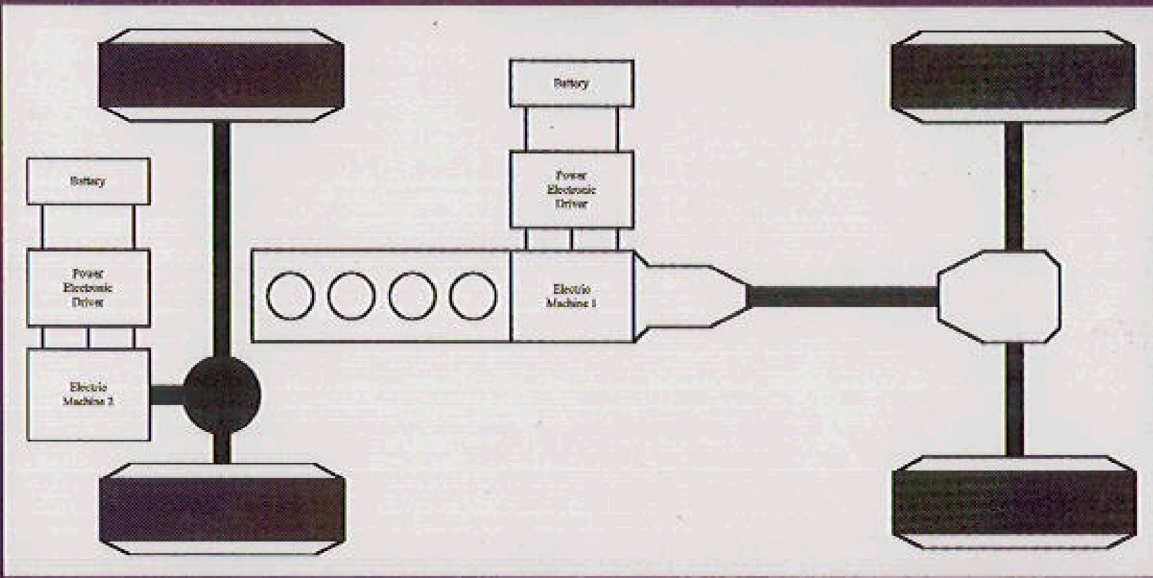

HANDBOOK OF AUTOMOTIVE POWER ELECTRONICS AND MOTOR DRIVES

EDITED BY

ALI EMADI

CRC Taylor & Francis
Taylor & Francis Group

Table of Contents

PART I. Automotive Power Systems 1

1. Conventional Cars 3
Roberto Giral-Castillón, Luis Martínez-Salamero, and Javier Maixé-Altés
1.1 Introduction 3
1.2 Evolution of the Distribution Electrical System 3
1.2.1 Control Strategy and Wiring Topology 5
1.2.2 Power Bus Topology 5
1.2.3 Components 6
1.3 The Conventional System of Electrical Distribution in Automobiles 6
1.3.1 Battery and Its Charging System 6
1.3.2 Motor Starter System 6
1.3.3 Management System 6
1.4 Wiring System 6
1.4.1 Fuses 8
1.4.1.1 Polymeric Positive Temperature Coefficient Devices 9
1.4.1.2 Smart Power Switches 11
1.4.2 Behavior Comparison among the Different Protection Devices 12
1.5 Load Control: Automotive Control Network Protocols 13
1.5.1 Controller Area Network (CAN) 14
1.5.2 Local Interconnect Network (LIN) 14
1.5.3 Byteflight 15
1.5.4 Time Triggered Protocol (TTP/C) 15
1.6 New Architectures 15
1.6.1 Electric Security 15
1.6.2 Voltage Effect on the Components 16
1.7 Alternative Architectures 16
1.7.1 High Frequency AC Bus System 16
1.7.2 Dual-Voltage DC Bus 17
References 18

2. Hybrid Electric Vehicles 21
John M. Miller
2.1 Parallel Configuration 26
2.2 Series Configuration 29

2.3 Combination Architectures 31
2.4 Grid Connected Hybrids 33
References 35

3. Hybrid Drivetrains 37
M. Ehsani and Yimin Gao
3.1 Concept of Hybrid Vehicle Drivetrain 37
3.2 Series Hybrid Drivetrain 38
3.3 Parallel Hybrid Drivetrains 40
3.3.1 Parallel Hybrid Drivetrains with Torque Coupling 40
3.3.1.1 Torque Coupler 40
3.3.1.2 Drivetrain Configuration and Operating Characteristics 41
3.3.2 Parallel Hybrid Drivetrain with Speed Coupling 46
3.3.2.1 Speed Coupler 46
3.3.2.2 Drivetrain Configurations and Operating Characteristics 47
3.4 Drivetrains with Selectable Torque Coupling and Speed Coupling 48
3.5 Parallel-Series Hybrid Drivetrain with Torque Coupling and Speed Coupling 50
3.6 Fuel Cell-Powered Hybrid Drivetrain 50
References 52

4. Electric Vehicles 55
Ramesh C. Bansal
4.1 Introduction 55
4.2 Hybrid Electric Vehicles 56
4.3 Main Components of an EV 57
4.3.1 Motors 57
4.4 Main Safety Components in an EV 58
4.5 Instrumentation 59
4.6 Main Auxiliaries in an EV 60
4.7 Types of Power Storage Used in EVs 63
4.7.1 Batteries 63
4.7.2 Types of Batteries Available Today 64
4.7.3 Flywheels 67
4.7.4 Ultracapacitors 67
4.8 Emissions Performance 68
4.9 Solar Cars 69
4.10 Fuel Cell Cars 69
4.10.1 Introduction 69
4.10.2 Fuel Cell Cars 71
Bibliographical Survey on Electric Vehicles 72
References 73

5. Optimal Power Management and Distribution in Automotive Systems 97
Zheng John Shen, X. Chen, A. Masrur, V.K. Garg, and A. Soltis
5.1 Introduction 97
5.2 Automotive Power/Energy Management and Distribution Architecture 99

5.2.1 Power Generation 99
5.2.2 Energy Storage 100
5.2.3 Power Bus 100
5.2.4 Electrical Load 101
5.2.5 Power Electronics 101
5.2.6 PMC 101
5.3 Optimization-Based Power Management System Strategy 101
5.3.1 Dynamic Resource Allocation 103
5.3.2 Practical Constraints of Vehicle Components 103
5.3.3 Uninterruptible Power Availability 103
5.3.4 Power Quality 103
5.3.5 System Stability 104
5.3.6 Fault Diagnosis and Prognosis 104
5.4 Case Study: Game-Theoretic Optimal Hybrid Electric Vehicle Management and Control Strategy 104
5.4.1 System Dynamics 105
5.4.2 Strategy Design 106
5.4.3 Game-Theoretic Approach 107
5.4.4 Simulation Results 110
5.5 Summary 112
References 112

PART II. Automotive Semiconductor Devices, Components, and Sensors 115

6. Automotive Power Semiconductor Devices 117
Zheng John Shen
6.1 Introduction 117
6.2 Diodes: The Rectification, Freewheeling, and Clamping Devices 120
6.2.1 Rectifier Diodes 121
6.2.2 Freewheeling Diodes 121
6.2.3 Zener Diodes 124
6.2.4 Schottky Diode 125
6.3 Power MOSFETs: The Low-Voltage Load Drivers 125
6.3.1 MOSFET Basics 127
6.3.2 MOSFET Characteristics 129
6.4 IGBTs: The High-Voltage Power Switches 139
6.4.1 IGBT Basics 141
6.4.2 IGBT Power Modules 146
6.4.3 Ignition IGBT 147
6.5 Power Integrated Circuits and Smart Power Devices 148
6.6 Emerging Device Technologies: Super-Junction and SiC Devices 150
6.7 Power Losses and Thermal Management 154
6.8 Summary 156
References 156

7. Ultracapacitors 159
John M. Miller
7.1 Theory of Electronic Double Layer Capacitance 161
7.2 Model and Cell Balancing 168

7.3 Sizing Criteria 174
7.4 Converter Interface 177
7.5 Ultracapacitors in Combination with Batteries 182
References 187

8. Flywheels 189
John M. Miller
8.1 Flywheel Theory 189
8.2 Flywheel Applications in Hybrid Vehicles 192
8.3 Energy Storage System Outlook 193
References 194

9. ESD Protection for Automotive Electronics 195
Albert Z.H. Wang
9.1 Introduction 195
9.2 ESD Failures and ESD Test Models 196
9.3 On-Chip ESD Protection 201
References 211

10. Sensors 213
Mario Mañana Canteli
10.1 Introduction 213
10.2 Architecture of Electronic Control Units 214
10.3 Voltage and Current Measurement 218
10.4 Temperature 221
10.5 Acceleration 222
10.6 Pressure 223
10.7 Velocity, Position, and Displacement 223
10.8 Other Sensors 224
10.9 Reliability Constraints in Automotive Environment 226
10.10 Conclusions 226
References 227

PART III. Automotive Power Electronic Converters **229**

11. DC-DC Converters 231
James P. Johnson
11.1 Why DC-DC Converters? 231
11.2 DC-DC Converter Basics 233
11.3 DC-DC Converter Types 233
11.4 Buck, Boost, and Buck-Boost Converter Commonalities 234
11.5 The Buck Converter 237
11.6 The Boost Converter 239
11.7 The Buck-Boost Converter 240
11.8 Isolated Inverter Driven Converters 241
11.9 Push-Pull Converter 242
11.10 Half-Bridge 243
11.11 Full-Bridge 244
11.12 Other Converter Types 244

11.13 Control 245
11.14 Essential Converter Circuits 247
11.15 Important Points to Consider 250
11.16 Simulation vs. Analytical Methods 251
11.17 Loss Calculations 251
11.18 Power Device Selections 251
11.19 EMI 252
11.20 Other Practical Converter Development Considerations 252
References 253

12. AC-DC Rectifiers 255
Byoung-Kuk Lee and Chung-Yean Won
12.1 Diode AC-DC Rectifier 255
12.1.1 Main Characteristics and Circuit Configuration 255
12.1.2 Analysis of Three-Phase Full-Bridge Diode Rectifier 255
12.1.2.1 Circuit without Input Inductors and DC-Link Capacitor 255
12.1.2.2 Circuit with Input Inductors and DC-Link Capacitor 256
12.1.2.3 Commutation Analysis Considering Effect of the Input Inductance 257
12.1.3 Analysis of Input Phase Current and Output Current of Diode Rectifier 259
12.1.4 Calculation of DC-Link Power 259
12.1.5 Calculations of DC-Link Capacitor According to Various Load Conditions 260
12.1.5.1 Case of Continuous Full Load Condition 260
12.1.5.2 Case of Overload Condition 261
12.1.5.3 Case of Motor Accelerating Condition 261
12.1.6 Design of Dynamic Breaking Unit 263
12.1.6.1 Design Procedure of Dynamic Breaking Resistor 263
12.2 Thyristor AC-DC Rectifier 264
12.2.1 Topology and Operation Modes 264
12.2.2 Fire Angle Control Scheme 264
12.2.2.1 Linear Fire Angle Control Scheme 265
12.2.2.2 Cosine Wave Crossing Scheme 267
12.2.2.3 PLL Scheme 267
12.2.3 Analysis of Three-Phase Full-Bridge Thyristor Rectifier 268
12.2.3.1 Equivalent Circuit and Output Voltage 268
12.2.3.2 Influence of Input Inductance 268
12.2.3.3 Selection of Input Inductance 271
References 271

13. Unbalanced Operation of Three-Phase Boost Type Rectifiers 273
Ana V. Stankovic
13.1 System Description and Principles of Operation 274
13.2 Analysis of the PWM Boost Type Rectifier under Unbalanced Operating Conditions 275
13.2.1 Harmonic Reduction in the PWM Boost Type Rectifier under Unbalanced Operating Conditions 278

13.3 Control Methods for Input/Output Harmonic Elimination of the PWM Boost Type Rectifiers under Unbalanced Operating Conditions 279
13.3.1 Control Method for Input/Output Harmonic Elimination under Unbalanced Input Voltages and Balanced Input Impedances 279
13.3.1.1 Theoretical Approach 279
13.3.1.2 Control Method 282
13.3.1.3 The Physical Meaning of the Proposed Solution in d-q Stationary Frame 283
13.3.2 Control Method for Input/Output Harmonic Elimination of the PWM Boost Type Rectifier under Unbalanced Input Voltages and Unbalanced Input Impedances 287
Derivation 287
13.3.2.1 Control Method 291
13.3 Conclusion 293
References 294

14. DC/AC Inverters 295
Mohan Aware
14.1 DC-to-AC Conversion 295
14.2 Types of Inverters 298
14.3 Voltage Source Inverters 299
14.3.1 Single-Phase Inverters 300
14.3.1.1 Half-Bridge Inverters 300
14.3.1.2 Full-Bridge Inverter 301
14.3.2 Three-Phase Inverters 304
14.3.2.1 Six-Step Operation 304
14.3.2.2 Voltage and Frequency Control 309
14.3.2.3 Motoring and Regeneration Mode 308
14.4 Current Source Inverters 308
14.5 Control Techniques 310
14.5.1 Voltage Control Technique 310
14.5.1.1 Sinusoidal PWM (SPWM) Technique 311
14.5.1.2 Modulating Function PWM Techniques 312
14.5.1.3 Voltage Space-Vector PWM Techniques 313
14.5.1.4 Programmed PWM Techniques 317
14.5.2 Current Control Technique 318
14.5.2.1 Hysteresis Current Control 318
14.5.2.2 Ramp-Comparison Current Control 319
14.5.2.3 Predictive Current Control 320
14.5.2.4 Linear Current Control 321
14.6 Multilevel Inverters 321
14.7 Hard Switching Effects 325
14.7.1 Switching Loss 325
14.7.2 Device Stress 325
14.7.3 EMI Problems 325
14.7.4 Effect on Insulation 325
14.7.5 Machine Bearing Current 325
14.7.6 Machine Terminal over Voltage 326
14.8 Resonant Inverters 326

14.8.1 Soft-Switching Principle 326
14.8.2 Resonant Link DC Converter (RLDC) 327
14.9 Auxillary Automotive Motors Control 338
14.9.1 Commutator Motors 329
14.9.2 Switched Field Motors 330
References 331

15. AC/AC Converters 333
Mehrdad Kazerani
15.1 Introduction 333
15.2 AC/AC Converter Topologies 334
15.2.1 Indirect AC/AC Converter 334
15.2.2 Direct AC/AC Converter 336
15.2.2.1 Naturally Commutated Cycloconverter (NCC) 336
15.2.2.2 Forced-Commutated Cycloconverter (Matrix Converter) 339
15.3 Summary 345
References 346

16. Power Electronics and Control for Hybrid and Fuel Cell Vehicles 347
Kaushik Rajashekara
16.1 Introduction 347
16.2 Hybrid Electric Vehicles 347
16.2.1 Series Hybrid Vehicle Propulsion System 348
16.2.2 Parallel Hybrid Vehicle Propulsion System 349
16.2.2.1 Toyota Prius 350
16.2.2.2 Crankshaft-Mounted Integrated Starter-Generator System 352
16.2.2.3 Side-Mounted Integrated Starter-Generator 353
16.3 Fuel Cell Vehicles 354
16.3.1 Fuel Cell Vehicle Propulsion System 355
16.3.2 Fuel Cell Vehicle Propulsion System Considerations 358
16.4 Power Electronics Requirements 359
16.5 Propulsion Motor Control Strategies 360
16.5.1 Slip Frequency Control 362
16.5.2 Vector Control of Propulsion Motor 362
16.5.3 Sensorless Operation 363
16.6 APU Control System in Series Hybrid Vehicles 364
16.7 Fuel Cell for APU Applications 366
References 369

PART IV. Automotive Motor Drives **371**

17. Brushed-DC Electric Machinery for Automotive Applications 373
Babak Fahimi
17.1 Fundamentals of Operation 374
17.1.1 Introduction 374
17.1.2 Torque Production in Brushed DC-Motor Drives 377
17.1.3 Impact of Temperature on Performance of a BLDC Drive 379
17.2 Series Connected DC-Motor Drives 383

18. Induction Motor Drives 387
Khaled Nigim
18.1 Introduction 387
18.2 Torque and Speed Control of Induction Motor 388
18.3 Basics of Power Electronics Control in Induction Motors 389
18.4 Induction Motor VSD Operating Modes 390
18.5 Fundamentals of Scalar and Vector Control for Induction Motors 393
18.5.1 Scalar Control 393
18.5.1.1 Open Loop Scalar Control 393
18.5.1.2 Closed Loop Scalar Control 393
18.5.2 Fundamentals of Field-Oriented Control (Vector Control) in Induction Motors 394
18.5.2.1 Field-Oriented Control 394
18.5.2.2 Direct Torque Control 397
18.6 Induction Motor Drives for Electric Vehicles 399
18.7 Conclusion 401
References 402
Appendix: Induction Motor Model in the Stationary Frame 403

19. DSP-Based Implementation of Vector Control of Induction Motor Drives 405
Hossein Salehfar
19.1 Introduction 405
19.2 Space Vector Control 405
19.3 Experimental Results 410
19.4 Conclusions 413
References 413

20. Switched Reluctance Motor Drives 415
Babak Fahimi and Chris Edrington
20.1 Introduction 415
20.2 Historical Background 416
20.3 Fundamentals of Operation 417
20.4 Fundamentals of Control in SRM Drives 424
20.4.1 Open Loop Control Strategy for Torque 425
20.4.1.1 Detection of the Initial Rotor Position 426
20.4.1.2 Computation of the Commutation Thresholds 427
20.4.1.3 Monitoring of the Rotor Position and Selection of the Active Phases 428
20.4.1.4 A Control Strategy for Regulation of the Phase Current at Low Speeds 429
20.5 Closed Loop Torque Control of the SRM Drive 430
20.6 Closed Loop Speed Control of the SRM Drive 433
20.7 Industrial Applications: Vehicular Coolant System 434
References 436

21. Noise and Vibration in SRMs 437
William Cai and Pragasen Pillay
21.1 Introduction 437
21.2 Numerical Models of SRM Stator Modal Analysis 438

21.3 Finite Element Results of the Stator Modal Analysis 438
21.4 Design Selection of Low Vibration SRMs 440
21.5 The Effects of a Smooth Frame on the Resonant Frequencies 445
21.6 Conclusions 447
References 447

22. Modeling and Parameter Identification of Electric Machines 449
Ali Keyhani, Wenzhe Lu, and Bogdan Proca
Nomenclature 449
22.1 Introduction 450
22.2 Case Study: The Effects of Noise on Frequency-Domain Parameter Estimation of Synchronous Machine 450
22.2.1 Problem Description 450
22.2.2 Parameters Estimation Technique 451
22.3.2.1 Estimation of D-Axis Parameters from the Time Constants 451
22.3.2.2 Estimation of Q-Axis Parameters 453
22.2.3 Study Process 453
22.2.4 Analysis of Results 454
22.2.4.1 D-Axis Parameter Estimation 454
22.2.5 Conclusions 459
22.3 Maximum Likelihood Estimation of Solid-Rotor Synchronous Machine Parameters 460
22.3.1 Introduction 460
22.3.2 Standstill Synchronous Machine Model for Time-Domain Parameter Estimation 460
22.3.2.1 D-Axis Model 460
22.3.2.2 Q-Axis Model 461
22.3.3 Effect of Noise on the Process and the Measurement 461
22.3.4 Maximum Likelihood Parameter Estimation 462
22.3.5 Estimation Procedure Using SSFR Test Data 464
22.3.6 Results 465
22.4 Modeling and Parameter Identification of Induction Machines 468
22.4.1 Model Identification 469
22.4.2 Parameter Estimation 472
22.4.2.1 Estimation of Stator Resistance 473
22.4.2.2 Estimation of L_1, L_m, and R_r 474
22.4.3 Sensitivity Analysis 476
Observation 478
22.4.4 Parameter Mapping to Operating Conditions 478
22.4.4.1 Magnetizing Inductance, L_m 479
22.4.4.2 Leakage Inductance, L_l 480
22.4.4.3 Rotor Resistance, R_r 480
22.4.5 Core Loss Estimation 483
22.4.5.1 Calculation of Rotor Losses at Frequencies of Interest 483
22.4.5.2 Calculation of Friction and Windage Losses Using ANN 483
22.4.5.3 Calculation of Core Losses 485
22.4.5.4 Calculation of Core Resistance 486

22.4.6 Model Validation 486
22.4.6.1 Steady-State Power Input 486
22.4.6.2 Dynamic 486
22.4.7 Conclusions 487
22.5 Modeling and Parameter Identification of Switched Reluctance Machines 490
22.5.1 Introduction 490
22.5.2 Inductance Model of SRM at Standstill 491
22.5.2.1 Three-Term Inductance Model 491
22.5.2.2 Four-Term Inductance Model 492
22.5.2.3 Five-Term Inductance Model 493
22.5.2.4 Voltages and Torque Computation 494
22.5.3 Parameter Identification from Standstill Test Data 494
22.5.3.1 Standstill Test Configuration 494
22.5.3.2 Standstill Test Results 495
22.5.4 Inductance Model of SRM for On-Line Operation 497
22.5.5 Two-Layer Recurrent Neural Network for Damper Current Estimation 499
22.5.5.1 Structure of Two-Layer Recurrent Neural Network 499
22.5.5.2 Training of Neural Network 501
22.5.6 Estimation Results and Model Validation 501
22.5.7 Conclusions 501
References 503
Appendix A 508
Appendix B 510

23. Brushless DC Drives 515
James P. Johnson
23.1 BLDC Fundamentals 515
23.2 Control Principles and Strategies 517
23.3 Torque Production 519
23.4 Advantages and Disadvantages 521
23.5 Torque Ripple 523
23.6 Design Considerations 525
23.7 Finite Element Analysis and Design Considerations for BLDC 525
23.8 Permanent Magnets 526
23.9 BLDC Simulation Model 528
23.10 Sensorless 535
References 536

24. Testing of Electric Motors and Controllers for Electric and Hybrid Electric Vehicles 537
Sung Chul Oh
24.1 Introduction 537
24.2 Current Status of Standardization of Electric Vehicles 538
24.2.1 Electric Vehicles and Standardization 538
24.2.2 Standardization Bodies Active in the Field 539
24.2.2.1 The International Electrotechnical Commission 539
24.2.2.2 The International Organization for Standardization 539
24.2.2.3 Other Regional Organizations 539

24.2.3 Standardization of Vehicle Components 540
24.2.4 Standardization Activities in Japan 540
24.2.4.1 Z108-1994: Measurement of Range and Energy Consumption (at Charger Input) 541
24.2.4.2 Z109-1995: Acceleration Measurement Test 541
24.2.4.3 Z110-1995: Test Method for Maximum Cruising Speed 541
24.2.4.4 Z111-1995: Measurement for Reference Energy Consumption (at Battery Output) 541
24.2.4.5 Z901-1995: Electric Vehicle: Standard Form of Specifications (Form of Main Specifications) 541
24.2.4.6 Z112-1996: Electric Vehicle: Standard Measurement of Hill Climbing Ability 541
24.2.4.7 E701-1994: Combined Power Measurement of Motor and Controller 542
24.2.4.8 E702-1994: Power Measurement of Motors Equivalent to On-Board Application 542
24.2.4.9 Japanese Standards Concerning Vehicle Performance and Energy Economy 542
24.3 Test Procedure Using M-G Set 542
24.3.1 Electric Motor 542
24.3.2 Controller 543
24.3.3 Application of Test Procedure 543
24.3.4 Analysis of Test Items for the Type Test 543
24.3.4.1 Motor Test 543
24.3.4.2 Controller Test (Controller Only) 544
24.4 Test Procedure Using Eddy Current-Type Engine Dynamometer 544
24.4.1 Test Strategy 544
24.4.2 Test Procedure 545
24.4.3 Discussion on Test Procedure 545
24.5 Test Procedure Using AC Dynamometer 546
24.5.1 Test Strategy 546
24.5.2 Test Items 547
24.5.3 Test Procedure 547
24.6 Testing of Electric Motor/Controller in Vehicle Environment 548
24.6.1 Concept of Hardware in the Loop 548
24.6.2 HIL Application to Motor/Controller 548
24.6.3 Test Description 550
24.6.4 Test Results 550
24.7 Conclusion 552
References 553

PART V. Other Automotive Applications **555**

25. Integrated Starter Alternator 557
William Cai
25.1 ISA Subsystem in Vehicle Systems 558
25.2 Powertrain Coupling Architecture 558
25.2.1 Crankshaft-Mounted ISA Configuration 559
25.2.2 Offset-Mounted ISA Configuration 560

25.3 Features and Performances of the ISA System 562
25.3.1 State of the Art 563
25.3.2 Features of the ISA Subsystem 564
25.3.2.1 Initial Cranking and Stop/Start 564
25.3.2.2 High-Efficient Large-Power Generation 566
25.3.2.3 Launching Torque Assistant 567
25.3.2.4 Braking Energy Regeneration 568
25.3.2.5 Low Loss and Cost via High System Voltage 568
25.3.2.6 Active Damping Oscillation and Absorbing Vibration 569
25.3.2.7 Cylinder Shutoff 571
25.3.2.8 Power APU and Other Electric Loads 571
25.4 Components in the ISA Subsystem 571
25.4.1 Electric Machine with Dual-Voltage Output 572
25.4.2 36 V Battery with 12 V Intermediate Terminal 572
25.4.3 Typical ISA Electrical System 572
25.4.4 Multifunction Inverter with a Neutral Inductor 573
25.4.5 Electric Machine 574
25.4.5.1 Specifications of the ISA Electric Machine 574
25.4.5.2 Types of ISA Electric Machines 577
25.4.5.3 Application Comparison of ISA Electric Machines 594
25.4.6 DC-AC Inverter and AC-DC Rectifier 595
25.4.6.1 Configuration of Three-Phase Converter 595
25.4.6.2 Inverter Configuration of the SRM 598
25.4.7 DC-to-DC Converter 599
25.4.7.1 Buck Mode of the DC-to-DC Converter 599
25.4.7.2 Boost Mode of the DC-to-DC Converter 599
25.4.7.3 Multifunction Inverter 600
25.5 ISA System Issues 602
25.5.1 Energy Storage and ISA System 602
25.5.2 ISA Cooling Styles 605
25.5.2.1 Air Cooling 605
25.5.2.2 Liquid Cooling 606
25.5.3 Other Issues 607
25.6 Summary 607
References 608

26. Fault Tolerant Adjustable Speed Motor Drives for Automotive Applications 611
Babak Fahimi
26.1 Introduction 611
26.1.1 Self-Organizing Controllers 612
26.1.1.1 Hierarchy of Control Methods in Induction Motor Drives 614
26.1.1.2 Smooth Transition between Various Control Methods 615
26.1.1.3 Reconstruction of the Phase Currents 619
26.2 Digital Delta Hysteresis Regulation 620
26.2.1 Current Reconstruction Algorithm for DDHR 621
References 623

27. Automotive Steering Systems 625
Tomy Sebastian, Mohammad S. Islam, and Sayeed Mir
27.1 Introduction 625
27.2 Steering System 625
27.2.1 Manual Steering 626
27.2.2 Hydraulically Assisted Steering 627
27.2.3 Electrohydraulic Power Steering 628
27.2.4 Electric Power Steering 629
27.3 Advanced Steering Systems 630
27.3.1 Four-Wheel Steering 631
27.3.2 Future-Generation Steering Systems 631
References 631

28. Current Intensive Motor Drives: A New Challenge for Modern Vehicular Technology 633
Babak Fahimi
28.1 Background 633
28.2 Magnetic Design of Current Intensive Motor Drives 634
28.3 Stability Considerations in Multiconverter Systems 637
28.4 Energy Transfer 639
28.5 Impact on Control 640

29. Power Electronics Applications in Vehicle and Passenger Safety 641
D.M.G. Preethichandra and Saman Kumara Halgamuge
29.1 Introduction 641
29.2 Power Electronics in Vehicle Safety 641
29.2.1 The CAN Bus Used to Network Vehicle Power Electronic Modules 642
29.2.2 Engine Safety Systems 644
29.2.3 Antitheft Alarm Systems 648
29.2.4 Adaptive Cruise Control (ACC) 649
29.2.5 Reverse Sensing and Parking System 650
29.3 Power Electronics in Passenger Safety 650
29.3.1 Seatbelt Control Systems 651
29.3.2 Power Window Safety Systems 652
29.3.3 Airbags 653
29.3.4 Driver Assistance Systems and Stress Monitoring 653
29.4 Conclusions 654
Acknowledgments 654
References 655

30. Drive and Control System for Hybrid Electric Vehicles 657
Weng Keong Kevin Lim, Saman Kumara Halgamuge, and Harry Charles Watson
30.1 Introduction 657
30.2 Control Strategy 659
30.2.1 Thermostat Series Control Strategy 660
30.2.2 Series Power Follower Control Strategy 660
30.2.3 Parallel ICE Assist Control Strategy 661
30.2.4 Parallel Electrical Assist Control Strategy 662

30.2.5 Adaptive Control Strategy 664
30.2.6 Fuzzy Logic Control Strategy 665
30.3 Power Electronic Control System and Strategy 669
30.4 Current HEVs and Their Control Strategies 672
30.4.1 Honda Insight 672
30.4.2 Toyota Prius 673
30.5 Conclusion 674
References 674

31. Battery Technology for Automotive Applications 677
Dell A. Crouch
31.1 Introduction 677
31.1.1 Battery Technology 678
31.1.1.1 Valve Regulated Batteries 680
31.1.2 Present Automotive Battery Requirements 680
31.1.2.1 Battery Performance Requirements 681
31.1.2.2 Battery Charging Requirements 681
31.1.2.3 Battery Termination Standards 682
31.2 Future Automotive Batteries 682
31.3 Combinations of Batteries and Ultracapacitors 685
31.4 Battery Monitoring and Charge Control 685
31.5 Conclusion 686
References 687

Index 689