

# Contents

<b>Abstract</b>	iii
<b>Acknowledgements</b>	ix
<b>List of Figures</b>	xix
<b>List of Tables</b>	xxiii
<b>List of Abbreviations</b>	xxv
<b>List of Symbols</b>	xxvii
<b>Power units equivalence</b>	xxxi
<b>1 General introduction</b>	1
1.1 Background . . . . .	2
1.1.1 Fundamental Model Based methods . . . . .	4
1.1.2 Magnetic Anisotropy Based methods . . . . .	5
Signal Injection Based methods . . . . .	5
Slotting and Rotational Frequency Sideband Harmonics Based methods .	6
1.1.3 Discussion . . . . .	8
1.1.4 Conclusion . . . . .	9
1.2 Objectives . . . . .	9
1.3 Thesis structure . . . . .	10
Bibliography . . . . .	13
<b>2 Sensorless speed estimation for the diagnosis of induction motors via MCSA. Review and commercial devices analysis</b>	19

Abstract . . . . .	20
2.1 Introduction . . . . .	20
2.2 Importance of SSE in diagnosis . . . . .	23
2.3 Methods Based on the Fundamental Model . . . . .	26
2.3.1 Model Reference Adaptive Systems . . . . .	27
2.3.2 Extended Kalman Filter Observer . . . . .	27
2.3.3 Artificial Intelligence . . . . .	28
2.3.4 Methods Based on the Fundamental Model in Online Diagnosis . . . . .	28
2.4 Methods Based on Magnetic Anisotropy . . . . .	29
2.4.1 Methods Based on Signal Injection . . . . .	30
2.4.2 Methods Based on Slotting and Eccentricity Harmonics . . . . .	30
2.4.3 Methods Based on Magnetic Anisotropy in Online Diagnosis . . . . .	33
2.5 Commercial Devices . . . . .	36
2.5.1 EXPLORER 4000 . . . . .	36
Mixed Eccentricity Harmonics: Detectability Problems in Two-Pole Machines . . . . .	37
Mixed Eccentricity Harmonics: Narrow Bandwidth Implications in Rotor Diagnosis . . . . .	38
2.5.2 MCEMAX . . . . .	43
Implications of Nameplate-Based Approximations . . . . .	43
Broken Bars Harmonic: Detectability Problems . . . . .	45
Mixed Eccentricity Harmonic: Detectability and Accuracy Problems . . . . .	48
Diagnosing with Static Eccentricity Harmonics . . . . .	49
2.5.3 Discussion and Lines of Improvement . . . . .	50
2.6 Conclusions . . . . .	52
Appendix A. Industrial Motors Data . . . . .	54
Appendix B. DAQ System . . . . .	55
Bibliography . . . . .	55
<b>3 A precise, general, non-invasive and automatic speed estimation method for MCSA diagnosis and efficiency estimation of induction motors</b>	<b>63</b>

Abstract . . . . .	64
3.1 Introduction . . . . .	64
3.2 Determining RSHs parameters . . . . .	66
3.2.1 Localizing the RSHs . . . . .	68
3.2.2 Determining the parameter $\nu$ . . . . .	69
3.3 On the order $k$ of the RSHs . . . . .	70
3.4 Algorithm . . . . .	71
3.4.1 Block A: Filtering and pre-treatment process . . . . .	72
3.4.2 Block B: Determination of RSHs parameters . . . . .	72
3.4.3 Block C: Slip/Speed estimation . . . . .	72
3.5 Simulation . . . . .	73
3.6 Lab Test . . . . .	75
3.7 Field Test . . . . .	77
3.7.1 Results: three critical examples . . . . .	79
3.7.2 Statistical analysis . . . . .	81
3.8 Conclusions . . . . .	82
Appendix A . . . . .	82
Bibliography . . . . .	83
<b>4 End-ring wear in deep-well submersible motor pumps</b>	<b>87</b>
Abstract . . . . .	88
4.1 Introduction . . . . .	88
4.2 Deep well submersible motor pumps: special features and failure mechanism . . . . .	90
4.2.1 Special features of induction motors in deep well submersible pumps . . . . .	90
4.2.2 Failure mechanism of deep well submersible motor rotor . . . . .	91
4.3 Rotor end-ring wear: false negatives . . . . .	92
4.3.1 Squirrel cage induction model . . . . .	93
4.3.2 False negatives due to low severity of end-ring wear . . . . .	93
4.3.3 False negatives in double segments wear . . . . .	94
4.3.4 False negatives in multiple segments wear . . . . .	95

4.4 Experimental results . . . . .	96
4.5 Field cases . . . . .	100
4.5.1 Field case 1 . . . . .	100
4.5.2 Field case 2 . . . . .	103
4.6 Conclusions . . . . .	105
Appendix A. Simulated motor data . . . . .	105
Bibliography . . . . .	106
<b>5 Comprehensive Analysis of Principal Slot Harmonics as Reliable Indicators for Early Detection of Inter-turn Faults in Induction Motors of Deep-Well Submersible Pumps</b>	<b>109</b>
Abstract . . . . .	110
5.1 Introduction . . . . .	110
5.2 Special features of induction motors in deep-well pumps . . . . .	112
5.3 Finite-element analysis . . . . .	113
5.3.1 Machine with unbalanced supply . . . . .	116
5.3.2 Machine with eccentricity . . . . .	118
5.3.3 Machine with rotor asymmetries . . . . .	120
5.4 Monitoring method for a reliable detection . . . . .	122
5.5 Field case . . . . .	123
5.6 Conclusion . . . . .	127
Appendix A. DAQ system . . . . .	127
Appendix B. Thresholds . . . . .	127
Bibliography . . . . .	128
<b>6 General discussion</b>	<b>131</b>
<b>7 Contributions and conclusions</b>	<b>137</b>
7.1 Contributions . . . . .	138
7.1.1 First publication and state-of-the-art review . . . . .	138
7.1.2 Second publication . . . . .	138
7.1.3 Third publication . . . . .	139

7.1.4	Fourth publication . . . . .	139
7.2	Conclusions . . . . .	140
7.2.1	First publication and state-of-the-art review . . . . .	140
7.2.2	Second publication . . . . .	140
7.2.3	Third publication . . . . .	141
7.2.4	Fourth publication . . . . .	141
7.3	Fulfillment of the objectives . . . . .	143
<b>8</b>	<b>Future works</b>	<b>145</b>
8.1	Extension of algorithm capabilities to estimate speed in transient conditions . . .	146
8.2	Development of a low-cost commercial system for MCSA diagnosis and efficiency estimation in induction motors . . . . .	146
	Bibliography . . . . .	147
<b>A</b>	<b>Short-circuit modeling</b>	<b>149</b>
A.1	Model . . . . .	150
A.2	Currents . . . . .	151
<b>B</b>	<b>Publications</b>	<b>153</b>
B.1	Journals . . . . .	154
B.2	Conferences . . . . .	154
B.3	Patents . . . . .	154