Table of Contents

Preface xi

Chapter 1. Faults in Electrical Machines and their Diagnosis 1
Sadok BAZINE and Jean-Claude TRIGEASSOU

1.1. Introduction 1
1.2. Composition of induction machines 3
1.2.1. The stator 4
1.2.2. The rotor 4
1.2.3. Bearings 5
1.3. Failures in induction machines 5
1.3.1. Mechanical failures 8
1.3.2. Electrical failures 9
1.4. Overview of methods for diagnosing induction machines 10
1.4.1. Diagnosis methods using an analytical model 12
1.4.2. Diagnostic methods with no analytical model 16
1.5. Conclusion 18
1.6. Bibliography 19

Chapter 2. Modeling Induction Machine Winding Faults for Diagnosis 23
Emmanuel SCHAEFFER and Smail BACHIR

2.1. Introduction 23
2.1.1. Simulation model versus diagnosis model 23
2.1.2. Objectives 24
2.1.3. Methodology 24
2.1.4. Chapter structure 25
2.2. Study framework and general methodology 26
2.2.1. Working hypotheses 26

2.2.2. Equivalence between winding systems 27
2.2.3. Equivalent two-phase machine with no fault 34
2.2.4. Consideration of a stator winding fault 37
2.3. Model of the machine with a stator insulation fault 40
2.3.1. Electrical equations of the machine with a stator short-circuit 40
2.3.2. State model in any reference frame 43
2.3.3. Extension of the three-phase stator model 47
2.3.4. Model validation 48
2.4. Generalization of the approach to the coupled modeling of stator and rotor faults 51
2.4.1. Electrical equations in the presence of rotor imbalance 53
2.4.2. Generalized model of the machine with stator and rotor faults 55
2.5. Methodology for monitoring the induction machine 57
2.5.1. Parameter estimation for induction machine diagnosis 58
2.5.2. Experimental validation of the monitoring strategy 61
2.6. Conclusion 64
2.7. Bibliography 67

Chapter 3. Closed-Loop Diagnosis of the Induction Machine 69
Imène BEN AMEUR BAZINE, Jean-Claude TRIGEASSOU, Khaled JELASSI and Thierry POINOT

3.1. Introduction 69
3.2. Closed-loop identification 71
3.2.1. Problems in closed-loop identification 71
3.2.2. Identification problems for diagnosing electrical machines 73
3.3. General methodology of closed-loop identification of induction machine 74
3.3.1. Taking control into account 74
3.3.2. Machine identification by closed-loop decomposition 76
3.3.3. Identification results 80
3.4. Closed-loop diagnosis of simultaneous stator/rotor faults 82
3.4.1. General model of induction machine faults 82
3.4.2. Parameter estimation with a priori information 83
3.4.3. Detection and localization 84
3.4.4. Comparison of identification results through direct and indirect approaches 87
3.5. Conclusion 89
3.6. Bibliography 90

Chapter 4. Induction Machine Diagnosis Using Observers 93
Guy CLERC and Jean-Claude MARQUES

4.1. Introduction 93
4.2. Model presentation 96
4.2.1. Three-phase model of induction machine without fault 96
4.2.2. Park's model of an induction machine without fault 100
4.2.3. Induction machine models with fault 104
4.3. Observers 104
4.3.1. Principle 104
4.3.2. Different kinds of observers. 108
4.3.3. Extended observer 115
4.4. Applying observers to diagnostics 119
4.4.1. Using Park's model 119
4.4.2. Use of the three-phase model 124
4.4.3. Spectral analysis of the torque reconstructed by the observer 125
4.5. Conclusion 127
4.6. Bibliography 128

Chapter 5. Thermal Monitoring of the Induction Machine 131
Luc LORON and Emmanuel FOULON

5.1. Introduction 131
5.1.1. Aims of the thermal monitoring on induction machines 131
5.1.2. Main methods of thermal monitoring of the induction machines 133
5.2. Real-time parametric estimation by Kalman filter 137
5.2.1. Interest and specificities of the Kalman filter 137
5.2.2. Implementation of an extended Kalman filter 138
5.3. Electrical models for the thermal monitoring 142
5.3.1. Continuous time models 143
5.3.2. Full-order model 144
5.3.3. Discretized and extended model 147
5.4. Experimental system 149
5.4.1. General presentation of the test bench. 149
5.4.2. Thermal instrumentation. 151
5.4.3. Electrical instrumentation 153
5.5. Experimental results 157
5.5.1. Tuning of the Kalman filter 157
5.5.2. Influence of the magnetic saturation 160
5.6. Conclusion 162
5.7. Appendix: induction machine characteristics 163
5.8. Bibliography 163

Chapter 6. Diagnosis of the Internal Resistance of an Automotive Lead-acid Battery by the Implementation of a Model Invalidation-based Approach: Application to Crankability Estimation 167
Jocelyn SABATIER, Mikaël CUGNET, Stéphane LARUELLE, Sylvie GRUGEON, Isabelle CHANTEUR, Bernard SAHUT, Alain OUSTALOUP and Jean-Marie TARASCON

6.1. Introduction 167
6.2. Fractional model of a lead-acid battery for the start-up phase 169
6.3. Identification of the fractional model. 171
6.3.1. Output error identification algorithm 171
6.3.2. Calculation of the output sensitivities 173
6.3.3. Validation of the estimated parameters 174
6.3.4. Application to start-up signals 174
6.4. Battery resistance as crankability estimator 175
6.5. Model validation and estimation of the battery resistance 178
6.5.1. Frequency approach of the model validation 178
6.5.2. Application to the estimation of the battery resistance 181
6.5.3. Simplified resistance estimator 184
6.6. Toward a battery state estimator 188
6.7. Conclusion 188
6.8. Bibliography 190

Chapter 7. Electrical and Mechanical Faults Diagnosis of Induction Machines using Signal Analysis 193
Hubert RAZIK and Mohamed EL KAMEL OUMAAMAR

7.1. Introduction 193
7.2. The spectrum of the current line 194
7.3. Signal processing 196
7.3.1. Fourier's transform 196
7.3.2. Periodogram 197
7.4. Signal analysis from experiment campaigns 199
7.4.1. Disturbances induced by a broken bar 199
7.4.2. Bearing faults 205
7.4.3. Static eccentricity 211
7.4.4. Inter turn short circuits 220
7.5. Conclusion 222
7.6. Appendices 223
7.6.1. Appendix A 223
7.6.2. Appendix B 223
7.7. Bibliography 224

Chapter 8. Fault Diagnosis of the Induction Machine by Neural Networks 227
Monia Ben Khader BOUZID, Najiba MRABET BELLAAJ, Khaled JELASSI, Gérard CHAMPENOIS and Sandrine MOREAU

8.1. Introduction 227
8.2. Methodology of the use of the ANN in the diagnostic domain 228
8.2.1. Choice of the fault indicators 229
8.2.2. Choice of the structure of the network 230
8.2.3. Construction of the learning and test base 231
8.2.4. Learning and test of the network 232
8.3. Description of the monitoring system 232
8.4. The detection problem 233
8.5. The proposed method for the robust detection 235
8.5.1. Generation of the estimated residues 236
8.6. Signature of the stator and rotor faults 237
8.6.1. Analysis of the residue in healthy regime 237
8.6.2. Analysis of the residue in presence of the stator fault 237
8.6.3. Analysis of the residue in presence of the rotor fault 241
8.6.4. Analysis of the residue in presence of simultaneous stator/rotor fault 244
8.7. Detection of the faults by the RN_d neural network 244
8.7.1. Extraction of the fault indicators 244
8.7.2. Learning sequence of the RN_d network 245
8.7.3. Structure of the RN_d network 246
8.7.4. Results of the learning of the RN_d network 247
8.7.5. Test results of the RN_d network 248
8.8. Diagnosis of the stator fault 251
8.8.1. Choice of the fault indicators for the RN_{cc} network 251
8.8.2. Learning sequence of the RN_{cc} network 253
8.8.3. Structure of the RN_{cc} network 254
8.8.4. Learning results of the RN_{cc} network 255
8.8.5. Results of the test of the RN_{cc} network 256
8.8.6. Experimental validation of the RN_{cc} network 259
8.9. Diagnosis of the rotor fault 263
8.9.1. Choice of the fault indicators of the RN_{bc} network 265
8.9.2. Learning sequence of the RN_{bc} network 265
8.9.3. Learning, test and validation results 266
8.10. Complete monitoring system of the induction machine 267
8.11. Conclusion 268
8.12. Bibliography 269

Chapter 9. Faults Detection and Diagnosis in a Static Converter 271
Mohamed BENBOUZID, Claude DELPHA, Zoubir KHATIR, Stéphane LEFEBVRE and Demba DIALLO

9.1. Introduction 271
9.2. Detection and diagnosis 273
9.2.1. Neural network approach 273
9.2.2. A fuzzy logic approach 280
9.2.3. Multi-dimensional data analysis 285
9.3. Thermal fatigue of power electronic moduli and failure modes 294
9.3.1. Presentation of power electronic moduli in diagnosis 294
9.3.2. Causes and main types of degradation of power electronics moduli 304
9.3.3. Interconnection degradation effects on electrical characteristics and potential use for diagnosis 310
9.3.4. Effects of interface degradation on thermal characteristics and potential use for diagnosis 313
9.4. Conclusion 316
9.5. Bibliography 316

List of Authors 321

Index 327