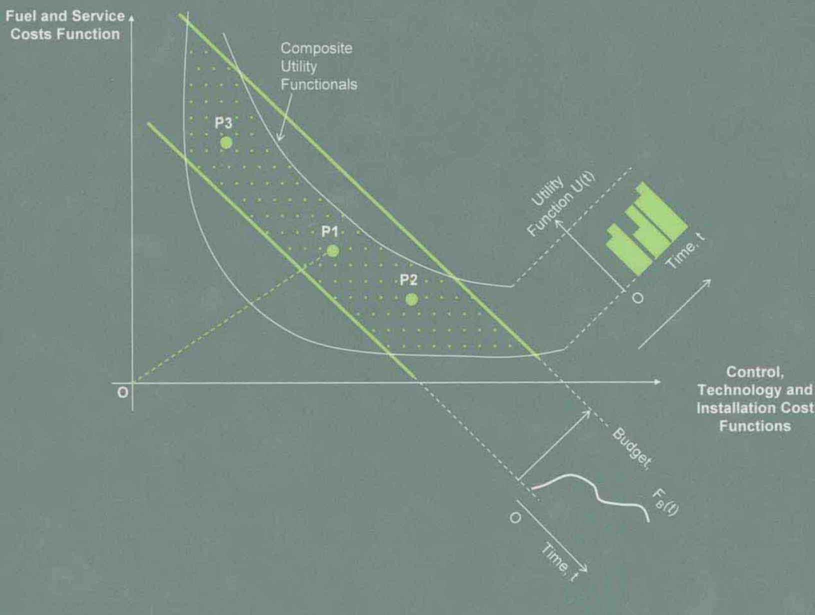
Economic Market Design and Planning *for* Electric Power Systems



JAMES MOMOH • LAMINE MILI

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IEEE PRESS SERIES ON POWER ENGINEERING
Mohamed E. El-Hawary, *Series Editor*

ECONOMIC MARKET DESIGN AND PLANNING FOR ELECTRIC POWER SYSTEMS

Edited by

JAMES MOMOH
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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.

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CONTENTS

CHAPTER 1

A FRAMEWORK FOR INTERDISCIPLINARY RESEARCH AND EDUCATION

James Momoh
Howard University

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.

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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 multidisciplinary 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

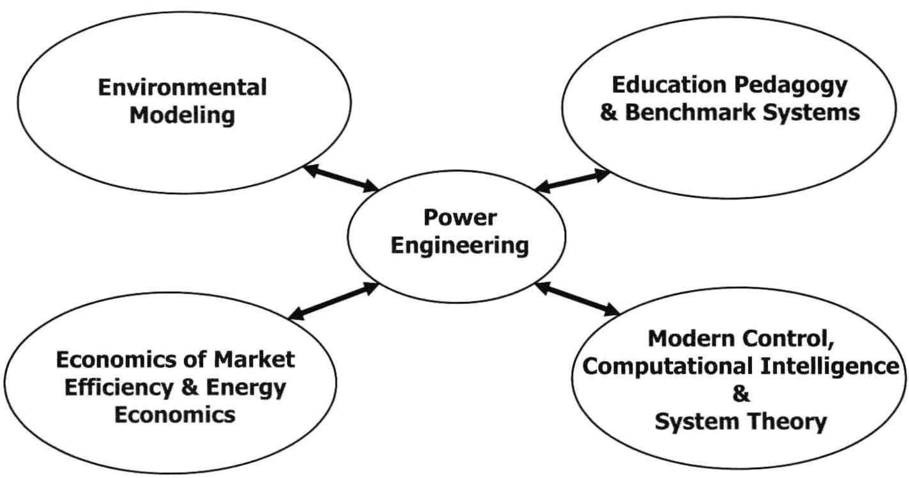

Figure 1.1. Unification of knowledge through research and education.

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.