
DETAILED CHAPTER CONTENTS

Chapter 1 POWER SYSTEMS: A CHANGING LANDSCAPE 1-1

- 1-1 NATURE OF POWER SYSTEMS 1-1
- 1-2 CHANGING LANDSCAPE OF POWER SYSTEMS AND UTILITY DEREGULATION 1-3
- 1-3 TOPICS IN POWER SYSTEMS 1-4
- REFERENCES 1-6
- PROBLEMS 1-6

Chapter 2 REVIEW OF BASIC ELECTRIC CIRCUITS AND ELECTROMAGNETIC CONCEPTS 2-1

- 2-1 INTRODUCTION 2-1
- 2-2 PHASOR REPRESENTATION IN SINUSOIDAL STEADY STATE 2-1
- 2-3 POWER, REACTIVE POWER, AND POWER FACTOR 2-3
 - 2-3-1 Sum of Real and Reactive Powers in a Circuit 2-9
 - 2-3-2 Power Factor Correction 2-9
- 2-4 THREE-PHASE CIRCUITS 2-10
 - 2-4-1 Per-Phase Analysis in Balanced Three-Phase Circuits 2-12
 - 2-4-2 Per-Phase Analysis of Balanced Circuits including Mutual Couplings 2-13
 - 2-4-3 Line-to-Line Voltages 2-13
 - 2-4-4 Delta-Connected Loads 2-14
 - 2-4-5 Power, Reactive Power and Power Factor In Three-Phase Circuits 2-15
- 2-5 REAL AND REACTIVE POWER TRANSFER BETWEEN AC SYSTEMS 2-17
- 2-6 APPARATUS RATINGS, BASE VALUES AND PER-UNIT QUANTITIES 2-18
 - 2-6-1 Ratings 2-18
 - 2-6-2 Base Values and Per-Unit Values 2-19
- 2-7 ENERGY EFFICIENCIES OF POWER SYSTEM APPARATUS 2-20
- 2-8 ELECTROMAGNETIC CONCEPTS 2-20
 - 2-8-1 Ampere's Law 2-20
 - 2-8-2 Flux Density B And The Flux ϕ 2-22
 - 2-8-3 Ferromagnetic Materials 2-22
 - 2-8-4 Flux ϕ 2-24
 - 2-8-5 Flux Linkage 2-25
 - 2-8-6 Inductances 2-25
 - 2-8-7 Faraday's Law: Induced Voltage In A Coil Due To Time-Rate Of Change Of Flux Linkage 2-26
 - 2-8-8 Leakage And Magnetizing Inductances 2-28
- REFERENCES 2-30
- PROBLEMS 2-30

Chapter 3 ELECTRIC ENERGY AND THE ENVIRONMENT 3-1

- 3-1 INTRODUCTION 3-1
- 3-2 CHOICES AND CONSEQUENCES 3-2
- 3-3 HYDRO POWER 3-2
- 3-4 FOSSIL-FUEL BASED POWER PLANTS 3-3
 - 3-4-1 Coal-Fired Power Plants 3-3
 - 3-4-2 Natural-Gas and Oil Power Plants 3-4
 - 3-4-2-1** Single-Cycle Gas Turbines 3-4
 - 3-4-2-2** Combined-Cycle Gas Turbines 3-5
 - 3-5 NUCLEAR POWER 3-5
 - 3-5-1 Nuclear Fusion 3-5
 - 3-5-2 Nuclear Fission Reactors 3-6
 - 3-5-2-1** Pressurized Water Reactors (PWR) 3-6
 - 3-5-2-2** Pressurized Heavy Water Reactors (PHWR) 3-7
 - 3-5-3-3 Fast Breeder Reactors 3-7
- 3-6 RENEWABLE ENERGY 3-7
 - 3-6-1 Wind Energy 3-7
 - 3-6-1-1 Types of Generation Schemes in Windmills 3-9
 - 3-6-1-2 Challenges in Harnessing Wind Energy 3-11
 - 3-6-2 Photovoltaic Energy 3-12
 - 3-6-3 Fuel Cells 3-13
 - 3-6-4 Biomass 3-14
- 3-7 DISTRIBUTED GENERATION (DG) 3-14
- 3-8 ENVIRONMENTAL CONSEQUENCES AND REMEDIAL ACTIONS 3-14
 - 3-8-1 Environmental Consequences 3-14
 - 3-8-2 Remedial Actions 3-15
- 3-9 RESOURCE PLANNING 3-15
- REFERENCES 3-16
- PROBLEMS 3-17

Chapter 4 AC TRANSMISSION LINES AND UNDERGROUND CABLES 4-1

- 4-1 NEED FOR TRANSMISSION LINES AND CABLES 4-1
- 4-2 OVERHEAD AC TRANSMISSION LINES 4-1
 - 4-2-1 Shield Wires, Bundling and Cost 4-2
- 4-3 TRANSPOSITION OF TRANSMISSION LINE PHASES 4-3
- 4-4 TRANSMISSION LINES PARAMETERS 4-4
 - 4-4-1 Resistance R 4-4
 - 4-4-2 Shunt Conductance G 4-5
 - 4-4-3 Series Inductance L 4-6
 - 4-4-4 Shunt Capacitance C 4-8
- 4-5 DISTRIBUTED-PARAMETER REPRESENTATION OF TRANSMISSION LINES 4-11
- 4-6 SURGE IMPEDANCE Z_c AND THE SURGE IMPEDANCE LOADING (SIL) 4-13

4-6-1	Line Loadability	4-15
4-7	LUMPED TRANSMISSION LINE MODELS IN STEADY STATE	4-15
4-7-1	Long-Length Lines	4-16
4-7-2	Medium-Length Lines	4-17
4-7-3	Short-Length Lines	4-17
4-8	CABLES	4-18
	REFERENCES	4-19
	PROBLEMS	4-19

Chapter 5 POWER FLOW IN POWER SYSTEM NETWORKS 5-1

5-1	INTRODUCTION	5-1
5-2	DESCRIPTION OF THE POWER SYSTEM	5-2
5-3	EXAMPLE POWER SYSTEM	5-3
5-4	BUILDING THE ADMITTANCE MATRIX	5-4
5-5	BASIC POWER FLOW EQUATIONS	5-5
5-6	NEWTON-RAPHSON PROCEDURE	5-7
5-7	SOLUTION OF POWER FLOW EQUATIONS USING N-R METHOD	5-9
5-8	FAST DECOUPLED N-R METHOD FOR POWER FLOW	5-14
5-9	SENSITIVITY ANALYSIS	5-14
5-10	REACHING THE BUS VAR LIMIT	5-14
	REFERENCES	5-15
	PROBLEMS	5-15

Chapter 6 TRANSFORMERS IN POWER SYSTEMS 6-1

6-1	INTRODUCTION	6-1
6-2	BASIC PRINCIPLES OF TRANSFORMER OPERATION	6-2
6-2-1	Transformer Exciting Current	6-2
6-2-2	Voltage Transformation	6-3
6-2-3	Transformer Equivalent Circuit	6-5
6-2-4	Core Losses	6-6
6-2-5	Equivalent Circuit Parameters	6-6
6-3	SIMPLIFIED TRANSFORMER MODEL	6-7
6-3-1	Transferring Leakage Impedances across the Ideal Transformer Portion	6-7
6-4	PER-UNIT REPRESENTATION	6-8
6-5	TRANSFORMER EFFICIENCIES AND LEAKAGE REACTANCES	6-10
6-6	REGULATION IN TRANSFORMERS	6-11
6-6-1	Transformers Tap-Changing For Voltage Control	6-11
6-7	AUTO-TRANSFORMERS	6-11
6-8	PHASE-SHIFT INTRODUCED BY TRANSFORMERS	6-13
6-8-1	Phase-Shift in Δ -Y Transformers	6-13
6-8-2	Phase-Angle Control	6-14
6-9	THREE-WINDING TRANSFORMERS	6-14
6-10	THREE-PHASE TRANSFORMERS	6-15

6-11 REPRESENTING TRANSFORMERS WITH OFF-NOMINAL TURNS RATIOS, TAPS
AND PHASE-SHIFT 6-16

6-11-1 Off-Nominal Turns-Ratios and Taps 6-17

6-11-2 Representing Transformer Phase-Shift 6-18

REFERENCES 6-18

PROBLEMS 6-18

Chapter 7 HIGH VOLTAGE DC (HVDC) TRANSMISSION SYSTEMS 7-1

7-1 INTRODUCTION 7-1

7-2 POWER SEMICONDUCTOR DEVICES AND THEIR CAPABILITIES 7-2

7-3 HVDC TRANSMISSION SYSTEMS 7-2

7-4 Current-Link HVDC Systems 7-3

7-4-1 Thyristor Converters 7-4

7-4-2 Power Flow in Current-Link Systems 7-11

7-4-3 Improvements in Current-Link Systems 7-13

7-5 Voltage-Link HVDC Systems 7-13

REFERENCES 7-18

PROBLEMS 7-18

Chapter 8 Distribution System, Loads and Power Quality 8-1

8-1 INTRODUCTION 8-1

8-2 DISTRIBUTION SYSTEMS 8-1

8-3 POWER SYSTEM LOADS 8-2

8-3-1 Nature of Power System Loads 8-3

8-3-1-1 Power-Electronics Based Loads 8-5

8-4 POWER QUALITY CONSIDERATIONS 8-7

8-4-1 Continuity of Service 8-7

8-4-1-1 Uninterruptible Power Supplies (UPS) 8-7

8-4-1-2 Solid State Transfer Switches 8-8

8-4-2 Voltage Magnitude 8-8

8-4-3 Voltage Waveform 8-10

8-4-3-1 Distortion and Power Factor 8-10

8-4-3-2 RMS Value of Distorted Current and the Total Harmonic Distortion (*THD*) 8-11

8-4-3-3 Obtaining Harmonic Components by Fourier Analysis 8-13

8-4-3-4 The Displacement Power Factor (*DPF*) and Power Factor (*PF*) 8-16

8-4-3-5 Deleterious Effects of Harmonic Distortion and a Poor Power Factor 8-17

8-4-3-6 Active Filters 8-19

8-5 LOAD MANAGEMENT 8-19

8-6 PRICE OF ELECTRICITY 8-20

REFERENCES 8-20

PROBLEMS 8-20

Chapter 9 SYNCHRONOUS GENERATORS 9-1

9-1 INTRODUCTION 9-1

9-2	STRUCTURE	9-2
9-2-1	Stator with Three-Phase Windings	9-3
9-2-2	Rotor with dc field winding	9-4
9-3	INDUCED-EMF IN THE STATOR WINDINGS	9-4
9-3-1	Induced EMF due to Rotation of the Field-Flux with the Rotor	9-5
9-3-2	Induced EMF due to the Rotating Magnetic Field called the Armature Reaction, Created by the Stator Currents	9-6
9-3-3	Combined Induced EMFs due to the Field Flux and the Armature Reaction	9-8
9-4	POWER OUTPUT, STABILITY AND THE LOSS OF SYNCHRONISM	9-9
9-4-1	Steady State Stability Limit	9-10
9-5	FIELD EXCITATION CONTROL TO ADJUST REACTIVE POWER	9-11
9-5-1	Over-Excitation	9-11
9-5-2	Under-Excitation	9-11
9-5-3	Synchronous Condensers	9-12
9-6	FIELD EXCITERS FOR AUTOMATIC VOLTAGE REGULATION (AVR)	9-12
9-7	SYNCHRONOUS, TRANSIENT AND SUB-TRANSIENT REACTANCES	9-13
9-7-1	Constant-Flux Model	9-13
	REFERENCES	9-15
	PROBLEMS	9-15
	Chapter 10 VOLTAGE REGULATION AND STABILITY IN POWER SYSTEMS	10-1
10-1	INTRODUCTION	10-1
10-2	RADIAL SYSTEM AS AN EXAMPLE	10-1
10-3	VOLTAGE COLLAPSE	10-4
10-4	PREVENTION OF VOLTAGE INSTABILITY	10-5
10-4-1	Synchronous generators	10-6
10-4-2	Static Reactive Power Compensators	10-7
10-4-2-1	Parallel Combination of SVC and TCR	10-8
10-4-2-2	STATCOMs	10-9
10-4-3	Thyristor-Controlled Series Capacitor (TCSC)	10-10
	REFERENCES	10-11
	PROBLEMS	10-11
	Chapter 11 TRANSIENT AND DYNAMIC STABILITY OF POWER SYSTEMS	11-1
11-1	INTRODUCTION	11-1
11-2	PRINCIPLE OF TRANSIENT STABILITY	11-1
11-2-1	Rotor-Angle Swing	11-3
11-2-2	Determining Transient Stability Using Equal-Area Criterion	11-5
11-2-2-1	Critical Clearing-Angle	11-8
11-3	TRANSIENT STABILITY EVALUATION IN LARGE SYSTEMS	11-10
11-4	DYNAMIC STABILITY	11-11
	REFERENCES	11-12

PROBLEMS 11-12

APPENDIX 11A INERTIA, TORQUE AND ACCELERATION IN ROTATING SYSTEMS
11-13

**Chapter 12 CONTROL OF INTERCONNECTED POWER SYSTEM AND ECONOMIC
DISPATCH 12-1**

12-1 CONTROL OBJECTIVES 12-1

12-2 VOLTAGE CONTROL BY CONTROLLING EXCITATION AND THE REACTIVE
POWER 12-2

12-2-1 Automatic Voltage Regulation (AVR) through Excitation Control 12-2

12-3 AUTOMATIC GENERATION CONTROL (AGC) 12-3

12-3-1 Load-Frequency Control 12-3

12-3-2 Automatic Generation Control (AGC) 12-6

12-3-3 Dynamic Performance of Interconnected Areas 12-9

12-4 ECONOMIC DISPATCH AND OPTIMUM POWER FLOW 12-11

12-4-1 Economic Dispatch 12-11

12-4-2 Unit Commitment and Spinning Reserve 12-14

12-4-3 Optimal Power Dispatch and Flow 12-15

REFERENCES 12-15

PROBLEMS 12-15

Chapter 13 TRANSMISSION LINE FAULTS, RELAYING, CIRCUIT BREAKERS 13-1

13-1 CAUSES OF TRANSMISSION LINE FAULTS 13-1

13-2 SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS 13-2

13-2-1 Calculating the Symmetrical Components 13-2

13-2-2 Applying the Sequence-Components to the Network and the Superposition 13-4

13-3 TYPES OF FAULTS 13-4

13-3-1 Symmetrical Three-Phase and Three-Phase to Ground Fault 13-5

13-3-2 Single-Line to Ground Fault 13-5

13-3-3 Double-line to Ground Fault 13-6

13-3-4 Double-Line Fault (ground is not involved) 13-7

13-4 SYSTEM IMPEDANCES FOR FAULT CALCULATIONS 13-8

13-4-1 Transmission Lines 13-8

13-4-2 Simplified Synchronous Generator Representation 13-8

13-4-3 Transformer Representation in Fault Studies 13-9

13-5 CALCULATION OF FAULT CURRENTS IN LARGE NETWORKS 13-11

13-6 PROTECTION AGAINST SHORT-CIRCUIT FAULTS 13-12

13-6-1 Current and Voltage Transformers 13-13

13-6-2 Relays 13-13

13-6-3 Circuit Breakers 13-17

13-6-3-1 Automatic Reclosure 13-17

13-6-3-2 Single-Phase (or Independent-Pole) Operation 13-17

13-6-3-3 Circuit Breaker Ratings 13-18

DCC-6

REFERENCES 13-19

PROBLEMS 13-20

**Chapter 14 TRANSIENT OVER-VOLTAGES, SURGE PROTECTION AND
INSULATION COORDINATION 14-1**

14-1 INTRODUCTION 14-1

14-2 CAUSES OF OVER-VOLTAGES 14-1

14-2-1 Lightning Strikes 14-1

14-2-1-1 Lightning Strike to Shield Wires 14-2

14-2-1-2 Lightning Strike to the Conductor 14-2

14-2-2 Switching Surges 14-2

14-3 TRANSMISSION LINE CHARACTERISTICS AND REPRESENTATION 14-3

14-3-1 Calculation of Over-Voltages 14-4

14-4 INSULATION TO WITHSTAND VOLTAGES 14-5

14-4-1 Basic Insulation Level (BIL) 14-5

14-4-2 Basic Switching Insulation Level (BSL) 14-6

14-4-3 Chopped Wave Insulation Level 14-6

14-5 SURGE ARRESTERS AND INSULATION COORDINATION 14-7

REFERENCES 14-7

PROBLEMS 14-7