

# Table of Contents

## Preface

v

<b>Chapter 1 Structure of Power System and Economic Aspects</b>	1
1.1 Modern Power System Structure.....	1
1.1.1 Generation .....	1
1.1.2 Transmission and sub-transmission.....	3
1.1.3 Distributions .....	3
1.1.4 Loads .....	3
1.2 Introduction to Power System Control .....	4
1.3 Curves used in System Operation and Planning .....	5
1.3.1 Load curve .....	5
1.3.2 Load duration curve.....	6
1.3.3 Integrated load duration curve .....	6
1.4 Base Load and Peak Load Power Stations .....	7
1.5 Commonly Used Terms and Factors .....	7
1.6 Load Forecasting .....	12
1.6.1 Classification of load forecasting .....	13
1.6.2 Forecasting procedure.....	13
<b>Chapter 2 Economic Load Dispatch</b>	19
2.1 Introduction .....	19
2.2 Provisions for Operational Planning and Economic Scheduling .....	20
2.3 Formulation of Economic Dispatch Problem .....	20
2.4 Characteristics of Thermal Power Plant .....	21
2.4.1 Input-output or heat characteristic .....	21
2.4.2 Operating cost curve .....	22
2.4.3 Heat rate curve.....	22
2.5 Characteristics of Hydro Power Plant .....	25
2.5.1 Incremental water rate characteristic .....	26
2.5.2 Incremental cost characteristic .....	26
2.6 Objective Function and Constraints for the Economic Dispatch Problem.....	26
2.7 Economic Dispatch Neglecting Losses and No Generation Limits .....	27
2.8 Economic Dispatch Neglecting Losses and Including Generator Limits.....	36
2.9 Economic Dispatch Including Losses .....	43
2.10 Transmission Loss Expression in terms of Real Power Generation—Derivation .....	57
2.11 Economic Dispatch in Other Units.....	63
<b>Chapter 3 Optimal Hydro-Thermal Scheduling</b>	71
3.1 Introduction .....	71
3.2 Hydro-Thermal Coordination .....	71
3.3 Classification of Hydro Power Plants.....	73
3.3.1 Classification on type .....	73
3.3.2 Classification on location .....	73
3.4 Long-Term Generation Scheduling of Hydro-Thermal Systems .....	75
3.4.1 Thermal fuel cost.....	75
3.4.2 Water storage equation .....	75
3.4.3 Hydro generation .....	75
3.4.4 Power balance equation .....	74

3.4.5 Problem formulation .....	76
3.4.6 Optimization strategy .....	77
3.5 MATLAB Programs on Hydro-Thermal Scheduling.....	81
3.6 Short-Term Generation Scheduling of Hydro-Thermal Systems.....	87
3.6.1 Thermal model.....	88
3.6.2 Hydro model .....	88
3.6.3 Power balance equation .....	88
3.6.4 Problem formulation .....	89
3.6.5 Solution of scheduling problem—Kirchmayer's method.....	89
3.6.6 Optimization strategy .....	92
3.7 Advantages of Operation of Hydro-Thermal Combination .....	100
<b>Chapter 4 Power System Unit Commitment</b>	105
4.1 Introduction .....	105
4.2 Comparison with Economic Load Dispatch.....	105
4.3 Need for Unit Commitment.....	106
4.4 Illustrative Example for Unit Commitment Problem .....	106
4.5 Constraints in Unit Commitment .....	109
4.5.1 Spinning reserve .....	109
4.5.2 Thermal unit constraints .....	111
4.5.3 Other constraints.....	112
4.6 Mathematical Model of Unit Commitment Problem .....	112
4.6.1 Objective function .....	112
4.6.2 Constraints for plant commitment schedules.....	113
4.6.3 Solution methods for unit commitment problem.....	114
4.7 Priority-List Method.....	114
4.8 Dynamic Programming for Unit Commitment .....	116
4.8.1 Solution of unit commitment problem with dynamic programming .....	116
4.8.2 Mathematical representation.....	116
4.9 Challenges for Unit Commitment .....	123
<b>Chapter 5 Power System Control</b>	127
5.1 Overview .....	127
5.2 Basic Generator Control Loops .....	128
5.3 Load Frequency Control.....	129
5.4 System Modeling of Load Frequency Control .....	130
5.4.1 Generator-Load model.....	130
5.4.2 Prime mover model .....	132
5.4.3 Governor model .....	134
5.4.4 Isolated power system representation.....	137
5.4.5 State-space representation of LFC .....	138
5.5 Control Area Concept.....	139
5.6 Performance of LFC Loop .....	140
5.6.1 Steady-state analysis.....	140
5.6.2 Dynamic analysis.....	143
5.7 Response Rates of Turbine-Governing Systems .....	151
5.8 Automatic Generation Control .....	153
5.8.1 Requirements of control strategy .....	153
5.8.2 Integral control .....	154
5.8.3 AGC in single-area system .....	154
5.8.4 Analysis of integral control .....	155
5.9 Reactive Power and Voltage Control .....	160
5.10 System Modeling of AVR .....	160

5.10.1 Amplifier model .....	160
5.10.2 Exciter model.....	161
5.10.3 Generator model .....	161
5.10.4 Sensor model .....	161
5.10.5 AVR block diagram representation and performance response .....	161
5.11 Excitation System Stabilizer .....	166
5.11.1 Stabilizer—rate feedback .....	166
5.11.2 Stabilizer—PID controller .....	168
5.12 AGC Including Excitation System .....	170
<b>Chapter 6 Load Frequency Control of Interconnected Power System</b>	177
6.1 Introduction .....	177
6.2 Load Frequency Control in Multi-area System .....	177
6.3 Analysis of Two-Area System .....	180
6.4 Tie-line Bias Control .....	188
6.4.1 Basic for selection of bias factor .....	189
6.4.2 Performance of GAC under normal and abnormal conditions .....	190
6.5 Dynamic State Variable Model .....	192
6.5.1 Model of single-area dynamic system in a state variable form .....	192
6.5.2 Model of two-area dynamic system in a state variable form.....	193
6.5.3 Advantage of state variable model .....	194
6.6 Introduction to Modern Control Applications .....	194
6.6.1 Pole-placement design.....	194
6.6.2 Optimal control design .....	201
6.7 Automatic Generation and Economic Dispatch Controls .....	204
6.8 Implementation of Automatic Generation Control .....	205
6.8.1 Filtering of ACE .....	206
6.8.2 Rate limits.....	206
6.8.3 Control performance criteria .....	207
6.8.4 Frequency of AGC execution .....	207
6.8.5 AGC tuning and performance.....	207
6.8.6 Emergency mode operation .....	208
6.9 Underfrequency Load Shedding.....	208
6.9.1 Hazards of under-frequency operation .....	208
6.9.2 Limitations of prime mover systems .....	208
6.9.3 Factors influencing frequency decay .....	208
6.9.4 Basis for selection of load-shedding schemes .....	209
<b>Chapter 7 Voltage and Reactive Power Control</b>	215
7.1 Introduction .....	215
7.2 Generation and Absorption of Reactive Power .....	215
7.3 Method of Voltage Control .....	216
7.4 Shunt Reactors and Capacitors .....	217
7.5 Series Capacitors .....	217
7.6 Synchronous Condensers .....	218
7.7 Tap-changing Transformers .....	219
7.8 Static VAR Compensators.....	222
7.8.1 Analysis of SVC .....	223
7.8.2 Expression for voltage and power .....	224
7.9 Passive Reactive Power Compensation.....	227
7.9.1 Distributed compensation .....	227
7.9.2 Discrete passive compensation .....	228
7.10 Compensation by Series Capacitor.....	229

7.11 Compensation by Shunt Capacitor .....	230
7.12 Compensation by STATCOM and SSSC.....	232
7.12.1 STATCOM at the midpoint of the line.....	232
7.12.2 SSSC at the midpoint of the line .....	235
<b>Chapter 8 Power System Security and State Estimation</b>	<b>243</b>
8.1 Introduction .....	243
8.2 Concept of System Security .....	243
8.3 Security Analysis.....	244
8.4 Security Enhancement.....	245
8.5 Steady State Security Analysis .....	246
8.5.1 Requirement of an SSS assessor.....	246
8.5.2 Network data.....	247
8.5.3 Bus power injection .....	247
8.5.4 Security constraints.....	247
8.5.5 Contingency list.....	248
8.6 Transient Stability Analysis .....	248
8.6.1 Digital simulation .....	248
8.6.2 Pattern recognition.....	249
8.6.3 Lyapunov method .....	249
8.7 State Estimation.....	249
8.7.1 State estimator .....	250
8.7.2 Static state estimation .....	250
8.8 Maximum Likelihood Estimation .....	250
8.8.1 The likelihood function .....	251
8.8.2 Measurement model and assumptions .....	252
8.8.3 WLS state estimation algorithm .....	253
8.9 Application of State Estimation.....	253
<b>Appendix</b>	<b>256</b>
<b>Bibliography</b>	<b>257</b>
 <b>Keyword Index</b>	 259