2.4.3 Future contracts and futures markets 36
2.4.4 Options 37
2.4.5 Contracts for difference 38
2.4.6 Managing the price risks 39
2.4.7 Market efficiency 39
2.5 Markets with Imperfect Competition 39
2.5.1 Market power 39
2.5.2 Models of imperfect markets 40
2.5.3 Monopoly 43
2.6 Further Reading 44
2.7 Problems 45

3 MARKETS FOR ELECTRICAL ENERGY 49
3.1 Introduction 49
3.2 What is the Difference Between a Megawatt-Hour and a Barrel of Oil? 49
3.3 The Need for a Managed Spot Market 51
3.4 Open Electrical Energy Markets 52
  3.4.1 Bilateral trading 52
  3.4.2 Electricity pools 55
  3.4.3 Comparison of pool and bilateral trading 58
3.5 The Managed Spot Market 59
  3.5.1 Obtaining balancing resources 60
  3.5.2 Gate closure 61
  3.5.3 Operation of the managed spot market 61
  3.5.4 Interactions between the managed spot market and the other markets 63
3.6 The Settlement Process 64
3.7 Further Reading 66
3.8 Problems 67

4 PARTICIPATING IN MARKETS FOR ELECTRICAL ENERGY 73
4.1 Introduction 73
4.2 The Consumer’s Perspective 73
  4.2.1 Retailers of electrical energy 75
4.3 The Producer’s Perspective 79
  4.3.1 Perfect competition 80
  4.3.2 The production versus purchase decision 88
  4.3.3 Imperfect competition 90
4.4 Perspective of Plants with Very Low Marginal Costs 99
4.5 The Hybrid Participant’s Perspective 99
4.6 Further Reading 101
4.7 Problems 102
5 SYSTEM SECURITY AND ANCILLARY SERVICES

5.1 Introduction 105
5.2 Describing the Needs
   5.2.1 Balancing issues 107
   5.2.2 Network issues 111
   5.2.3 System restoration 117
5.3 Obtaining Ancillary Services
   5.3.1 Compulsory provision of ancillary services 117
   5.3.2 Market for ancillary services 119
   5.3.3 Demand-side provision of ancillary services 119
5.4 Buying Ancillary Services
   5.4.1 Quantifying the needs 120
   5.4.2 Co-optimization of energy and reserve in a centralized electricity market 121
   5.4.3 Allocating the costs 129
5.5 Selling Ancillary Services 130
5.6 Further Reading 136
5.7 Problems 137

6 TRANSMISSION NETWORKS AND ELECTRICITY MARKETS

6.1 Introduction 141
6.2 Decentralized Trading Over a Transmission Network
   6.2.1 Physical transmission rights 141
   6.2.2 Problems with physical transmission rights 143
6.3 Centralized Trading Over a Transmission Network
   6.3.1 Centralized trading in a two-bus system 148
   6.3.2 Centralized trading in a three-bus system 155
   6.3.3 Losses in transmission networks 175
   6.3.4 Mathematical formulation of nodal pricing 181
   6.3.5 Managing transmission risks in a centralized trading system 190
6.4 Further Reading 199
6.5 Problems 200

7 INVESTING IN GENERATION

7.1 Introduction 205
7.2 Generation Capacity from an Investor’s Perspective
   7.2.1 Building new generation capacity 205
   7.2.2 Retiring generation capacity 212
   7.2.3 Effect of a cyclical demand 213
7.3 Generation Capacity from the Customers’ Perspective
   7.3.1 Expansion driven by the market for electrical energy 217
## 8 INVESTING IN TRANSMISSION

8.1 Introduction
8.2 The Nature of the Transmission Business
8.3 Cost-based Transmission Expansion
8.3.1 Setting the level of investment in transmission capacity
8.3.2 Allocating the cost of transmission
8.4 Value-based Transmission Expansion
8.4.1 Quantifying the value of transmission
8.4.2 The transmission demand function
8.4.3 The transmission supply function
8.4.4 Optimal transmission capacity
8.4.5 Balancing the cost of constraints and the cost of investments
8.4.6 Effect of load fluctuations
8.4.7 Revenue recovery for suboptimal transmission capacity
8.4.8 Effect of economies of scale
8.4.9 A three-bus example
8.4.10 Concept of reference network
8.4.11 Generalization
8.5 Further Reading
8.6 Problems

APPENDIX – ANSWERS TO SELECTED PROBLEMS

ABBREVIATIONS AND ACRONYMS

INDEX