

Preface x

Chapter 1

Magnetic Circuits and Magnetic Materials 1

- 1.1 Introduction to Magnetic Circuits 2
- 1.2 Flux Linkage, Inductance, and Energy 11
- 1.3 Properties of Magnetic Materials 19
- 1.4 AC Excitation 23
- 1.5 Permanent Magnets 30
- 1.6 Application of Permanent Magnet Materials 35
- 1.7 Summary 42
- 1.8 Problems 43

Chapter 2

Transformers 57

- 2.1 Introduction to Transformers 57
- 2.2 No-Load Conditions 60
- 2.3 Effect of Secondary Current; Ideal Transformer 64
- 2.4 Transformer Reactances and Equivalent Circuits 68
- 2.5 Engineering Aspects of Transformer Analysis 73
- 2.6 Autotransformers; Multiwinding Transformers 81
- 2.7 Transformers in Three-Phase Circuits 85
- 2.8 Voltage and Current Transformers 90
- 2.9 The Per-Unit System 95
- 2.10 Summary 103
- 2.11 Problems 104

Chapter 3

Electromechanical-Energy-Conversion Principles 112

- 3.1 Forces and Torques in Magnetic Field Systems 113
- 3.2 Energy Balance 117
- 3.3 Energy in Singly-Excited Magnetic Field Systems 119
- 3.4 Determination of Magnetic Force and Torque from Energy 123
- 3.5 Determination of Magnetic Force and Torque from Coenergy 129
- 3.6 Multiply-Excited Magnetic Field Systems 136
- 3.7 Forces and Torques in Systems with Permanent Magnets 142
- 3.8 Dynamic Equations 151
- 3.9 Analytical Techniques 155
- 3.10 Summary 158
- 3.11 Problems 159

Chapter 4

Introduction to Rotating Machines 173

- 4.1 Elementary Concepts 173
- 4.2 Introduction to AC and DC Machines 176
- 4.3 MMF of Distributed Windings 187
- 4.4 Magnetic Fields in Rotating Machinery 197
- 4.5 Rotating MMF Waves in AC Machines 201
- 4.6 Generated Voltage 208
- 4.7 Torque in Nonsalient-Pole Machines 214
- 4.8 Linear Machines 227
- 4.9 Magnetic Saturation 230

- 4.10 Leakage Fluxes 233
- 4.11 Summary 235
- 4.12 Problems 237

Chapter 5

Synchronous Machines 245

- 5.1 Introduction to Polyphase Synchronous Machines 245
- 5.2 Synchronous-Machine Inductances; Equivalent Circuits 248
- 5.3 Open- and Short-Circuit Characteristics 256
- 5.4 Steady-State Power-Angle Characteristics 266
- 5.5 Steady-State Operating Characteristics 275
- 5.6 Effects of Salient Poles; Introduction to Direct- and Quadrature-Axis Theory 281
- 5.7 Power-Angle Characteristics of Salient-Pole Machines 289
- 5.8 Permanent-Magnet AC Motors 293
- 5.9 Summary 295
- 5.10 Problems 297

Chapter 6

Polyphase Induction Machines 306

- 6.1 Introduction to Polyphase Induction Machines 306
- 6.2 Currents and Fluxes in Polyphase Induction Machines 311
- 6.3 Induction-Motor Equivalent Circuit 313
- 6.4 Analysis of the Equivalent Circuit 317
- 6.5 Torque and Power by Use of Thevenin's Theorem 322
- 6.6 Parameter Determination from No-Load and Blocked-Rotor Tests 330
- 6.7 Effects of Rotor Resistance; Wound and Double-Squirrel-Cage Rotors 340
- 6.8 Summary 347
- 6.9 Problems 348

Chapter 7

DC Machines 357

- 7.1 Introduction 357
- 7.2 Commutator Action 364
- 7.3 Effect of Armature MMF 367
- 7.4 Analytical Fundamentals: Electric-Circuit Aspects 370
- 7.5 Analytical Fundamentals: Magnetic-Circuit Aspects 374
- 7.6 Analysis of Steady-State Performance 379
- 7.7 Permanent-Magnet DC Machines 384
- 7.8 Commutation and Interpoles 390
- 7.9 Compensating Windings 393
- 7.10 Series Universal Motors 395
- 7.11 Summary 396
- 7.12 Problems 397

Chapter 8

Variable-Reluctance Machines and Stepping Motors 407

- 8.1 Basics of VRM Analysis 408
- 8.2 Practical VRM Configurations 415
- 8.3 Current Waveforms for Torque Production 421
- 8.4 Nonlinear Analysis 430
- 8.5 Stepping Motors 437
- 8.6 Summary 446
- 8.7 Problems 448

Chapter 9

Single- and Two-Phase Motors 452

- 9.1 Single-Phase Induction Motors: Qualitative Examination 452
- 9.2 Starting and Running Performance of Single-Phase Induction and Synchronous Motors 455
- 9.3 Revolving-Field Theory of Single-Phase Induction Motors 463
- 9.4 Two-Phase Induction Motors 470

9.5 Summary 488

9.6 Problems 489

Chapter 10

Introduction to Power Electronics 493

10.1 Power Switches 494

10.2 Rectification: Conversion of AC to DC 507

10.3 Inversion: Conversion of DC to AC 538

10.4 Summary 550

10.5 Bibliography 552

10.6 Problems 552

Chapter 11

Speed and Torque Control 559

11.1 Control of DC Motors 559

11.2 Control of Synchronous Motors 578

11.3 Control of Induction Motors 595

11.4 Control of Variable-Reluctance Motors 613

11.5 Summary 616

11.6 Bibliography 618

11.7 Problems 618

Appendix A

Three-Phase Circuits 628

A.1 Generation of Three-Phase Voltages 628

A.2 Three-Phase Voltages, Currents, and Power 631

A.3 Y- and Δ -Connected Circuits 635

A.4 Analysis of Balanced Three-Phase Circuits; Single-Line Diagrams 641

A.5 Other Polyphase Systems 643

Appendix B

Voltages, Magnetic Fields, and Inductances of Distributed AC Windings 644

B.1 Generated Voltages 644

B.2 Armature MMF Waves 650

B.3 Air-Gap Inductances of Distributed Windings 653

Appendix C

The dq0 Transformation 657

C.1 Transformation to Direct- and Quadrature-Axis Variables 657

C.2 Basic Synchronous-Machine Relations in dq0 Variables 660

C.3 Basic Induction-Machine Relations in dq0 Variables 664

Appendix D

Engineering Aspects of Practical Electric Machine Performance and Operation 668

D.1 Losses 668

D.2 Rating and Heating 670

D.3 Cooling Means for Electric Machines 674

D.4 Excitation 676

D.5 Energy Efficiency of Electric Machinery 678

Appendix E

Table of Constants and Conversion Factors for SI Units 680

Index 681