP Problem	39
2.5.2	LMP in Stochastic and Dynamic Market with Uncertainty	40
2.6	Conclusions	42
	Bibliography	42

3 ALTERNATIVE ECONOMIC CRITERIA AND PROACTIVE PLANNING FOR TRANSMISSION INVESTMENT IN DEREGULATED POWER SYSTEMS

45

Enzo E. Sauma and Shmuel S. Oren

3.1	Introduction	46
3.2	Conflict Optimization Objectives for Network Expansions	49
3.2.1	A Radial-Network Example	49
3.2.2	Sensitivity Analysis in the Radial-Network Example	56
3.3	Policy Implications	57
3.4	Proactive Transmission Planning	57
3.4.1	Model Assumptions	58
3.4.2	Model Notation	60
3.4.3	Model Formulation	61
3.4.4	Transmission Investment Models Comparison	62
3.5	Illustrative Example	64
3.6	Conclusions and Future Work	67
	Bibliography	68
	Appendix	68

4 PAYMENT COST MINIMIZATION WITH DEMAND BIDS AND PARTIAL CAPACITY COST COMPENSATIONS FOR DAY-AHEAD ELECTRICITY AUCTIONS

71

*Peter B. Luh, Ying Chen, Joseph H. Yan, Gary A. Stern, William E. Blankson,
and Feng Zhao*

4.1	Introduction	72
4.2	Literature Review	73
4.3	Problem Formulation	73
4.4	Solution Methodology	75
4.4.1	Augmented Lagrangian	76
4.4.2	Formulating and Solving Unit Subproblems	76
4.4.3	Formulating and Solving Bid Subproblems	79

4.4.4	Solve the Dual Problem	80
4.4.5	Generating Feasible Solutions	80
4.4.6	Initialization and Stopping Criteria	81
4.5	Results and Insights	81
4.6	Conclusion	84
	Acknowledgment	84
	Bibliography	84

5	<i>DYNAMIC OLIGOPOLISTIC COMPETITION IN AN ELECTRIC POWER NETWORK AND IMPACTS OF INFRASTRUCTURE DISRUPTIONS</i>	87
----------	--	-----------

Reetabrata Mookherjee, Benjamin F. Hobbs, Terry L. Friesz, and Matthew A. Rigdon

5.1	Introduction and Motivation	87
5.2	Summary and Modeling Approach	89
5.3	Model Description	90
5.3.1	Notation	90
5.3.2	Generating Firm's Extremal Problem	92
5.3.3	ISO's Problem	94
5.4	Formulation of NCP	95
5.4.1	Complementary Conditions for Generating Firms	95
5.4.2	Complementary Conditions for the ISO	97
5.4.3	The Complete NCP Formulation	98
5.5	Numerical Example	98
5.6	Conclusions and Future Work	108
	Acknowledgment	108
	Appendix: Glossary of Relevant Terms from Electricity Economics	108
	Bibliography	110

6	<i>PLANT RELIABILITY IN MONOPOLIES AND DUOPOLIES: A COMPARISON OF MARKET OUTCOMES WITH SOCIALLY OPTIMAL LEVELS</i>	113
----------	---	------------

George Deltas and Christoforos Hadjicostis

6.1	Introduction	114
6.2	Modeling Framework	116
6.3	Profit Maximizing Outcome of a Monopolistic Generator	118
6.4	Nash Equilibrium in a Duopolistic Market Structure	120
6.5	Social Optimum	122
6.6	Comparison of Equilibria and Discussion	123
6.7	Asymmetric Maintenance Policies	125
6.8	Conclusion	127
	Acknowledgment	128
	Bibliography	128

7	<i>BUILDING AN EFFICIENT RELIABLE AND SUSTAINABLE POWER SYSTEM: AN INTERDISCIPLINARY APPROACH</i>	131
----------	--	------------

James Momoh, Philip Fanara, Jr., Haydar Kurban, and L. Jide Iwarere

7.1	Introduction	131
7.1.1	Shortcoming in Current Power Systems	132
7.1.2	Our Proposed Solutions to the Above Shortcomings	132

7.2	Overview of Concepts	133
7.2.1	Reliability	133
7.2.2	Bulk Power System Reliability Requirements	134
7.2.3	Public Perception	135
7.2.4	Power System / New Technology	135
7.3	Theoretical Foundations: Theoretical Support for Handling Contingencies	140
7.3.1	Contingency Issues	140
7.3.2	Foundation of Public Perception	141
7.3.3	Available Transmission Capability (ATC)	142
7.3.4	Reliability Measures/Indices	143
7.3.5	Expected Socially Unserved Energy (ESUE) and Load Loss	145
7.3.6	System Performance Index	147
7.3.7	Computation of Weighted Probability Index (WPI)	148
7.4	Design Methodologies	149
7.5	Implementation Approach	150
7.5.1	Load Flow Analysis with FACTS Devices (TCSC) for WSCC System	150
7.5.2	Performance Evaluation Studies on IEEE 30-Bus and WSCC Systems	151
7.6	Implementation Results	151
7.6.1	Load Flow Analysis with FACTS Devices (TCSC) for WSCC System	151
7.6.2	Performance Evaluation Studies on IEEE 30-Bus System	153
7.6.3	Performance Evaluation Studies on the WSCC System	155
7.7	Conclusion	157
	Acknowledgments	158
	Bibliography	158

8 RISK-BASED POWER SYSTEM PLANNING INTEGRATING SOCIAL AND ECONOMIC DIRECT AND INDIRECT COSTS

161

Lamine Mili and Kevin Dooley

8.1	Introduction	162
8.2	The Partitioned Multiobjective Risk Method	164
8.3	Partitioned Multiobjective Risk Method Applied to Power System Planning	166
8.4	Integrating the Social and Economic Impacts in Power System Planning	169
8.5	Energy Crises and Public Crises	170
8.5.1	Describing the Methodology for Economic and Social Cost Assessment	170
8.5.2	The CRA Method	172
8.5.3	Data Analysis of the California Crises and of the 2003 U.S. Blackout	173
8.6	Conclusions and Future Work	176
	Bibliography	177

9 MODELS FOR TRANSMISSION EXPANSION PLANNING BASED ON RECONFIGURABLE CAPACITOR SWITCHING

181

James McCalley, Ratnesh Kumar, Venkataramana Ajjarapu, Oscar Volij, Haifeng Liu, Licheng Jin, and Wenzhuo Shang

9.1	Introduction	181
-----	--------------	-----

9.2	Planning Processes	184
9.2.1	Engineering Analyses and Cost Responsibilities	185
9.2.2	Cost Recovery for Transmission Owners	187
9.2.3	Economically Motivated Expansion	188
9.2.4	Further Reading	189
9.3	Transmission Limits	189
9.4	Decision Support Models	191
9.4.1	Optimization Formulation	192
9.4.2	Planning Transmission Circuits	195
9.4.3	Planning Transmission Control	199
9.4.4	Dynamic Analysis	213
9.5	Market Efficiency and Transmission Investment	219
9.6	Summary	232
	Acknowledgments	232
	Bibliography	232

10 NEXT GENERATION OPTIMIZATION FOR ELECTRIC POWER SYSTEMS 237

James Momoh

10.1	Introduction	237
10.2	Structure of the Next Generation Optimization	239
10.2.1	Overview of Modules	239
10.2.2	Organization	241
10.3	Foundations of the Next Generation Optimization	242
10.3.1	Overview	242
10.3.2	Decision Analysis Tools	243
10.3.3	Selected Methods in Classical Optimization	248
10.3.4	Optimal Control	250
10.3.5	Dynamic Programming (DP)	252
10.3.6	Adaptive Dynamic Programming (ADP)	253
10.3.7	Variants of Adaptive Dynamic Programming	255
10.3.8	Comparison of ADP Variants	258
10.4	Application of Next Generation Optimization to Power Systems	260
10.4.1	Overview	260
10.4.2	Framework for Implementation of DSOPF	261
10.4.3	Applications of DSOPF to Power Systems Problems	262
10.5	Grant Challenges in Next Generation Optimization and Research Needs	272
10.6	Concluding Remarks and Benchmark Problems	273
	Acknowledgments	273
	Bibliography	274

INDEX

277

A FRAMEWORK FOR INTERDISCIPLINARY RESEARCH AND EDUCATION

James Momoh

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1.1 INTRODUCTION

Electric Power Networks Efficiency and Security (EPNES) deals with fundamental issues of understanding the security, efficiency and behavior of large electric power systems, including utility and United States Navy power system topologies, under varying disruptive or catastrophic events. A robust power system is to be measured in terms of various attributes such as survivability, security, efficiency, sustainability, and affordability.

There is an urgent need for the development of innovative methods and conceptual frameworks for analysis, planning, and operation of complex, efficient, and secure electric power networks. If this need is to be met and sustained in the long run, appropriate educational resources must be developed and available to teach those who will design, develop, and operate those networks. Hence, educational pedagogy and curricula improvement must be a natural part of this endeavor. The next generation of high-performance dynamic and adaptive nonlinear networks, of which power systems are an application, will be designed and upgraded with the interdisciplinary knowledge required to achieve improved survivability, security, reliability, reconfigurability and efficiency.

Additionally, in order to increase interest in power engineering education and to address workforce issues in the deregulated power industry, it is necessary to develop an interdisciplinary research-based curriculum that prepares engineers, economists, and scientists to plan and operate power networks. To accomplish this goal, it must be recognized that these networks are socio-technical systems, meaning that successful functioning depends as much on social factors as on technical characteristics. Robust power networks are a critical component of larger efforts to achieve sustainable economic growth on a global scale.

The continued security of electric power networks can be compromised not only by technical breakdowns, but also by deliberate sabotage, misguided economic incentives, regulatory difficulties, the shortage of energy production and transmission facilities, and the lack of appropriately trained engineers, scientists and operations personnel.

Addressing these issues requires an interdisciplinary approach that brings together researchers from engineering, environmental and social-economic sciences. NSF anticipates that the research activities funded by this program will increase the likelihood that electric power will be available throughout the United States at all times, at reasonable prices, and with minimal deleterious environmental impacts. It is hoped that a convergence of socio-economic principles with new system theories and computational methods for systems analysis will lead to development of a more efficient, robust, and secure distributed network system. Figure 1.1 depicts the unification of knowledge through research and education.

Research is needed to develop the power system automation technology that meets all of the technical, economic and environmental constraints. Research in the individual disciplines has been performed without the unification of the overall research theme across boundaries. This may be due to lack of unifying educational pedagogy and collaborative problem solving among domain experts, both of which could provide deeper understating of power systems under different conditions.

In order to overcome the existing barriers between intellectual disciplines relevant to development of efficient and secure power networks, innovative and integrated curricula and pedagogy must be developed that incorporates advanced systems theory, economics, environmental science, policy and technical issues. These new curriculum will motivate both students and faculty to think in a multi-disciplinary manner, in order to better prepare the workforce for the power industry of the future. The EPNES solicitation therefore embraces a multidisciplinary approach in both proposed research and education activities. Some potential cross

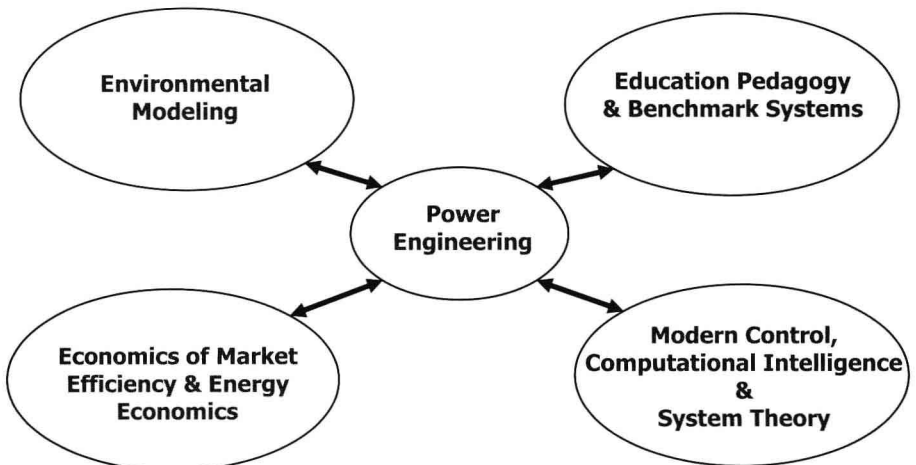


Figure 1.1. Unification of knowledge through research and education.

cutting courses are Financial Engineering, Power Market and Cost Benefit Analysis and Power Environment, Advances System Theory and Computational Intelligence, Power Economics, and Computational Tools for Deregulated Power Industry.

We recommend that all multidisciplinary courses use canonical benchmark systems for verification/validation of developed theories and tools. When possible, the courses should be co-taught by professors across disciplines. To promote broader dissemination of knowledge and understanding, courses should be developed for both undergraduate and graduate students. These courses should also be made available through workshops and lectures, electronically, and should be posted on the host institution website. Furthermore, an assessment strategy should be developed and applied on an ongoing basis to ensure sustainability of the program and its impact on attracting students and improving workforce competencies in promoting or developing an efficient and reliable power systems enterprise.

1.2 POWER SYSTEM CHALLENGES

The EPNES initiative is designed to engender major advances in the integration of new concepts in control, modeling, component technology, and social and economic theories for electrical power networks' efficiency and security. It challenges educators and scientists to develop new interdisciplinary research-based curricula and pedagogy that will motivate students' learning and increase their retention across affected disciplines. As such, interdisciplinary research teams of engineers, scientists, social scientists, economists, and environmental experts are required to collaborate on the grand challenges. These challenges include but are not limited to the following categories.

A. *Systems and Security*

- **Advanced Systems Theory:** Advanced theories and computer-aided modeling tools to support and validate complex modeling and simulation, advanced adaptive control theory, and intelligent-distributed learning agents with relevant controls for optimal handling of systems complexity and uncertainty.
- **Robust Systems Architectures and Configurations:** Advanced analytical methods and tools for optimizing and testing configurations of functional elements/architectures to include control of power electronics and systems components, complexity analysis, time-domain simulation, dynamic priority load shedding for survivability, and gaming strategies under uncertainties.
- **Security and High-Confidence Systems Architecture:** New techniques and innovative tools for fault-tolerant and self-healing networks, situational awareness, smart sensors, and analysis of structural changes. Applications include adaptive control algorithms, systems and component security, and damage control systems for continuity of service during major disruptions.

B. *Economics, Efficiency and Behavior*

- **Regulatory Constraints and Incentives:** New research ideas that explore the influence of regulations on the economics of electric networks.