

---

# Contents

---

<b>Preface</b>	<b>xiii</b>
<b>Part I Analogue control circuits</b>	<b>1</b>
<b>1 PWM-based sliding mode control schemes for DC/DC power converters</b>	<b>3</b>
1.1 Introduction	3
1.2 Basic sliding mode control theory	4
1.3 PWM-based SM control	6
1.4 PWM-based SM voltage control	7
1.5 PWM-based SM current control	15
1.6 Practical implementation and design issues	19
1.7 Conclusions	24
References	24
<b>2 Synthetic-ripple hysteretic controllers for DC/DC converters</b>	<b>27</b>
2.1 Hysteretic controllers for DC/DC converters	28
2.2 Building blocks and non-idealities	30
2.2.1 Converter	30
2.2.2 Carrier generation circuit	32
2.2.3 Hysteretic controller	33
2.2.4 Voltage feedback	35
2.3 Synthetic carrier generation circuit	40
2.3.1 Passive filtering technique	41
2.3.2 Active filtering technique	43
2.4 Load current feedforward	46
2.5 Linear model development	48
2.5.1 Modelling an SRG	48
2.5.2 Modelling a hysteretic controller	49
2.6 Conclusions	50
References	50
<b>3 One-cycle controlled power inverters</b>	<b>53</b>
3.1 Introduction	53
3.2 OCC: operating principle and applications overview	55
3.3 OCC inverters for PV applications	59
3.3.1 OCC for single-phase PV inverters	60

3.3.2	OCC for three-phase PV inverters	66
3.4	OCC stability analysis by means of <i>Poincaré</i> maps	69
3.5	Conclusions	73
	References	73
<b>Part II</b>	<b>Digital control circuits</b>	<b>77</b>
<b>4</b>	<b>Digital PWM control of high-frequency DC-DC switched-mode power converters</b>	<b>79</b>
4.1	The digital control loop	80
4.1.1	Timing diagram and controller operation	82
4.1.2	Loop delays	83
4.2	Dynamic modeling and system-level compensator design	84
4.2.1	Loop small-signal modeling	85
4.2.2	Compensator design and discretization	85
4.3	Quantization effects and limit cycling	87
4.3.1	A/D quantization	88
4.3.2	Modulation quantization	88
4.3.3	No-limit-cycling design criteria	88
4.4	Controller implementation	91
4.4.1	Analog-to-digital converter	92
4.4.2	Digital compensator	94
4.4.3	Digital MPM	96
4.5	Summary of Key Points	99
	References	99
<b>5</b>	<b>Microcontroller-based electronic ballasts for high-intensity discharge lamps</b>	<b>103</b>
5.1	HID lamp operation principles and modelling	103
5.1.1	HID lamps	103
5.1.2	HID lamps operating requirements	105
5.1.3	HID lamps modelling	107
5.2	Electronic ballasts for HID lamps	109
5.2.1	AC-operated electronic ballasts	109
5.2.2	DC-operated electronic ballasts	111
5.3	Digital control applied to electronic ballasts	111
5.3.1	General control strategy applied to HID lamps	111
5.3.2	PFC converter	112
5.3.3	DC-DC converter	112
5.3.4	Low-frequency inverter	113
5.3.5	Igniter	113
5.3.6	Protections	114
5.4	Practical example	114
5.4.1	HID lamp ballast	114
5.4.2	Microcontroller PIC16F684	115
5.4.3	Control strategy	116

5.4.4	Lamp starting	116
5.4.5	Warm-up process	117
5.4.6	Steady state	118
5.4.7	Protections	119
5.4.8	Experimental results	119
5.5	Summary	122
	References	122
<b>6</b>	<b>FPGA-based controllers for direct sliding mode control of PWM boost rectifiers</b>	<b>125</b>
6.1	Introduction	125
6.2	Sliding mode control: theory and application for power converters control	126
6.3	Direct sliding mode control for single-phase PWM rectifier	127
6.3.1	Single-phase PWM rectifier model	127
6.3.2	Steady-state operation limits	129
6.3.3	Synthesis of the direct sliding mode control	130
6.3.4	FPGA-based controller	132
6.4	Direct sliding mode control for three-phase PWM rectifier	136
6.4.1	Three-phase PWM rectifier model	136
6.4.2	Steady-state operation limits	138
6.4.3	Synthesis of the direct sliding mode control	139
6.4.4	FPGA-based controller	143
6.5	Conclusion	148
	References	149
<b>7</b>	<b>DSP controllers for three-phase unity-power-factor rectifiers</b>	<b>151</b>
7.1	Introduction	151
7.2	DSP boards for power converters control	151
7.3	Topologies for three-phase unity-power-factor rectifiers	152
7.3.1	Three-phase rectifiers: VSR and CSR	154
7.3.2	Novel topologies: Y- or $\Delta$ -switch rectifier and VIENNA rectifier	157
7.4	Phase-locked loops algorithms	159
7.4.1	Implementation of PLL algorithms with fixed sampling time in three-phase systems	160
7.4.2	Implementation of single-phase PLLs with fixed sampling time	162
7.4.3	Implementation of PLL algorithms with varying sampling time in three-phase systems	167
7.4.4	Implementation of single-phase PLLs with varying sampling time	168
7.4.5	Comments	170
7.5	Control algorithms for UPF rectifiers	172
7.5.1	$dq$ frame-based control	172
7.5.2	$pq$ theory-based control	175

7.5.3	Predictive control	178
7.6	Conclusions	184
	References	185
<b>8</b>	<b>DSP controllers for grid-connected three-phase voltage-sourced inverters</b>	<b>189</b>
8.1	Introduction	189
8.2	Modeling and control structures of grid-connected three-phase voltage-sourced inverters (VSIs)	191
8.2.1	Modeling in an orthogonal stationary reference frame (StatRF)	191
8.2.2	Modeling in an orthogonal synchronous reference frame (SRF)	199
8.2.3	Control of a grid-connected PV inverter with LCL filter	205
8.3	DSP control of a grid-connected PV inverter with LCL filter in the StatRF	211
8.3.1	Design and programming of the current loops in the StatRF	211
8.3.2	Design and programming of the voltage loop in the StatRF	218
8.4	DSP control of a grid-connected PV inverter with LCL filter in the SRF	222
8.4.1	Design and programming of the current loops in the SRF	222
8.4.2	Design and programming of the voltage loop in the SRF	230
8.5	Experimental results	230
8.6	Conclusions	237
	Acknowledgment	237
	References	238
<b>9</b>	<b>FPGA-DSP controllers for DC-DC converters in renewable energy applications</b>	<b>241</b>
9.1	Introduction	241
9.2	FPGA and DSP-based multi-functional digital controller	241
9.2.1	Controller platform	241
9.2.2	DSP-FPGA synchronization	244
9.2.3	Explanation of function blocks in the FPGA device	246
9.2.4	Implementation of a touch panel	246
9.3	Development of new topologies and control schemes for DC-DC converters	248
9.3.1	High step-up passive clamp circuits	248
9.3.2	Three-phase interleaved high step-up converters	254
9.4	Application of the new topologies for PV installations	263
9.5	Conclusions	264
	References	265
<b>10</b>	<b>Multilevel converters: topologies, modulation and control</b>	<b>267</b>
10.1	Introduction	267
10.2	Multilevel converter topologies	268

10.2.1	Diode-clamped converter (DCC)	269
10.2.2	Flying capacitor (FC) converter	270
10.2.3	Cascaded H-bridge multilevel converter	272
10.2.4	Modular multilevel converter	274
10.3	Modulation techniques for multilevel converters	275
10.3.1	Low switching frequency modulation techniques	277
10.3.2	High switching frequency modulation techniques	278
10.3.3	MMC: circulating current control and capacitor voltage balance	287
10.3.4	Common and differential circuits	287
10.4	Digital controller implementations for multilevel converters	293
10.4.1	Centralised digital controllers for converters with a low number of levels	293
10.4.2	Distributed digital controllers for converters with large number of levels	295
10.5	Conclusions	297
	References	298
<b>Part III</b>	<b>New trends in control circuits for power electronics</b>	<b>307</b>
<b>11</b>	<b>State-of-the-art intelligent gate drivers for IGBT power modules – monitoring, control and management at the heart of power converters</b>	<b>309</b>
11.1	Introduction to gate drivers	309
11.1.1	Power electronic systems, IGBTs and gate driver units	310
11.1.2	Sensing and control systems	313
11.2	Innovative gate driver and system architecture	316
11.2.1	System integration	316
11.2.2	High temperature operation	318
11.3	Integrated data acquisition methods	319
11.3.1	Voltage measurement	321
11.3.2	Current measurement	322
11.3.3	Temperature measurement	325
11.4	Intelligent control	326
11.4.1	Condition monitoring	326
11.4.2	Control of switching characteristics	327
11.4.3	Series connection	329
11.4.4	Parallel connection	331
11.5	Summary	333
	Acknowledgements	333
	References	333
<b>12</b>	<b>Control of integrated switched capacitor power converters</b>	<b>337</b>
12.1	Introduction	337
12.2	Charge pump design considerations	338

12.3	Control schemes	341
12.3.1	Two-stage regulation strategies	343
12.3.2	Reconfiguration schemes	346
12.3.3	Pulse frequency modulation and pulse control schemes	349
12.3.4	Interleaving multiphase regulation	352
12.4	Conclusions	354
	References	354
<b>13</b>	<b>DSP-based natural frame control schemes for three-phase unity power factor rectifiers</b>	<b>357</b>
13.1	Introduction	357
13.2	Physical model of the power converter	358
13.3	Conventional sliding mode control in three-phase converters	359
13.4	Decoupled model of the power converter	360
13.4.1	Decoupled model derivation	361
13.4.2	Controllability and observability of the proposed model	363
13.5	Sliding mode control scheme based on estimators	363
13.5.1	Discrete decoupled model	364
13.5.2	KF algorithm	365
13.5.3	Practical considerations: selection of Q and R matrices	365
13.5.4	Practical considerations: computational load reduction	366
13.6	Sliding mode control of a UPFR	366
13.6.1	Inner control loop	367
13.6.2	Outer control loop	367
13.7	Sliding mode control operating at fixed switching frequency	369
13.7.1	Variable hysteresis band calculation	369
13.7.2	Switching decision algorithm	371
13.7.3	Switching frequency spectrums	373
13.8	Experimental results	375
13.9	Summary	375
	References	378
<b>14</b>	<b>Dual-core DSP for control and communication in AC microgrids</b>	<b>381</b>
14.1	Introduction	381
14.2	Control in AC microgrids	382
14.2.1	Microgrid architecture	382
14.2.2	Power converters in AC microgrids	383
14.2.3	Microgrid scenarios	385
14.3	Control of grid-forming power converters	386
14.3.1	Primary control	386
14.3.2	Secondary control	388
14.3.3	Tertiary control	390
14.4	Communication in AC microgrids	391
14.4.1	Communication protocols	391
14.4.2	Example of a low-scale laboratory microgrid	392

14.5	Dual-core DSP for control and communication	394
14.5.1	Control and communication in DSP technology	394
14.5.2	Description of the dual-core system architecture	395
14.5.3	Control functions implemented in the C28 core	397
14.5.4	Communication procedures implemented in the M3 core	398
14.5.5	Extension to other control and communication schemes in AC microgrids	400
14.6	Experimental tests in the low-scale laboratory microgrid	401
14.6.1	Performance evaluation of the primary control	402
14.6.2	Performance evaluation of the secondary control	404
14.6.3	Effects of packet loss in the communication network	406
14.7	Conclusions	407
	References	408
<b>15</b>	<b>Use of computational intelligence for designing power electronics converters</b>	<b>411</b>
15.1	Introduction	411
15.2	Formulation of fitness function	413
15.2.1	Type-one fitness function	413
15.2.2	Type-two fitness function	414
15.2.3	Fitness function for the PCS	414
15.2.4	Fitness function for FN	416
15.3	Description of GA	417
15.4	Description of ACO	420
15.4.1	Data structure	421
15.4.2	Procedures	421
15.5	Design examples and implementation issues	423
15.5.1	Design objectives	423
15.5.2	Design using GA	424
15.5.3	Design using ACO	427
15.6	Summary	427
	References	429
	<b>Index</b>	<b>431</b>