
Variable
speed
electric
drives

Volume 2

Reminders on power
and control electronics
Electronics variable speed drives

Jean Bonal
Guy Séguier



Prométhée
Schneider Electric

Intercept Ltd

Editions
TEC
& **DOC**

Contents

PREFACE	XI
INTRODUCTION	XIII

Part one Power semiconductors

CHAPTER 1	
REMINDER ON SWITCHING AND POWER SEMICONDUCTORS	3

1. Switching	4
1.1. Generators, loads, sources	4
1.2. Characterisation of the role of the “switch”	7
1.3. Switching cell. Methods of switching	11
1.4. Switching vocabulary	13
2. Power semiconductors	17
2.1. Diodes	18
2.2. Thyristors	21
2.3. GTO thyristors	27
2.4. Bipolar power transistors	30
2.5. MOS power transistors	34
2.6. IGBT transistors	38
2.7. The position occupied by the IGBT	40
2.8. Notes on power component characteristics	43

CHAPTER 2
NOTES ON THE APPLICATION OF POWER SEMICONDUCTORS 45

1. Power semiconductor cooling	45
1.1. The heat transfer mechanisms	46
1.2. The losses to be dissipated	49
1.3. Junction-cold source thermal resistance	53
1.4. Notes on the various methods of cooling	55
1.5. Thermal impedance. Transient states	59
1.6. Comments on the mounting of power semiconductors	64
2. Converter cabling	64
2.1. Reminder on lines with distributed constants	65
2.2. Effect of the load on the operation of a line with distributed constants	70
2.3. Effect of frequency on constants per unit length	76
2.4. Notes on electromagnetic susceptibility	79

Part 2

Converters and commutation control

CHAPTER 3
RECTIFIERS AND CYCLOCONVERTERS 89

1. Diode rectifiers	90
1.1. Standard circuits. Simplified study	90
1.2. Output voltage. Input current	94
1.3. Switching. Voltage drop	96
1.4. Continuous or discontinuous conduction	98
2. Thyristor rectifiers	99
2.1. Operation. Study of voltages	99
2.2. Currents. Power diagram	102
2.3. Switching. Voltage drop	103
2.4. Continuous or discontinuous conduction	105
2.5. Commutation control of all-thyristor rectifiers	109
3. Combinations and variants	113
3.1. Mixed bridges	113
3.2. Series combinations	116
3.3. Parallel combinations	117
3.4. Back-to-back combinations	119
3.5. Notes on rectifiers with four bridge branches	123

4. Cycloconverters	126
4.1. Principle. Circuits used	126
4.2. Waveforms of the output voltage and input current	129
4.3. Harmonics	133
4.4. Reactive power consumption	135
4.5. General comments	137

CHAPTER 4 --- VOLTAGE CONTROLLERS

1. Single-phase voltage controller	139
1.1. Operation	139
1.2. Characteristics	142
1.3. Comments on commutation control	145
2. Three-phase voltage controllers	145
2.1. Possible configurations	145
2.2. Operation	147
2.3. Characteristics	149

CHAPTER 5 --- CHOPPERS

1. Non reversible choppers with two switches	152
1.1. Principle of operation	154
1.2. Imperfections in the current source Continuous or discontinuous conduction	155
1.3. Imperfections in the voltage source. Filtering	159
1.4. Control of the switches	162
1.5. Notes on the variable speed control of the series excited motor	166
2. Reversible choppers	168
2.1. Bidirectional chopper with two switches	168
2.2. Bridge chopper	172
3. Combinations of choppers with offset controls	177
3.1. Interleaved choppers	178
3.2. Multilevel choppers	181

CHAPTER 6 --- INVERTERS

1. Three-phase full-wave voltage source inverter	188
1.1. General relationships	188
1.2. Waveforms	190
1.3. Characteristics	192

2. Three-phase PWM voltage source inverter	194
2.1. Natural sampling modulation	194
2.2. Natural sampling modulation variants	201
2.3. Calculated modulation	203
2.4. Vector modulation	204
3. Three-phase multilevel voltage source inverter	208
3.1. Operation of a single-phase half bridge	209
3.2. Three-phase inverter with full-wave control	213
4. Three-phase full-wave current source inverter	216
4.1. General relationships	216
4.2. Waveforms	217
4.3. Characteristics	219
4.4. Supply of a synchronous motor	220
4.5. Supply of an asynchronous induction motor	221
5. Three-phase PWM current source inverter	231
5.1. Sine wave modulation	231
5.2. Calculated modulation	235
5.3. Vector modulation	236

CHAPTER 7 --- PWM RECTIFIERS. ACTIVE FILTERS

1. PWM rectifiers	239
1.1. The two configurations	240
1.2. Current source PWM rectifiers	242
1.3. Voltage source PWM rectifiers	247
2. Active filters	252
2.1. Aims assigned to the filter	252
2.2. Structures of active filters	254
2.3. Hybrid filtering	256

Part 3 Converter control

CHAPTER 8 --- REMINDERS ABOUT SERVODRIVES

1. Laplace transform	263
1.1. Definition. Simple examples	263
1.2. Properties of the Laplace transform	266
1.3. Theorems	269

2. Transfer functions and plots	270
2.1. Response to a pulse or a ramp	271
2.2. Harmonic response. Its representations	275
2.3. Cut-off frequency. Passband	280
2.4. Combination of transfer functions	281
2.5. Transfer functions and plots of systems of a higher order than two	284
3. Systems with closed loop control	290
3.1. Structure of the control	292
3.2. Controllers and correctors	295
3.3. Study of stability through the open loop harmonic response	300
4. Notes on digital control	306
4.1. Principle of digital control	307
4.2. Sampled quantities and systems	308
4.3. Comparison between analogue and digital control	310
5. Notes on state feedback control	312
5.1. State formalism	312
5.2. Solution of the state equation	315
5.3. Digital control	317
5.4. State feedback. Observer	320
6. Appendix : transfer functions of a few simple mechanical systems	323

CHAPTER 9 DIRECT-CURRENT MOTOR CONTROL

1. Introductory remarks	327
2. Model building. Study of the steady state	328
2.1. Model of the motor	328
2.2. Use of reduced variables	331
2.3. Study of the steady state	333
3. Speed control of the motor operating at constant flux	338
3.1. Choice of control system	338
3.2. Model of the supply-motor-load combination	340
3.3. Current controller	346
3.4. Speed controller	350
3.5. Note on position control	355
4. Speed control of the motor by controlling the flux	356
4.1. Coordination of the two controls	356
4.2. Excitation adjustment	358

CHAPTER 10 **ASYNCHRONOUS INDUCTION MOTOR CONTROL** 363

1. Introduction	363
2. Model of the asynchronous motor in the dynamic state	365
2.1. Preliminary step : vector representation of a three-phase system	365
2.2. Hypotheses. Quantities represented	367
2.3. Flux and current equations	368
2.4. Voltage equations. Torque	368
2.5. Equivalent diagram	369
3. Scalar control of the motor supplied by a voltage source inverter	371
3.1. Very simplified control	371
3.2. Speed control with flux regulation by the stator voltage modulus	373
3.3. Improved flux control: speed control by the stator voltage components	375
3.4. Speed control with flux controlled by the stator current	375
4. Scalar control of the motor supplied by a current source inverter	382
4.1. Preliminary remarks	382
4.2. Separate control of rotor current and frequency	383
4.3. Flux control	384
4.4. Notes on operation with field weakening	385
5. Vector control	386
5.1. Decoupling the flux and the torque	386
5.2. Locking the current components. Example	388
5.3. Direct flux vector control	390
5.4. General comments on vector control	393
5.5. Application to the current source inverter	394
6. Direct torque control	395
6.1. Principle	396
6.2. Stator flux and electromagnetic torque control	397
6.3. Motor models	399
6.4. Example of a control system diagram	400
7. Comparison and development of controls	401

CHAPTER 11 **SYNCHRONOUS MOTOR CONTROL** 403

1. Preliminary remarks	403
1.1. Main differences compared with asynchronous machines	403
1.2. The variable speed synchronous motor. Study programme	404

2. The synchronous machine in the steady state	405
2.1. Synchronous motor with wound rotor and non salient poles	405
2.2. Synchronous motor with wound rotor and salient poles	407
2.3. Notes on permanent magnet synchronous machines	410
3. The voltage-fed or current-fed synchronous machine	410
3.1. Torque control of a voltage-fed machine	411
3.2. Torque control of a current-fed machine	413
3.3. Criteria for comparison of the methods of control	414
3.4. Control of a non salient pole synchronous machine	415
3.5. Control of a salient pole synchronous machine	418
4. The converter-fed asynchronous motor supplied by a line-commutated current source inverter	418
4.1. Study of commutation. Consequences of converter-fed control	419
4.2. Machine control	433
4.3. Comments	438
BIBLIOGRAPHY	441
SYMBOLS USED	443
INDEX	445