ELECTRIC POWER GENERATION

IEEE Press
445 Hoes Lane
Piscataway, NJ 08855

ELECTRIC POWER GENERATION
The Changing Dimensions

Digambar M. Tagare

IEEE PRESS SERIES ON POWER ENGINEERING

IEEE PRESS

WILEY

A JOHN WILEY & SONS, INC., PUBLICATION

Library of Congress Cataloging-in-Publication Data:

Tagare, D. M.
Electricity power generation : the changing dimensions / Digambar M. Tagare.
p. cm.
Summary: “This book offers an analytical overview of established electric generation processes, along with the present status & improvements for meeting the strains of reconstruction. These old methods are hydro-electric, thermal & nuclear power production. The book covers climatic constraints; their affects and how they are shaping thermal production. The book also covers the main renewable energy sources, wind and PV cells and the hybrids arising out of these. It covers distributed generation which already has a large presence is now being joined by wind & PV energies. It covers their accommodation in the present system. It introduces energy stores for electricity; when they burst upon the scene in full strength are expected to revolutionize electricity production. In all the subjects covered, there are references to power marketing & how it is shaping production. There will also be a reference chapter on how the power market works”—Provided by publisher.
ISBN 978-0-470-60028-3 (hardback)
1. Electric power production. I. Title.
TK1001.T33 2010
621.31—dc22 2010022385

Printed in Singapore.

oBook ISBN: 978-0-470-87265-9
ePDF ISBN: 978-0-470-87266-6

10 9 8 7 6 5 4 3 2 1

CONTENTS

Foreword **xxi**

Preface **xxv**

1. Electricity History—A Review of the Road Ahead **1**

1.1 History of Growth of the Electricity Business 1

1.1.1 Societal and Organizational Changes 1

1.2 Innovative Technology Developments and Growth of Conglomerates 2

1.3 Economic Growth—GDP and Electricity Consumption 3

1.2.1 Factors Leading to Further Growth of Conglomerates 2

1.4 Monopolies Develop Built-In Defects 4

1.5 Breakup of Bell Systems Leads to Unbundling 5

1.5.1 New Technologies Open Competition to Small-Scale Capital 6

1.5.2 Oil Cartels Deliver a Blow 6

1.5.3 Environmental Concerns Raise Costs 7

1.6 Importance of Renewable Energy Recognized—Wind Energy Becomes a Challenger 7

1.6.1 A System Changeover is Necessary 8

1.7 Structural Changes 8

1.7.1 Working of the Old Model 8

1.8 Cost Breakdown in the Old Model 10

1.9 Step-by-Step Restructuring 11

1.9.1 Generation 11

1.9.2 Distribution 11

1.9.3 Evolution of the Free Market 11

1.9.4 Transmission 12

1.10 The New Decision Authorities 12

1.11 Open Power Marketing Now Rerestructuring Electricity Power System 13

References 13

2. Risks, Operation, and Maintenance of Hydroelectric Generators 15
2.1 The Present Scenario 15
2.2 Types and Sizes of Hydroelectricity Projects 15
2.3 Advantages of Hydroelectricity 18
2.4 Slow progress of Hydroelectricity Projects 19
2.4.1 Land Acquisition, Evacuees, and Resettlement 19
2.4.2 Archeological Problems 20
2.4.3 Environmental Problems 20
2.4.4 Added Features of Hydroelectric Projects 20
2.5 Factors Propelling the Phased Progress of the Hydroelectric Industry 21
2.5.1 Phase 1 (1900–1920)—Technocentric Phase 21
2.5.2 Phase 2 (1920–1980)—Capital-Directed Phase 21
2.5.3 Phase 3 (1980 Onward)—Sociotechnical Phase, Infrastructure Nature 22
2.6 Hydro Projects Fall Short of Attracting Private Investment 22
2.7 Dam Building Progress Over a Century 22
2.7.1 Principal Risks Associated with Development of Hydro Projects 22
2.7.2 India Has a High Proportion of Hydroelectricity 24
2.8 Desirable Configuration for Hydro Projects to Attract Private Investment 24
2.8.1 Challenges 25
2.9 Operation of a Hydroelectric Plant 25
2.9.1 Typical Layout 25
2.9.2 Capability Curve for a Hydrogenerator 26
2.9.3 Efficiency of a Hydro Unit 26
2.10 Unit Allocation within a Large HE Plant 28
2.11 Speed Control of a Water Turbine 28
2.11.1 Governor for Water Turbine Generators (WTGs) 28
2.12 Startup Process for a WTG 29
2.13 Speed Controls are Rigid 30
2.14 Speed Increase Due to Sudden Load Cutoff 30
2.15 Frequency and Harmonic Behavior After a Sudden Load Rejection 30
2.15.1 Voltage Behavior After a Load Cutoff 33
2.16 Effect of Penstock Pressure Pulsations 33
2.17 AC Excitation of Rotor Field 33
2.18 Unit Commitment from Hydroelectric Generators, Including Pumped Storage Systems 34
2.19 ICMMS of Hydroelectric Generating Units 34
2.20 Controls and Communications in hydro Systems 35
2.21 General Maintenance 35
2.22 Limitations of Scheduled and Breakdown Maintenance 36
2.23 Reactive Maintenance—Key Elements 36
2.24 Key Components of an ICMMS—Case of a Hydroelectric System 37

2.25 Intelligent Electrohydraulic Servomechanism 37
2.26 Online Monitoring and Forecasting 38
2.26.1 Partial Discharges (PDs) in the Stator Coils of Alternators 38
2.26.2 Air Gap Monitoring of Vertical Hydraulic Generators 39
2.27 Subsynchronous Resonance (SSR) and Twisting of Rotor Shafts 39
References 40

3. Hydroelectric Generation—Pumped Storage, Minor Hydroelectric, and Oceanic-Based Systems 45
3.1 Water as an Energy Supplier and an Energy Store 45
3.2 Pumped Water Storage System for Electricity Generation 46
3.3 Operation of a Pumped Storage System 46
3.4 Pumped Storage Systems Have Limited Scope 47
3.5 Pumped Storage Systems and Wind Energy 48
3.6 Small Hydroelectric Plants (SHPs) 49
3.7 Types of SHP Projects—Sizes 49
3.8 Location-Wise Designations of SHPs 50
3.9 Components of an SHP 50
3.10 Typical Layouts Of SHPs 51
3.10.1 The Generator 51
3.10.2 Dam-Based SHPs 54
3.10.3 Canal-Based SHPs 54
3.11 Project Costs of an SHP 54
3.12 Drawing Electricity from the Ocean 55
3.12.1 Nature of Energy Available from the Oceans 55
3.12.2 Le Rance Tidal Power Plant 56
3.13 Underwater Turbine and Column-Mounted Generator 57
3.14 Wave Energy 58
Appendix 3-1 World's Largest Hydro-Electric Projects 60
Itaipu Hydro Project 60
Signs of the Times in Brazilian Electricity 60
Appendix 3-2 Remote Control of the Hydroelectric System at Guri 61
Remote Terminal Units (RTUs) 65
Operation of Generator RTU 65
Common Services RTUs 66
Switchyard RTUs 66
Automatic Generation Control (AGC) and Automatic Voltage Control (AVC) 66
Working of the Guri Control System 66
References 67

4. Thermal Power Generation—Steam Generators 69
4.1 Thermal Electricity Generation Has the Largest Share—The Present Scenario 69
4.2 Planning of Thermal Stations—Risks and Challenges 70

4.2.1 Project Risks 70
4.2.2 Fuels for Thermal Generation 71
4.3 Cost Breakdown and Consumption Pattern of Electricity 71
4.4 Main Energy Suppliers 71
4.4.1 Coal 71
4.4.2 Natural Gas 73
4.4.3 Mineral Oils 74
4.4.4 Nuclear Power 74
4.5 Workings of a Coal-Fired Steam Generator Unit 74
4.5.1 Coal Flow 74
4.6 Types of Boilers 76
4.6.1 A Modern 100 MW Boiler 77
4.6.2 Vertical Water-Wall Furnace with Rifled Tubes 78
4.6.3 Integrated Coal Gasification Combined Cycle Furnace 78
4.7 Classification of Generating Units 78
4.7.1 Base-Load Generators 78
4.7.2 Peak-Load Generators 79
4.7.3 Intermediate-Load Generators 79
4.8 Combined-Cycle Power Plant (CCPP) 79
4.8.1 A Denitrifying Arrangement 80
4.8.2 Typical Rating Ratios Between Gas and Steam Portions 81
4.8.3 Advances in Synchronous Generators 81
References 83

5. Thermal Station Power Engineering 87
5.1 Start-Up Process of a CCPP 87
5.2 Short-Term Dynamic Response of a CCPP to Frequency Variation 88
5.3 Cascade Tripping of a CCPP Due to Frequency Excursion 88
5.4 Operation Planning to Meet Load Demands—Flow Diagram 89
5.5 Capacity Curves for Thermal Electricity Generation 90
5.6 Operational Economy Includes Fuel Considerations 92
5.6.1 Costs 92
5.6.2 Reliability of Supply 92
5.6.3 Emission Caps Considerations 92
5.7 Efficiency in Operating Practices 92
5.8 Ancillary Services Compulsorily 93
5.8.1 Reactive Power Supply 93
5.8.2 Load Following 94
5.8.3 Loss Compensation 94
5.8.4 Energy Imbalance 94
5.8.5 Scheduling and Dispatch Services 94
5.9 Changing Performance Requirements for Thermal Plant Operators 94

5.10 Expanding Grids Demand Tight Frequency Tolerances 95
5.11 Reserves are Important in Frequency Control 95
5.12 Reserves Based on Droop Characteristic 96
5.13 Primary Frequency Control 96
5.14 Secondary Frequency Control (SFC) 98
5.15 Tertiary Frequency Control 100
5.16 Rigid Frequency Controls are Bringing in Changes 100
5.17 Voltage Control Services 100
5.18 Voltage Measurement at POD into the Transmission System 101
5.19 Attractive Market Prices Lead to Reserves Over and Above the Compulsory Limits 101
5.20 Importance of Operating Frequency Limits for a Thermal Generator 101
5.21 System Protection 103
5.22 Maintenance Practices 104
5.22.1 Corrective Maintenance 104
5.22.2 Preventive Maintenance 104
5.22.3 Predictive Maintenance 104
5.23 Challenges in Meeting Environmental Obligations 105
5.24 MHD Generators 105
Appendix 5-1 Energy Efficiency Program [36] 106
Generation Project Types 106
Appendix 5-2 Capability Curves of a 210 MW Generator 106
Appendix 5-3 Design of an MHD Generator System and its Output Conversion 107
Extracting Electricity from the MHD Generator 110
References 111

6. Environmental Constraints in Thermal Power Generation—Acid Rain 115

6.1 Introduction to Acid Rain and Carbon Emissions 115
6.2 World Concern Over Environmental Pollution and Agreements to Control It 116
6.3 U.S. Clean Air Act and Amendments 116
6.4 Complying with Constraints on the SO_2 Emission Rate 117
6.4.1 Options Available 117
6.4.2 Costs Involved in Reduction of SO_2 Emissions 119
6.5 Surcharges on Emissions 120
6.6 Complying with Constraints on Denitrifying 122
6.6.1 Burners Out of Service (BOOS) 123
6.6.2 NO_x Variation with Load 124
6.7 Continuous-Emission Monitoring Systems (CEMS) 126
6.8 The European Systems: Helsinki Protocol on SO_2 and Sofia Protocol on NO_x 126

6.9 The Japanese Example—City-Wise and Comprehensive 127
6.10 A Plant Running Out of Emission Allowances 128
6.11 NO_x Permits are Projected as Important Players in Price Fixing of Power in a Free Market 128
6.12 Air Pollution by Carbon Dioxide—CO_2 129
Appendix 6-1 Ambient Air Quality Standards for Residential Areas 129
Appendix 6-2 Ambient Air Quality Standards for Industrial Areas 130
Appendix 6-3 Details on Desulphurization Plants in the United States 131
References 132

7. Environmental Constraints in Thermal Power Generation—Carbon and the Kyoto Proposals 135
7.1 Continuing Growth of CO_2 in the Air 135
7.2 Co_2 from Different Fuels 135
7.3 CO_2 Emission by Fuel Type 136
7.4 Coal has the Highest Rate of Growth Among Energy Suppliers 136
7.5 Earth's Oceans and Seas Absorb CO_2 137
7.6 Developments on the Front of Reduction in Greenhouse Gas Emissions 138
7.7 Kyoto Proposals 138
7.8 Clause 1 of Kyoto Protocol of 1998 139
7.9 Original Kyoto Proposals 139
7.10 Proposals for Parties to the 2007 Protocol 140
7.10.1 Emission Trading with ERUs and LULUCF 141
7.10.2 Joint Implementation 141
7.10.3 Clean Development Mechanism (CDM) 141
7.10.4 Certified Emission Reductions (CERs) 141
7.10.5 CER to the Rescue of Protocol Parties 141
7.10.6 Passage of the CDM Proposal 142
7.11 Project Report Needs 142
7.11.1 Eligibility Criteria 142
7.11.2 Additionality Factor 143
7.12 An Illustrative Validation Report 143
7.13 A Workout for Emission Factors and Emissions for a Hydro and for a Wind Energy Installation 144
7.14 Open Skies Divided in Tons of CO_2 Per Nation 145
7.15 An example of Baseline and Emission Reductions 145
7.16 Methodological Tools to Calculate the Baseline and Emission Factor 147
7.17 Tool to Calculate the Emission Factor for an Electricity System 147
7.18 Simple Operating Margins 147
7.19 Incentives for Emission Reduction 148
Appendix 7-1 Default Efficiency Factors for Power Plants 151
References 151

8. Nuclear Power Generation 153
8.1 Nuclear Power Generation Process in Brief 153
8.1.1 Risks Involved 153
8.1.2 Scattered Designs and Systems 154
8.2 Rise, Fall, and Renaissance of Nuclear Power Plants 154
8.3 Power Uprates 155
8.4 Advantages of Nuclear Plants 156
8.5 Some Types of Nuclear Power Reactors 156
8.6 Other Types from Different Countries 157
8.7 Planning of NP Plants 157
8.7.1 U.S. Plant Planning Process for an NPP—Stages 1 to 3 157
8.7.2 Periods Involved at Each Stage 158
8.8 Financial Risks in Planning 158
8.9 Operation of NP Plants 158
8.9.1 Personnel 159
8.9.2 Technical 160
8.10 Safety Measures to Prevent Explosion in a Reactor Vessel 160
8.11 Prevention of Accidents 160
8.11.1 Lightning Strikes 160
8.11.2 Utility Bus Voltage Dips 161
8.11.3 The Generator Output Trips 162
8.11.4 Off-Site Supply Trips 162
8.12 Class IE Equipment and Distribution Systems—Ungrounded Earthing Systems 163
8.13 Environmental Considerations—Radiation Hazard 164
8.14 Waste Management 164
8.14.1 Reprocessing 164
8.14.2 Underground Storage Tanks 165
8.15 Environmental Benefits 165
8.16 Challenges for Research 166
8.17 Rapid Increase in Population Expected 166
8.18 Fast Breeder Reactors 166
Appendix 8-1 Nuclear Reactor Accident at Three Mile Island 167
Appendix 8-2 Chernobyl Accident 168
Appendix 8-3 Worldwide Capacity and Generation of Nuclear Energy 169
References 170

9 Wind Power Generation 173
9.1 Introduction to Wind 173
9.1.1 Technology Growth in Wind Turbine Generators 174
9.1.2 Nature of Wind 174
9.1.3 Components of a Wind Turbine Generator 174
9.2 Operation of Wind Turbine Generators 175
9.2.1 Output of a WTG 175

9.2.2 Performance Improvement through Blade Pitch Control 176
9.2.3 Efficiency of a WTG 176
9.2.3 Losses in a WTG 177
9.2.4 Flickers in the Output of a WTG 177
9.3 Connection of Wind Energy Plants to the Grid—The Grid Code 179
9.3.1 Low-Voltage Ride-through 179
9.4 American Grid Code 180
9.5 A Resistive Braking of a WTG 181
9.6 Power and PF Control 182
9.7 Modeling of a Wind Turbine Generator 182
9.7.1 Objectives 183
9.7.2 Method 183
9.7.3 Present Problem Areas in Modeling 183
9.7.4 Model Validations 184
9.8 Economics of Wind Energy 184
9.8.1 How Does a Modern Power System Operate on the Marketing Side? 184
9.8.2 Unit Commitment and Scheduling 185
9.9 Capacity Factor of a WTG 186
9.10 Capacity Credit Considerations 186
9.11 Capacity Factor for WECs in a Hybrid System 187
9.12 Wind Penetration Limit 187
9.13 Wind Power Proportion 187
9.14 Wind Integration Cost in United States 188
9.15 Wind Energy Farms 188
9.16 Promoting Growth of Wind Electricity 188
9.17 Maintenance of WTG 190
9.18 UNFCCC and Wind Energy 190
References 190

10. Photovoltaic Energy—Solar Cells and Solar Power Systems 195
10.1 Photovoltaic Energy—How it Works 195
10.2 Advantages of Photovoltaic Energy 195
10.3 Disadvantages of PV Energy 196
10.4 Solar Thermal Density—Insolation 196
10.5 Output of a PV Cell 197
10.6 Variation with Ambient Temperature 197
10.7 Voltage-Versus-Current Characteristics of a Solar Cell 198
10.8 Matching the PV with the Load 199
10.8.1 Maximum Power Point Tracker (MPPT) 199
10.8.2 VMPPT and CMPPT 200
10.9 Old Working Model of an MPPT 201
10.10 Maximizing the Output of a Solar Panel 201
10.10.1 By Orienting the Solar Panel 201
10.10.2 By Water Cooling the Solar Panel Backs 202

10.11 Interface with a Power System 202
10.12 Power Conditioning Systems 202
10.12.1 Quality Requirements of a PCS 203
10.12.2 Converting DC into AC 204
10.13 Super Capacitors and Storage Batteries 204
10.14 NERC Guidelines for Connecting a PV Systm to a Grid 204
10.15 Problems of Interfacing PV Systems with the Grid 205
10.16 Penetration Percentage by a PV Energy System into a Utility Grid 206
10.17 Progress in Application of PV Energy 206
10.17.1 PV Cells and Agricultural Pumps 206
References 213

11. Direct Conversion into Electricity—Fuel Cells 217
11.1 Fuel Cells Bypass Intermediate Steps in the Production of Electrical Energy 217
11.2 Working of a Fuel Cell 217
11.3 A Reformer for Getting Hydrogen From Methane 218
11.4 Fuels for a Fuel Cell 219
11.5 Fuel Cells on the Forefront of Development 220
11.5.1 Advantages of the PEM Fuel Cells 220
11.5.2 Disadvantages of PEM Fuel Cells 220
11.6 Comparison between Fuel Cells 221
11.7 Typical Characteristics of Various Fuel Cells 221
11.8 Developments in Fuel Cells 223
11.8.1 Molten Carbonate Fuel Cell 222
11.8.2 CO_2 Recycling under Pressure Swing Absorption 224
11.9 Applications of Fuel Cells 224
11.9.1 Automobile Propulsion 224
11.9.2 Residential Applications 225
11.9.3 Electricity Utilities 225
11.10 An SOFC–Gas Turbine System 225
11.10.1 Special Advantages 226
11.11 Efficiencies of Various Systems in Thermal Power Generation Technologies 227
References 228

12. Hybrid Systems 231
12.1 Coupling of Energy Sources 231
12.2 What Exactly are Hybrids? 231
12.2.1 Where Hybrids Can be Effective 232
12.3 Stand-Alone Hybrid Power Systems 232
12.3.1 Options for A Rural Electric Supply—Case of a Remote Mexican Village 232
12.3.2 Six Alternatives with Advantages and Disadvantages in a Mexican Case Study 233

12.4 Use of Renewable Sources of Energy in Mexico—San Antonio Aqua Bendita 234
12.5 Some Definitions 235
12.5.1 Loss Probability of Supply Power (LPSP) 235
12.5.2 Battery Capacity 235
12.5.3 Inverter Rating 235
12.5.4 Functions of a Battery Controller 235
12.5.5 Storage Batteries are Important in PV/Wind and Storage Battery Stand-alone Hybrid Systems 235
12.6 Cost Balance Between PV Cells and Storage Batteries 236
12.6.1 Other Hybrid Illustrations 236
12.7 Hybrids Incorporating Fuel Cells 237
12.7.1 PV–Fuel Cell Hybrids for a Spaceship 237
12.7.2 Diesel Generator–Wind Energy Hybrids 238
12.8 Midsea Hybrids 238
12.9 Workings of a WTG and Diesel Generator 238
12.9.1 Starting of WTGs 238
12.9.2 A Case of Low Wind 239
12.9.3 A Case of Wind Gust 239
12.9.4 In a Hybrid System, Can We Draw Energy Wholly from WG? 239
12.9.5 An Irish Rule on Permissible Wind Penetration 240
12.10 Wind Energy Penetration Limit 240
12.11 Wind Power–Fuel Cell Hybrids 240
12.12 Interfacing Nonconventional Energy Sources with Utility Systems–Static Power Controllers (SPCs) 241
12.13 Protective Controls Between a Utility and a Newcomer 241
12.13.1 Routine Controls 241
12.13.2 Specific Controls 242
References 243

13. Combined Generation—Cogeneration 247
13.1 Definition and Scope 247
13.2 Rise of Cogeneration 248
13.3 Basic Purpose of Cogeneration 248
13.4 Three Types of Cogenerators 248
13.4.1 Primary Product—Steam 248
13.4.2 Primary Product—Electricity 249
13.4.3 Equal Production—Steam and Electricity 249
13.5 Advantages Offered by Cogeneration 249
13.6 Planning of Cogeneration 250
13.6.1 Planning by Old Established Cogenerating Units 250
13.6.2 New High-Tech Industries 251
13.6.3 Small Establishments 251

13.7 Economic Objectives for a Cogenerator 253
13.7.1 Optimization of Fuel Input 254
13.7.1 Profit Maximization Under TOU Rates—An Illustration 254
13.8 Operation of Cogenerators 254
13.8.1 Within Its Own Complex 254
13.8.2 As a Tie-Up Between a Cogenerator and a Utility 256
13.9 Working Together with Cogeneration 256
13.9.1 Excitation Control of Cogenerators 257
13.9.2 Short-Circuit Faults and Overcurrent 258
13.9.3 Clearing Times for an Out-of-Step Relay Control 259
13.9.4 Loss of Excitation Relay—Maloperations 259
13.9.5 A Series Inductance in the Tie Line Works as a Stabilizer 260
13.10 Islanding of Cogeneration Section 260
13.10.1 Sudden Overloads 260
13.10.2 Sudden Load Cut-offs 260
13.11 Environmental Considerations 262
13.12 Cogeneration in Brazil 263
Appendix B-1 A Typical Cogenerating System for a High-Tech, Science-Based Industrial Park in Taiwan 264
A Load Shedding Scheme 265
Appendix 13-2 NERC Directive 266
Appendix 13-3 Combined Power Generation and Captive Power Plants—A Typical Example 268
Background 268
Problems in Cogeneration and Grid Interconnections 268
Grid Discipline for the CPP 269
Appendix 13-4 Cogeneration in Sugar Mills in India 269
References 270

14. Distributed Generation (DG) and Distributed Resources (DR) 275
14.1 Definition and Scope 275
14.1.1 Definitions 275
14.1.2 Scope 275
14.2 Who are the Players in Distribution Generation? 276
14.3 Prominent Features of DRs 276
14.4 Types of DGs 276
14.4.1 Background 278
14.5 Push Factors, Stay-Put Costs, and Investment Prospects for Electricity 278
14.6 Investment Options 278
14.6.1 Load Growth, Including Time Factor 279
14.6.2 Costs of Available Alternatives—DG versus Substations 279
14.6.3 Costs of Overloading Existing Assets 280

14.6.4 Costs of Unserved Energy 281
14.6.5 Interruption Costs 281
14.6.6 Line Losses Will Keep on Increasing with the Load 281
14.7 Planning Sites for a DG 282
14.7.1 Voltage Support for a Rural Line with Active and Reactive Power under Different Load Conditions 284
14.8 Operation of DGs in an Electric Power System 284
14.8.1 A Ride Through a Voltage Dip 285
14.8.2 Small-Disturbance Stability of a DG 286
14.8.3 Working of a Protective Fuse and a Backup Recloser Affected by the Presence of a DG 287
14.8.4 Correlation between a Fuse and a Trip Relay 288
14.8.5 Boost-up of Fault Current by an Inverter and its Effect on Reclosing 289
14.8.6 An Inductance Generator with a D-Statcom 289
14.9 Islanding of an EPS Section from the Main Body 289
14.9.1 Disconnect on Islanding 289
14.9.2 Vector Surge Relay (Out of Step) 290
14.9.3 Rate of Change of Frequency Relay 291
14.9.4 Built-in Protection for Inverter Systems 291
14.10 Allowable Penetration Levels by DRs 291
14.11 Synchronous Generator as a DG with Excitation Controls 292
14.12 How Can a DG Earn Profits? 293
14.12.1 Peak Load Servicing 293
14.12.2 Selling Contingency Security Reserves to a Utility 293
14.13 Scope for Gas-Based DGs 293
14.14 Diesel Generators 293
14.15 Evaluation of Service Rendered by Stand-by DGs 294
14.16 Reliability Cost for a DG Set 294
14.17 Maintenance and Protection of Diesel Generators 295
14.17.1 Noise Limit for Diesel Generator Sets (up to 100 KVA) 295
14.17.2 Emission Limits for New Diesel Engines (up to 800 kW) for Generator Set Applications 295
14.17.3 Poona Pattern of Energy Supply from Stand-by Sets to a Utility 295
14.18 UK Policy on Generation of Low-Carbon Electricity 296
References 297

15. Interconnecting Distributed Resources with Electric Power Systems 301
15.1 Scope 301
15.2 Definitions per IEEE Std 1547-2003 302
15.3 DR Ceases to Energize the Area EPS 302
15.4 Protective Devices 302

15.5 Schematic of an Interconnection Between a DR and an Area EPS 302
15.6 Restraints on a DR Operator 302
15.7 Responsibilities and Liabilities of EPS Area Operators 303
15.8 Power Quality Windows 304
15.8.1 Frequency 305
15.8.2 Harmonics 305
15.8.3 Allowable Voltage Distortion Limits for Power Generating Equipment 305
15.8.4 Maximum Harmonic Voltage Distortions at PCC at Voltages up to 69 kV 306
15.9 Limitation of DC Injection 306
15.10 Islanding of a Local-Area EPS that Includes a DR 306
15.11 Reconnection 308
15.12 Safety Aspects 309
15.13 Testing of Interconnecting Equipment 309
15.14 Interconnections Will be Important in Tomorrow's Scenario 309
Appendix 15-1 CBIP Standard Recommendation, Extracts from Publication 2517, July 1996 [4] 310
Recommendations 310
Target Compatibility Levels 310
References 311

16. Energy Storage—Power Storage Super Capacitors 315
16.1 Energy Storage and the Future for Renewable Energy Sources 315
16.2 Advantages of Energy Storage 315
16.3 Factors for Choosing Type and Rating of a Storage System 316
16.3.1 Network Parameters 316
16.3.2 Connection and Cycling Costs 316
16.4 Nature of Support by Electricity Storage Systems 317
16.5 Load Density, Short-Circuit Capacity, and Storage of Energy 318
16.6 Photovoltaic Energy—PV Energy in Residential Applications 318
16.7 Maximum PV Penetration and Maximum Allowable Storage go Hand in Hand 319
16.8 Planning the Size of a Store for PV Inclusion in a Distribution System 319
16.9 Types of Storage Devices for PV Systems 321
16.10 Wind Energy 322
16.11 Storage Technologies 323
16.12 Determining the Size Storage for Wind Power 323
16.13 Control Modes for Stores and WTG 323
16.14 Energy Rating of Stores 328
16.15 Categories of Energy Storages 329
Appendix 16-1 A Supercapacitor 330
References 334

17. Hydrogen Era 337

17.1 Fossil-Based Fuels 337
17.2 Hydrogen Properties 337
17.3 Hydrogen Advantages 338
17.4 Production of Hydrogen 340
17.4.1 Presently Developed Processes for Production of H_2 340
17.4.2 Processes under Development for Bulk Production of H_2—Coal Gasification 340
17.4.3 Processes under Laboratory/Scientific Exploration—Thermochemical Water Splitting 341
17.5 Potential Market Segments for Hydrogen 342
17.6 Present Roadblocks to use of Hydrogen 342
17.6.1 Costs of H_2 are High 342
17.6.2 Basic Infrastructure Does Not Exist 342
17.6.3 Petroleum Products are Well Established 342
17.7 Governments Envision a Hydrogen Era 343
17.8 An Example to Consider 343
Appendix 17-1 Proceedings of the National Hydrogen Energy Road Map, Workshop Arranged by U.S. DOE 343
Appendix 17-2 HTGR Knowledge Base 347
IAEA-TECDOC—1085: Hydrogen as an Energy Carrier and its Production by Nuclear Power 347
References 347

18. Basic Structure of Power Marketing 351

18.1 Reconstruction of the Electricity Business 351
18.2 Unbundling of Old Monopoly 352
18.3 Open Access to Critical Facilities 352
18.4 How Does the New System Work? 353
18.5 Market Participants And Their Functions 353
18.6 New Key Personnel 354
18.6.1 Role of a Systems Operator (Technical) 354
18.6.2 Role of a System Operator (Financial) 355
18.7 Role of a Regulator or Regulatory Commission 355
18.8 Tools for the System Operator 355
18.9 Secondary Markets 365
18.10 Free Market Objectives 356
18.10.1 Objectives for the Transmission Systems 356
18.10.2 Objectives for the Wholesale Market: A Standard Market Design (SMD) 357
18.11 Success of the Free Market 357
18.12 How Do Electricity Markets Operate? 358
18.13 Flow of Operating Funds 358
18.14 Effect of Reconstruction on Electricity Business—Capital Investment Prospects 358

18.14.1 Generation 358
18.14.2 Peak-load Generators and Base-load Generators 359
18.14.3 Investment and Costs of Compliance with Emission Control Measures 359
18.14.4 BACT Favored by Regulators 359
18.14.5 Output Limitations 360
18.14.6 Cap and Trade 360
18.14.7 Effect on Transmission Systems: Investment Incentives and Responsibilities 360
18.15 National Grid Transmission System 361
Appendix 18-1 A Vast Array of Tools to Support Tomorrow's Market Participants 361
References 363

19. Looking into the Future 365

Index 367

IEEE Press Series on Power Engineering

FOREWORD

It is with pleasure that I write this foreword to *Electricity Power Generation: The Changing Dimensions,* written by my esteemed friend, Mr. D. M. Tagare. Mr. Tagare and I have worked in the field of power generation and power management over the last 50 years. Mr. Tagare is known in India for his outstanding work in the field of power capacitors and filters. He was the chairman of capacitor division of Indian Electrical and Electronics Manufacturers Association and piloted growth and development of the industry for a number of years. He has published books on capacitors and reactive management that have received worldwide acclaim. This book is the result of decades of experience. It will enhance the knowledge of persons working in the power sector, both young and old. The book provides the latest knowledge on issues of electricity generation.

The electricity sector structure has changed rapidly, especially during the last 20 years. From a monopoly line-function structure, power generation and power trading have been transformed into a competitive industry. This has attracted the attention of planners, economists, managers, industrial engineers, and civil servants. Thus, there is a migration of other sector experts to the electricity sector. These experts require education and knowledge of electricity generation, not only basic, but most up-to-date, covering the latest and upcoming technologies, such as fuel cells and hydrogen. All these areas together with new and renewable energy generation are well covered in the book. Besides meeting the needs of working engineers in the sector, this book will also meet the needs of students working in the field of energy management, energy consultants, auditors, civil servants, industrial managers, economists, and planners. The book will serve as handbook and will be a useful addition to technical libraries.

Every technology over the years seeks to improve efficiencies; electricity power generation is no exception. Constant endeavor is made to achieve higher efficiencies through higher pressures and temperatures and so on. The development of power electronics, computer engineering, and information technology (IT) has added new dimensions to the electricity generation sector. Complete automation in working is achieved. Thus, the electricity engineer is required to acquire knowledge in these fields as applicable to his or her sector. The book includes updates on these subjects associated with electrical engineering. This enhances the value of the book by directly covering these