Table of Contents

Preface
Formulae and abbreviations

A Basic Problems

1 Principles of Vector Orientation and Structure of a Vector Orientated Controlled System Using Three-Phase AC Machines 1
1.1 Formation of the space vectors and its vector orientated philosophy 1
1.2 Basic structures of field-orientated control for three-phase AC drives 6
1.3 Basic structures of grid voltage orientated control for DFIM generators 11
1.4 References to chapter 1 15

2 Inverter Control with Space Vector Modulation 17
2.1 Principle of vector modulation 18
2.2 Calculation and output of the switching times 23
2.3 Restrictions of the procedure 26
2.3.1 Actually utilizable vector space 26
2.3.2 Synchronization between modulation and signal processing 28
2.3.3 Consequences of the protection time and its compensation 29
2.4 Realization examples 31
2.4.1 Modulation with microcontroller SAB 80C166 33
2.4.2 Modulation with digital signal processor TMS 320C20/C25 37
2.4.3 Modulation with double processor configuration 45
2.5 Special modulation procedures 49
2.5.1 Modulation with two legs 49
2.5.2 Synchronous modulation 51
2.5.3 Stochastic modulation 53
2.6 References to chapter 2 58

3 Machine Models as Prerequisite to Design Controllers and Observers 61
3.1 General issues of state space representation 61
3.1.1 Continuous state space representation 61
3.1.2 Discontinuous state space representation 63
3.2 Induction machine with squirrel-cage rotor (IM) 69
3.2.1 Continuous state space models of the IM in stator-fixed and 70

	field-synchronous coordinate systems	
3.2.2	Discrete state space models of the IM	78
3.3	Permanent magnet excited synchronous machine (PMSM)	85
3.3.1	Continuous state space model of the PMSM in the field synchronous coordinate system	85
3.3.2	Discrete state model of the PMSM	88
3.4	Doubly-fed induction machine (DFIM)	90
3.4.1	Continuous state space model of the DFIM in the grid synchronous coordinate system	90
3.4.2	Discrete state model of the DFIM	93
3.5	Generalized current process model for the two machine types IM and PMSM	95
3.6	Nonlinear properties of the machine models and the way to nonlinear controllers	97
3.6.1	Idea of the exact linearization	98
3.6.2	Nonlinearities of the IM model	100
3.6.3	Nonlinearities of the DFIM model	102
3.6.4	Nonlinearities of the PMSM model	103
3.7	References to chapter 3	105
4	**Problems of Actual-Value Measurement and Vector Orientation**	107
4.1	Acquisition of the current	108
4.2	Acquisition of the speed	110
4.3	Possibilities for sensor-less acquisition of the speed	116
4.3.1	Example for the speed sensor-less control of an IM drive	118
4.3.2	Example for the speed sensor-less control of a PMSM drive	125
4.4	Field orientation and its problems	127
4.4.1	Principle and rotor flux estimation for IM drives	128
4.4.2	Calculation of current set points	134
4.4.3	Problems of the sampling of operation of the control system	135
4.5	References to chapter 4	139
B	**Three-Phase AC Drives with IM and PMSM**	
5	**Dynamic Current Feedback Control for Fast Torque Impression in Drive Systems**	143
5.1	Survey about existing current control methods	144
5.2	Environmental conditions, closed loop transfer function and control approach	155
5.3	Design of a current vector controller with dead-beat behaviour	159

5.3.1	Design of a current vector controller with dead-beat behaviour with instantaneous value measurement of the current actual-values	159
5.3.2	Design of a current vector controller with dead-beat behaviour for integrating measurement of the current actual-values	163
5.3.3	Design of a current vector controller with finite adjustment time	165
5.4	Design of a current state space controller with dead-beat behaviour	167
5.4.1	Feedback matrix **K**	168
5.4.2	Pre-filter matrix **V**	169
5.5	Treatment of the limitation of control variables	172
5.5.1	Splitting strategy at voltage limitation	174
5.5.2	Back correction strategy at voltage limitation	180
5.6	References to chapter 5	182
6	**Equivalent Circuits and Methods to Determine the System Parameters**	185
6.1	Equivalent circuits with constant parameters	186
6.1.1	Equivalent circuits of the IM	186
6.1.1.1	T equivalent circuit	186
6.1.1.2	Inverse Γ equivalent circuit	188
6.1.1.3	Γ equivalent circuit	189
6.1.2	Equivalent circuits of the PMSM	190
6.2	Modelling of the nonlinearities of the IM	191
6.2.1	Iron losses	191
6.2.2	Current and field displacement	194
6.2.3	Magnetic saturation	198
6.2.4	Transient parameters	204
6.3	Parameter estimation from name plate data	204
6.3.1	Calculation for IM with power factor cosφ	205
6.3.2	Calculation for IM without power factor cosφ	208
6.3.3	Parameter estimation from name plate of PMSM	210
6.4	Automatic parameter estimation for IM in standstill	211
6.4.1	Pre-considerations	211
6.4.2	Current-voltage characteristics of the inverter, stator resistance and transient leakage inductance	213
6.4.3	Identification of inductances and rotor resistance with frequency response methods	215
6.4.3.1	Basics and application for the identification of rotor	215

	resistance and leakage inductance	
6.4.3.2	Optimization of the excitation frequencies by sensitivity functions	217
6.4.3.3	Peculiarities at estimation of main inductance and magnetization characteristic	219
6.4.4	Identification of the stator inductance with direct current excitation	221
6.5	References to chapter 6	223
7	**Online Adaptation of the Rotor Time Constant for IM Drives**	225
7.1	Motivation	225
7.2	Classification of adaptation methods	231
7.3	Adaptation of the rotor resistance with model methods	235
7.3.1	Observer approach and system dynamics	236
7.3.2	Fault models	239
7.3.2.1	Stator voltage models	239
7.3.2.2	Power balance models	242
7.3.3	Parameter sensitivity	244
7.3.4	Influence of the iron losses	249
7.3.5	Adaptation in the stationary and dynamic operation	251
7.4	References to chapter 7	254
8	**Optimal Control of State Variables and Set Points for IM Drives**	257
8.1	Objective	257
8.2	Efficiency optimized control	258
8.3	Stationary torque optimal set point generation	261
8.3.1	Basic speed range	261
8.3.2	Upper field weakening area	265
8.3.3	Lower field weakening area	269
8.3.4	Common quasi-stationary control strategy	272
8.3.5	Torque dynamics at voltage limitation	275
8.4	Comparison of the optimization strategies	279
8.5	Rotor flux feedback control	282
8.6	References to chapter 8	285
9	**Nonlinear Control Structures with Direct Decoupling for Three-Phase AC Drive Systems**	287
9.1	Existing problems at linear controlled drive systems	287
9.2	Nonlinear control structure for drive systems with IM	288
9.2.1	Nonlinear controller design based on "exact linearization"	289

9.2.2	Feedback control structure with direct decoupling for IM	293
9.3	Nonlinear control structure for drive systems with PMSM	295
9.3.1	Nonlinear controller design based on "exact linearization"	295
9.3.2	Feedback control structure with direct decoupling for PMSM	298
9.4	References to chapter 9	300

C Wind Power Plants with DFIM

10	**Linear Control Structure for Wind Power Plants with DFIM**	301
10.1	Construction of wind power plants with DFIM	301
10.2	Grid voltage orientated controlled systems	303
10.2.1	Control variables for active and reactive power	304
10.2.2	Dynamic rotor current control for decoupling of active and reactive power	305
10.2.3	Problems of the implementation	308
10.3	Front-end converter current control	309
10.3.1	Process model	310
10.3.2	Controller design	312
10.4	References to chapter 10	314
11	**Nonlinear Control Structure with Direct Decoupling for Wind Power Plants with DFIM**	315
11.1	Existing problems at linear controlled wind power plants	315
11.2	Nonlinear control structure for wind power plants with DFIM	316
11.2.1	Nonlinear controller design based on "exact linearization"	316
11.2.2	Feedback control structure with direct decoupling for DFIM	319
11.3	References to chapter 11	323
12	**Appendices**	325
12.1	Normalizing - the important step towards preparation for programming	325
12.2	Example for the model discretization in the section 3.1.2	328
12.3	Application of the method of the least squares regression	330
12.4	Definition and calculation of Lie derivation	334
12.5	References to chapter 12	335
	Indices	337