
PRINCIPLES OF ELECTRIC MACHINES WITH POWER ELECTRONIC APPLICATIONS

Second Edition

MOHAMED E. EL-HAWARY

IEEE Power Engineering Society, *Sponsor*



IEEE Press Power Engineering Series
Mohamed E. El-Hawary, *Series Editor*



A JOHN WILEY & SONS, INC., PUBLICATION

CONTENTS

PREFACE	ix
Chapter 1 INTRODUCTION	1
1.1 Electric Machines / 1	
1.2 Roots in Observation / 2	
1.3 Beginnings / 3	
1.4 Foundations of Electromagnetism / 5	
1.5 The Dawn of Electrodynamics / 7	
1.6 Early Electric Generators / 9	
1.7 Early Electric Motors / 10	
1.8 Alternating Current / 11	
1.9 Power Electronics: Scope and A Brief History / 13	
1.10 Structure of the Power System / 18	
1.11 Outline of the Text / 21	
Chapter 2 PRINCIPLES OF ELECTROMAGNETISM AND ELECTROMECHANICAL ENERGY CONVERSION	23
2.1 Introduction / 23	
2.2 Magnetic-Field Laws / 24	
2.3 Permeability and Magnetic-Field Intensity / 31	
2.4 Magnetic Circuits / 35	
2.5 Flux Linkages, Induced Voltages, Inductance, and Energy / 50	

- 2.6 Hysteresis Loop / 54
- 2.7 Eddy-Current and Core Losses / 59
- 2.8 Energy Flow Approach / 60
- 2.9 Field Energy / 64
- 2.10 Multiply Excited Systems / 69
- 2.11 Reluctance Motors / 72
- 2.12 Doubly Excited Systems / 75
- 2.13 Salient-Pole Machines / 77
- 2.14 Round or Smooth Air-Gap Machines / 80
- 2.15 Machine-Type Classification / 84
- 2.16 P -Pole Machines / 85
- Problems / 89

Chapter 3 POWER ELECTRONIC DEVICES AND SYSTEMS 103

- 3.1 Introduction / 103
- 3.2 Power Semiconductor Devices / 103
- 3.3 Control Characteristics of Power Devices / 106
- 3.4 Power Semiconductor Diodes / 108
- 3.5 Power Transistors / 115
- 3.6 The Thyristors / 138
- 3.7 Power Electronic Systems / 175
- 3.8 Power Integrated Circuits and Smart Power / 178
- Problems / 179

Chapter 4 DIRECT-CURRENT MOTORS 183

- 4.1 Introduction / 183
- 4.2 Construction Features / 184
- 4.3 Circuit Model of dc Generator / 185
- 4.4 Circuit Model of dc Motors / 187
- 4.5 dc Series Motors / 190
- 4.6 dc Shunt Motors / 203
- 4.7 Compound Motors / 212
- 4.8 Motor and Load Matching / 224
- 4.9 Conventional Speed Control of dc Motors / 224
- 4.10 Reversal of Direction of Rotation / 241
- 4.11 Starting dc Motors / 241
- 4.12 Adjustable Speed dc Motor Drives / 251

- 4.13 ac–dc Drives for dc Motors / 255
- 4.14 dc–dc Drives for dc Motors / 261
- Problems / 265

Chapter 5 TRANSFORMERS

273

- 5.1 Introduction / 273
- 5.2 Ideal Transformers / 274
- 5.3 Transformer Models / 278
- 5.4 Transformer Performance Measures / 286
- 5.5 Single-Phase Connections / 292
- 5.6 Three-Winding Transformers / 296
- 5.7 Three-Phase Systems and Transformer Connections / 300
- 5.8 Autotransformers / 313
- Problems / 316

Chapter 6 INDUCTION MOTORS AND THEIR CONTROL

323

- 6.1 Introduction / 323
- 6.2 MMF Waves and the Rotating Magnetic Field / 324
- 6.3 Slip / 329
- 6.4 Equivalent Circuits / 331
- 6.5 Simplified Equivalent Circuits / 334
- 6.6 Torque Characteristics / 338
- 6.7 Some Useful Relations / 341
- 6.8 Internal Mechanical Power / 344
- 6.9 Effects of Rotor Impedance / 348
- 6.10 Classification of Induction Motors / 351
- 6.11 Starting Induction Motors / 354
- 6.12 Conventional Speed Control of Induction Motors / 362
- 6.13 Adjustable Speed Drives: General Considerations / 370
- 6.14 Variable-Voltage–Constant-Frequency Drives / 372
- 6.15 Variable-Voltage–Variable-Frequency Drives / 376
- 6.16 dc-Link-Converter Drives / 381
- 6.17 Voltage-Fed Inverter Drives / 383
- 6.18 Current-Fed Inverter Drives / 385
- 6.19 Cycloconverter Drives / 386
- 6.20 Regulation of Slip Power / 387
- Problems / 389

Chapter 7 SYNCHRONOUS MACHINES	397
7.1 Introduction / 397	
7.2 Round-Rotor Machines: Equivalent Circuit / 401	
7.3 Armature Reaction / 406	
7.4 Principal Steady-State Characteristics / 410	
7.5 Power Angle Characteristics and the Infinite-Bus Concept / 415	
7.6 Synchronous-Motor Operation / 423	
7.7 Salient-Pole Machines / 430	
Problems / 437	
Chapter 8 FRACTIONAL-HORSEPOWER ALTERNATING CURRENT MOTORS	443
8.1 Introduction / 443	
8.2 Rotating Magnetic Fields in Single-Phase Induction Motors / 443	
8.3 Equivalent Circuits for Single-Phase Induction Motors / 448	
8.4 Power and Torque Relations / 454	
8.5 Starting Single-Phase Induction Motors / 459	
Problems / 473	
BIBLIOGRAPHY	475
INDEX	477