

Contents

Preface.....	xi
Acknowledgments	xv
Author	xvii
1 Physics of Electric Machines	1
1.1 Introduction	1
1.2 Laws of Induction and Interaction: A Qualitative View	2
1.3 Induction and Interaction: A Closer Look.....	4
1.3.1 Induction of Voltage in a Coil.....	4
1.3.2 Induced Current and Consideration of the Law of Interaction	6
1.3.3 A Simple Electric Motor: Law of Interaction in Action.....	7
1.3.4 Laws of Induction and Interaction in a Combined Case	9
1.4 Energy Conversion in Electromechanical Systems.....	11
1.4.1 Use of Law of Interaction for Calculating Torque.....	11
1.4.2 Analysis of Energy Conversion Using the Law of Conservation of Energy	14
1.4.3 Energy Conversion in a Linear System.....	19
1.5 Nonlinear Phenomena in Magnetic Circuits	21
1.5.1 Solution for a Linear Core.....	22
1.5.2 Solution for a Nonlinear Core	23
1.5.3 Inclusion of Hysteresis	26
1.6 Closing Remarks	27
Problems.....	27
References	29
2 Principles of Alternating Current Machines	31
2.1 Introduction	31
2.2 Arrangement of Windings in AC Machines	31
2.2.1 Concentrated Windings	31
2.2.2 Short-Pitched Windings	34
2.2.3 Distributed Windings	36
2.2.4 Sinusoidally Distributed Windings	38
2.3 Poly-Phase Machine Windings	40
2.3.1 Three-Phase Concentrated Windings.....	40
2.3.2 Three-Phase Sinusoidally Distributed Windings	41

2.4	Increasing the Number of Poles.....	43
2.4.1	A Single-Phase Multipole Winding	43
2.4.2	Three-Phase Arrangement	44
2.4.3	Rotating Field of a Multipole Machine	45
2.5	Examples of Winding Arrangements.....	47
2.6	Winding Inductances	48
2.6.1	Self and Mutual Inductances of a Simple Round-Rotor Machine.....	49
2.6.2	Self and Mutual Inductances of a Salient Pole Machine	52
2.6.3	Machine Inductances with Distributed Windings	54
2.6.4	Methods for Analysis of AC Machines.....	57
	Problems.....	58
3	Principles of Direct Current Machines	61
3.1	Introduction	61
3.2	Elementary Direct Current Machine.....	62
3.2.1	Induction of Voltage and Its Rectification in a DC Machine.....	62
3.2.2	Process and Implications of Commutation.....	64
3.3	Field and Armature Interaction in a DC Machine	66
3.4	Dynamic Modeling of a Separately Excited DC Machine	67
3.5	Steady State Observations and a Lead to Drive Principles	74
3.5.1	Steady State Operation.....	74
3.5.2	Development of a Drive Strategy.....	74
3.6	Closed-Loop Speed Control of DC Machines.....	77
3.6.1	Elementary Speed Control Loop via Armature Voltage	77
3.6.2	Variable Speed Drive with an Inner Loop Current Control.....	79
3.7	Converter Circuits for Speed Control	82
3.8	Closing Remarks	82
	Problems.....	82
	References	83
4	Induction Machine Modeling	85
4.1	Introduction	85
4.2	Machine Equations in the ABC Phase Domain.....	85
4.3	Reference Frame Transformation of Machine Equations.....	89
4.3.1	Principles of Reference Frame Transformation	89
4.3.2	Transformation of Flux Linkage and Voltage Equations	92
4.3.3	Transformation of Electromagnetic Torque Equation	94

4.4	Derivation of a Steady State Model	95
4.5	Equivalent Circuit Parameter Determination and Preparation.....	98
4.6	Closing Remarks	103
Problems.....		103
References		105
5	Steady State Induction Machine Drives	107
5.1	Introduction	107
5.2	Analysis of the Steady State Model	107
5.3	Lead to the Development of Drive Strategies	113
5.4	Stator Voltage Control.....	114
5.5	Stator Frequency Control	115
5.6	Constant Terminal Volts/Hertz Control.....	116
5.7	Controlled Stator Current Operation	121
5.8	Closing Remarks	126
Problems.....		126
References		128
6	High-Performance Control of Induction Machines	129
6.1	Introduction	129
6.2	Field-Oriented Control (Vector Control).....	130
6.2.1	Alternative Implementation Methods	136
6.2.2	Other Types of Field-Oriented Control.....	137
6.3	Direct Torque Control.....	138
6.3.1	Principles of Direct Torque Control	138
6.3.2	Stator Flux and Electromagnetic Torque Estimator.....	140
6.4	Closing Remarks	143
Problems.....		143
References		144
7	High-Performance Control of Synchronous Machines	145
7.1	Introduction	145
7.2	Three-Phase Permanent Magnet Synchronous Machine Modeling	146
7.2.1	Development of a Model in the ABC Domain.....	146
7.2.2	Derivation of the Torque Equation	148
7.2.3	Machine Equations in the Rotor Reference Frame	150
7.2.4	Development of a Steady State Model	153
7.3	Torque Control of a PMSM	154
7.3.1	Principles of Torque and Speed Control.....	154
7.3.2	Practical Considerations	156
7.4	Closing Remarks	156
Problems.....		157
References		158

8 Power Electronic Circuits for Electric Motor Drives	159
8.1 Introduction	159
8.2 Conversion from an AC Source.....	160
8.2.1 Three-Phase AC-DC Converters.....	160
8.2.2 AC-AC Conversion: Three-Phase Cycloconverters.....	165
8.3 Conversion from a DC Source.....	168
8.3.1 Switching Cell of a Two-Level Voltage-Source Converter.....	168
8.3.2 Crafting a Controlled DC Output Voltage	169
8.3.3 Crafting a Controlled AC Output Voltage	171
8.3.4 Crafting a Controlled AC Output Current.....	173
8.3.5 AC-DC-AC Converters	174
8.4 Practical Considerations for Power Electronic Circuits.....	176
8.4.1 Torque Vibrations.....	176
8.4.2 Switching Losses.....	177
8.4.3 Noise and Electromagnetic Interference	178
8.5 Closing Remarks	178
Problems.....	179
References	180
9 Simulation-Based Design of Electric Drive Systems	181
9.1 Introduction	181
9.2 Principles of Simulation-Based Optimization	182
9.2.1 Design of a Suitable Objective Function.....	183
9.2.2 Requirements for a Nonlinear Optimization Algorithm.....	184
9.3 Example Cases of Simulation-Based Optimal Design of Electric Drive Systems	185
9.3.1 Design of an Indirect Vector-Controlled Induction Machine Drive	185
9.3.2 Multiobjective Optimization.....	190
9.3.3 Multiple Optimal Solutions.....	194
9.4 Closing Remarks	199
References	200
Appendix A: Numerical Simulation of Dynamical Systems.....	201
Appendix B: Power Semiconductor Devices	207
Appendix C: Trigonometric Identities	211
Index	213