Contents

About the Authors ix

Preface xi

1 Power electronic devices, circuits, topology, and control 1
   1.1 Power electronics 1
   1.2 The evolution of power device technology 3
   1.3 Power electronic circuit topology 4
      1.3.1 Switching 5
      1.3.2 Basic switching cell 6
      1.3.3 Circuit topology of power electronics 6
   1.4 Pulse-width modulation control 9
   1.5 Typical power electronic converters and their applications 15
   1.6 Transient processes in power electronics and book organization 16
   References 17

2 Macroscopic and microscopic factors in power electronic systems 19
   2.1 Introduction 19
   2.2 Microelectronics vs. power electronics 21
      2.2.1 Understanding semiconductor physics 22
      2.2.2 Evaluation of semiconductors 23
   2.3 State of the art of research in short-timescale transients 27
      2.3.1 Pulse definition 28
      2.3.2 Pulsed energy and pulsed power 30
   2.4 Typical influential factors and transient processes 35
      2.4.1 Failure mechanisms 35
      2.4.2 Different parts of the main circuit 38
      2.4.3 Control modules and power system interacting with each other 40
   2.5 Methods to study the short-timescale transients 41
   2.6 Summary 42
   References 43
3 Power semiconductor devices, integrated power circuits, and their short-timescale transients 47
  3.1 Major characteristics of semiconductors 47
  3.2 Modeling methods of semiconductors 48
    3.2.1 Hybrid model of a diode 49
  3.3 IGBT 49
  3.4 IGCT 52
  3.5 Silicon carbide junction field effect transistor 54
  3.6 System-level SOA 58
    3.6.1 Case 1: System-level SOA of a three-level DC–AC inverter 59
    3.6.2 Case 2: System-level SOA of a bidirectional DC–DC converter 59
    3.6.3 Case 3: System-level SOA of an EV battery charger 60
  3.7 Soft-switching control and its application in high-power converters 65
    3.7.1 Case 4: ZCS in dual-phase-shift control 65
    3.7.2 Case 5: Soft-switching vs. hard-switching control in the EV charger 67
References 68

4 Power electronics in electric and hybrid vehicles 71
  4.1 Introduction of electric and hybrid vehicles 71
  4.2 Architecture and control of HEVs 72
  4.3 Power electronics in HEVs 73
    4.3.1 Rectifiers used in HEVs 74
    4.3.2 Buck converter used in HEVs 79
    4.3.3 Non-isolated bidirectional DC–DC converter 81
    4.3.4 Control of AC induction motors 87
  4.4 Battery chargers for EVs and PHEVs 93
    4.4.1 Unidirectional chargers 95
    4.4.2 Inductive charger 106
    4.4.3 Wireless charger 110
    4.4.4 Optimization of a PHEV battery charger 112
    4.4.5 Bidirectional charger and control 116
References 126

5 Power electronics in alternative energy and advanced power systems 129
  5.1 Typical alternative energy systems 129
  5.2 Transients in alternative energy systems 130
    5.2.1 Dynamic process 1: MPPT control in the solar energy system 130
    5.2.2 Dynamic processes in the grid-tied system 133
    5.2.3 Wind energy systems 138
5.3 Power electronics, alternative energy, and future micro-grid systems 141
5.4 Dynamic process in the multi-source system 145
5.5 Speciality of control and analyzing methods in alternative energy systems 149
5.6 Application of power electronics in advanced electric power systems 150
   5.6.1 SVC and STATCOM 151
   5.6.2 SMES 153
References 155

6 Power electronics in battery management systems 157
   6.1 Application of power electronics in rechargeable batteries 157
   6.2 Battery charge management 158
      6.2.1 Pulsed charging 158
      6.2.2 Reflex fast charging 159
      6.2.3 Current variable intermittent charging 160
      6.2.4 Voltage variable intermittent charging 161
      6.2.5 Advanced intermittent charging 162
      6.2.6 Practical charging schemes 162
   6.3 Cell balancing 166
      6.3.1 Applying an additional equalizing charge phase to the whole battery string 167
      6.3.2 Method of current shunting – dissipative equalization 169
      6.3.3 Method of switched reactors 170
      6.3.4 Method of flying capacitors 171
      6.3.5 Inductive (multi-winding transformer) balancing 172
      6.3.6 ASIC-based charge balancing 172
      6.3.7 DC–DC converter-based balancing 173
   6.4 SOA of battery power electronics 175
      6.4.1 Enhanced system-level SOA considering the battery impedance and temperature 175
      6.4.2 Interaction with other devices at different temperatures 177
References 180

7 Dead-band effect and minimum pulse width 183
   7.1 Dead-band effect in DC–AC inverters 184
      7.1.1 Dead-band effect 186
   7.2 Dead-band effect in DC–DC converters 189
      7.2.1 Phase shift-based dual active bridge bidirectional DC–DC converter 189
      7.2.2 Dead-band effect in DAB bidirectional DC–DC converter 193
   7.3 Control strategy for the dead-band compensation 199


7.4 Minimum Pulse Width (MPW) 204
   7.4.1 Setting the MPW 209
7.5 Summary 211
References 212

8 Modulated error in power electronic systems 215
   8.1 Modulated error between information flow and power flow 215
   8.2 Modulated error in switching power semiconductors 217
      8.2.1 Voltage-balanced circuit for series-connected semiconductors 217
      8.2.2 Accompanied short-timescale transients 221
   8.3 Modulated error in the DC–AC inverter 231
   8.4 Modulated error in the DC–DC converter 234
   8.5 Summary 246
   References 246

9 Future trends of power electronics 249
   9.1 New materials and devices 249
   9.2 Topology, systems, and applications 255
   9.3 Passive components 259
   9.4 Power electronics packaging 260
   9.5 Power line communication 262
   9.6 Transients in future power electronics 265
   References 266

Index 269