CONTENTS

Preface to the Second Edition

Acknowledgments

CHAPTER 1  Benefits of Electric Power and a History of the Electric Power Industry

1.1 Societal Benefits of Electricity 1
1.2 Origin of the Industry 2
1.3 The Development of the National Electric Power Grid 5
1.4 “The Golden Age” 8
   Blackouts and the Reliability Crisis 9
   The Environmental Crises—The Shift to Low-Sulfur Oil 10
   The Fuel Crisis—The Shift from Oil 10
   The Financial Crisis 11
   The Legislative and Regulatory Crisis 12
1.5 Global Warming Crisis and Concerns about Carbon Emissions 13
1.6 Restructuring, Competition, and the Industry Ownership Structure 13

CHAPTER 2  The Electric Power System

2.1 The Customers 16
2.2 Sources of the Electric Energy—Generation 17
2.3 The Delivery System 20
   Interconnections 24
   The Grid 24
Steam Cycle—Steam Turbines 69
Combustion (Gas) Turbines 70
Combined Cycle 71
Nuclear 72
Reciprocating Engines 73
Microturbines 74
Combined Heat and Power (CHP) or Cogeneration 74

5.4 Thermal Conversion: Nonfuel Heat Sources 74
   Geothermal 74
   Solar Thermal Generation 75

5.5 Mechanical Energy Conversion 75
   Hydroturbines and Hydropumped Storage 75
   Wind Turbines 77
   Distributed Generation and Other Sources 78

5.6 Renewable Technologies and Greenhouse Gas Emissions 79
   Supply-Side Options to Reduce Greenhouse Gas Emissions 79
   Financial Options to Reduce Carbon Emissions 83

5.7 Characteristics of Generating Plants 84
   Size 85
   Efficiency 87
   Availability 88
   Schedulable and Unschedulable Units 90

5.8 Capital Cost of Generation 90
5.9 Generator Life Extension 91
5.10 The Technology of Generation 91
    Synchronous Generators 91
    Variable Frequency and Direct Current Generation 92

5.11 System Needs and Evaluation of Intermittent Resources 93

CHAPTER 6 The Technology of the Electric Transmission System 97
6.1 Components 97
6.2 HVAC 98
    Overhead Lines 98
    Overhead Line Capability—Ratings 99
    Transmission Cable 101
    Cable Capacity 101
    Submarine Cables 102
    Superconducting Cables 102
6.3 Substations 102
    Substation Equipment 103
CHAPTER 7 Distribution

7.1 Function of Distribution 115
7.2 Primary Distribution Feeders 116
   Radial Systems 116
   Loop Systems 117
   Primary Network Systems 117
   Secondary Systems 117
7.3 Distribution Capacity 118
7.4 Losses 119
7.5 Distribution Facility Ratings 119
7.6 Metering 120
7.7 Control of Distribution Voltages 120
   Distribution Transformers 121
   Voltage Regulators 122
   Capacitors 123
7.8 Distribution System Reliability 123
7.10 Quality of Service 124
7.11 Design of Distribution Systems 125
7.12 Distributed Generation 125
7.13 Operation of Distribution Systems 126
7.14 Smart Grids and Microgrids 127

CHAPTER 8 Energy Storage and Other New Technologies 129

8.1 Energy Storage 131
   Benefits of Energy Storage to Generation 131
   Benefits of Energy Storage to Transmission and Distribution 132
8.2 Energy Storage Concepts and Technologies 133
   Mechanical Systems 133
   Thermal Energy Storage 136
   Chemical Energy Storage 138
   Batteries 138
   Hydrogen Energy Storage Systems 139
   Electrical Storage 140
   Superconducting Magnetic Energy Storage 141
   Power Conversion Equipment 141
8.3 Smart Grid 142
    Microgrids 146
8.4 New Nuclear Plant Designs 146
8.5 Carbon Sequestration and Clean Coal Technologies 150
8.6 Superconductors 153

CHAPTER 9 Reliability 155
9.1 Causes of Outages 155
9.2 Costs of Power Outages 157
9.3 Ways to Measure Reliability 158
9.4 Planning and Operating a Reliable and Adequate Power System
    Generation 164
    Transmission 165
    Distribution 166
9.5 Summary 166

CHAPTER 10 The Physical Network: The North American Electric Reliability Corporation (NERC) and Its Standards 167
10.1 NERC as Electric Reliability Organization 169
10.2 NERC Standards 171
    Functional Model 171
10.3 Development of Standards 176
    Reliability Principles 177
    Market Interface Principles 177
    Compliance with NERC Standards 179
    Other NERC Responsibilities 179
The Future 180

CHAPTER 11 The Physical Network: Operation of the Electric Bulk Power 181
11.1 Balancing Authorities 181
    Area Control 182
    Operating Reserves 184
11.2 Reliability Coordinators 184
11.3 Transmission Operators 186
    Power Transfer Limits 186
    Determination of Total Transfer Capability 187
    Parallel Path Flow and Loop Flow 188
    Reduction of Power Transfers—Congestion Management 189
    Ancillary Services 189
11.4 Voltage and Reactive Control 191
11.5 Emergencies 192
   Operating Emergencies 193
11.6 Information Exchange 194

CHAPTER 12  The Physical Network: Planning of the Electric Bulk Power System
12.1 Planning Standards 198
12.2 Generation Planning 198
12.3 Transmission Planning 200
   Transmission System Planning Studies 203
12.4 Least Cost Planning 205
12.5 The New Planning Environment 205
   Recent Transmission Projects 211

CHAPTER 13  The Regulatory Network: Legislation
13.1 Pricing and Regulation 213
13.2 Federal Legislation 214
13.3 Federal Utility Holding Company Act (PUHCA) 214
13.4 Federal Power Act 216
13.5 Other 1930 Federal Laws 219
13.6 Department of Energy Organization Act 219
13.7 Public Utility Regulatory Policies Act (PURPA) 220
13.9 The Energy Policy Act of 2005 (EPAAct05) 224
13.10 The Energy Independence and Security Act of 2007 227
13.11 Environmental Laws 227

CHAPTER 14  The Regulatory Network: The Regulators
14.1 The Regulators 231
   Federal Energy Regulatory Commission (FERC) 231
   Environmental Protection Agency (EPA) 233
   Department of Energy (DOE) 234
   Nuclear Regulatory Commission (NRC) 236
   Recent Federal Regulations 237
   FERC Actions after EPAAct92 237
   FERC Actions Implementing EPAAct05 242
   Market Manipulation 242
   Electricity Reliability and Infrastructure 242
   Expansion and Modernization of the Nation’s Electricity Grid 245
   Siting Major New Transmission Facilities 245
PURPA Reforms 246
Repeal of PUHCA—Mergers and Acquisitions 246
Market-Based Rates 247
Recent EPA Actions 248
State Regulatory Authority 249
State Utility Restructuring 250
Overall Regulatory Problems 251

CHAPTER 15  The Information, Communication, and Control Network and Security 253
15.1 Smart Grid 253
15.2 Financial and Business Operations 254
15.3 System Operations 255
15.4 Distribution Operations 255
15.5 Cyber Security 256
15.6 Nuclear Plant Security 259

CHAPTER 16  The Fuel and Energy Network 261
16.1 Resource Procurement 264
   Fuel Measurements 265
16.2 Fuel Transportation 265
16.3 Fuel Diversity 266
16.4 Fossil Fuels Used 267
16.5 Renewable Energy 269
16.6 Fuel Purchasing 271
16.7 Emission Rights 271

CHAPTER 17  The Business Network: Market Participants 273
17.1 Investment and Cost Recovery 273
17.2 The Changing Industry Structure 274
   Functional Unbundling 274
   Additional Utility Responses 275
   ISO/RTO Formation 275
   Holding Company Formation 275
   Power Plant Divestitures 277
17.3 New Structures 279
   Power Producers 279
   Independent Transmission Companies and Operators 279
   Impact of Restructuring on the Transmission System 280
   Distributors 280
   Power Marketers 281
17.4 New Corporate Ownership 281
CHAPTER 18  The Money Network: Wholesale Markets  285
18.1 The Energy Markets  286
   Standard Market Design (SMD)  288
   Locational Marginal Pricing (LMP)  289
18.2 Transmission  291
   Transmission Rights  291
   Physical Transmission Rights (PTRs)  292
   Financial Transmission Rights (FTRs)  293
   Wheeling and Customer Choice  294
   Contracts and Agreements  294
   Average System versus Incremental Costs  295
18.3 Customer Late Issues  294
   Construction Work in Progress (CWIP)  295
   Setting of Rates  296
   Rate Freezes  296
   Allocation of Costs and Economic Benefits  296
   Average Costs versus Incremental Costs  297
18.4 Market versus Operational Control  298
18.5 Market Power Issues  298
   Price Caps  299
18.6 The Future  299

CHAPTER 19  The Professional and Industry Organizations  301
19.1 The Professional Organizations  301
   The Institute of Electrical and Electronics
   Engineers (IEEE)  301
   The American Society of Civil Engineers
   (ASCE)  303
   American Society of Mechanical Engineers
   (ASME) and the American Institute of
   Chemical Engineers (AIChE)  304
   CIGRE  304
19.2 Industry Associations  304
   NEMA  304
   The Association of Edison Illuminating
   Companies (AEIC)  305
   The American Public Power Association
   (APPA)  305
   The Edison Electric Institute (EEI)  306
The Electricity Consumer Resource Council (ELCON) 306
The National Rural Electric Cooperative Association (NRECA) 307
Electric Power Supply Association (EPSA) 307
The Nuclear Energy Institute (NEI) 308

19.3 Public Interest Groups 308
The National Association of Regulatory Utility Commissioners (NARUC) 308
Environmental Defense Fund (EDF) 308
Public Citizen 309
Public Interest Law Project 309

19.4 Research Organizations 309
The Electric Power Research Institute (EPRI) 310
Other Research 310
The National Regulatory Research Institute (NRRI) 311
The Power Systems Engineering Research Center (PSERC) 311

Index 313