Index

Note: page numbers in *italics* refer to figures; page numbers in **bold** refer to tables.

ABS (anti-lock braking systems) 491
AC catenaries 32, 257–9
AC machines 28–30, 29
control strategies 30–2
see also induction machines; synchronous machines; variable reluctance machines
AC resistance of a conductor 424
AC voltage sources 32, 32
AC/AC converters see matrix converters
AC/AC shunting locomotives 307, 308
AC/DC diode bridges 17–18, 403, 518–19
AC/DC/AC power converters
bi-directional (regenerative) 20–2
parallelization 21, 22
unidirectional 17–20
ACR-Evodrive/Freedrive 320–1, 321
active front ends (AEFs) 20, 149–50, 405
adaptive flux observer 86–7
adhesion coefficients (railway traction) 251, 252, 253
adhesion curves (vehicle traction) 480, 482, 486
aerodynamic force 470
AEFs (active front ends) 20, 149–50, 405
AHTS (anchor handlers) 453–4
air core inductors 235, 327
air resistance 377
anchor handlers (AHTS) 453–4
anti-lock braking systems (ABS) 491
asynchronous machines see induction machines
axial flux PMSMs 586, 608–9
azimuth propellers 371–2, 373, 393, 450
back-to-back converters see grid-connected converters
band stop filters (BSFs) 135
batteries
as DC source 14
electric vehicles 500, 525–9
materials 34
nickel metal hydride (NiMH) 288, 321, 500, 526
overcharge/overdischarge protection 515, 517
railway traction 288–95
on-board energy storage 306–7
trackside energy storage 301–2
SOC hysteresis control 501–3
technologies 525–7, 528, 546
see also lithium-ion batteries
battery chargers 499, 500, 515–24, 548
bi-directional 521, 522, 523
charging strategies 523–4
contactless inductive 518
DC/DC converters 520–1
power factor correction 518–20
practical example 523
battery management systems (BMSs) 294–5, 296, 527, 530–2, 533, 533
battery packs 527, 528, 529, 542
bearing currents 25
bi-directional battery chargers 521, 522, 523
bi-directional converters 148
AC/AC matrix converter 23
AC/DC/AC power converters 20–1

© 2017 John Wiley & Sons, Ltd. Published 2017 by John Wiley & Sons, Ltd.
bi-directional converters (cont’d)
  current source converter (CSC) 23, 24
  DC/AC power converter 14
  DC/DC/AC power converter 15
  BLDCs (brushless DC motors) 30, 102–3
  BMSs (battery management systems) 294–5, 296, 527, 530–2, 533, 533
Bode diagrams 129, 171, 172, 173, 182, 203
boost converters 323
braking
  anti-lock braking systems (ABS) 491
  DC choppers 19–20
  electric 593–4
  vehicle traction 489–91, 492
  see also regenerative braking
braking resistors 242–4, 245, 246, 344
brushless DC motors (BLDCs) 30, 102–3
BSFs (band stop filters) 135
buck converters 323
buck-boost converters 324–7, 331–2, 520–1

cables, electric see power cables
  cables, elevator see ropes
capacitors
  DC bus 19–20, 237–8
  materials 34
  see also LC filters; LCL filters; supercapacitors
capacity of line to ground 424–5
carbon-based batteries 546
cascaded buck-boost converters 331–2
catenaries 32, 255–9
c c a t e n a r y     w i r e     2 3 1
CCCV (constant current constant voltage) charging 524
circle flux trajectory 31–2
circuit breakers 232, 233, 431
Citadis Ecopack 321
cluftes 493
common mode chokes 25, 26
common mode currents 24–6
commom mode output filters 26
common mode voltages 24–5
compensation ropes 558, 559, 568
component reliability 617–18
constant current constant voltage (CCCV) charging 524
constant torque and constant current contours 107, 108, 109
constant voltage, current, and torque contours 117, 120, 122, 123
contactless inductive chargers 518
contra-rotating propellers 373, 374
current harmonics 171, 401, 403, 435–6
  see also harmonic filters
current regulators see synchronous current regulators
  current source converters (CSCs) 23, 24, 392, 460, 461, 462
cycloidal propellers 374–5
DAB (dual active bridge) converters 327–9
damping resistance 154, 173, 174
damping windings 417
dc bus capacitors 19–20, 237–8
dc bus voltage
  calculation 157
  control 176, 183, 201, 212, 216, 275, 316
elevators 589
  railway traction 239, 240, 243, 258, 259–60, 275
  light rail vehicles (LRVs) 316, 323
dc catenaries 32, 255–7
dc choppers 19–20
elevators 589, 590
  railway traction 256, 258, 341, 351
  ship propulsion 401
dc resistance of a conductor 424
dc voltage sources 14, 16–17, 32, 32
dc/ac power converters 13–15
  in AC/DC/AC power converters 19, 21
  multilevel topologies 15
  output voltages 16
two-level converter 14
dc/dc converters 28
  battery chargers 518, 520–1
eelectric vehicles 511–13, 514
elevators 590–1
  hybrid vehicles 499
  on-board energy storage 322–7
  topologies 520–1, 522
dc/dc/ac power converters 15–17
dc-link capacitors 19–20, 237–8
dc-link modeling 157–9
dc-link voltage see dc bus voltage
deflector sheaves 558, 561, 566, 568
delayed signal cancelation (DSC) 189, 190
dHB (dual half-bridge) converters 330–1
diesel electric traction vehicles 259–60
diesel engines 413–16
diesel-electric ship propulsion 416, 419, 420, 450–2
diesel-electric shunting locomotives
  on-board energy storage 302–7
  power profile and diesel generator operation 304
  series-hybrid powertrain configuration 304, 305–6, 308
differential (drive train) 493, 494
diode bridge rectifiers 17–18, 403, 518–19
diode schematic representation 13
direct self-control (DSC) 32
direct torque control (DTC) 31–2, 407
direct torque space vector modulation 31, 304, 305–6, 308
  series-hybrid powertrain configuration 304, 305–6, 308
drive train configurations 13–26
diesel-electric shunting locomotives 302–7
drive train configurations 13–26
  electric vehicles 493–6, 545
  railway traction 304, 305–6, 307, 308, 332
  ship propulsion 394–7
dry film capacitors 237, 238
dSC (direct self-control) 32
DSOGI-PLL (dual second-order generalized integrator
  phase-locked loop) 202, 204
DTC (direct torque control) 31–2, 407
dual active bridge (DAB) converters 327–9
dual half-bridge (DHB) converters 330–1
ducted propellers 371, 372
dynamic positioning (DP) 409, 455–7
drving vehicles 559, 566, 567–8, 595, 608
  drive train configurations 13–26
  doors and accesses, elevators 561, 563
  DP (dynamic positioning) 409, 455–7
  DSC (direct self-control) 32
DSOGI-PLL (dual second-order generalized integrator
  phase-locked loop) 202, 204
DTC (direct torque control) 31–2, 407
dual active bridge (DAB) converters 327–9
dual half-bridge (DHB) converters 330–1
ducted propellers 371, 372
dynamic positioning (DP) 409, 455–7
earping 426–7
electric brakes, elevators 593–4
electric double-layer capacitors see supercapacitors
electric drives
  electric machine and mechanical load interaction 11
  general description 9–13
  schematic block diagram representation 10
see also drive train configurations
electric vehicles 468–549
  battery chargers 515–24
    bi-directional 521, 522, 523
    charging strategies 523–4
    DC/DC converters 520–1
    power factor correction 518–20
    practical example 523
  commercial examples 543–6, 544, 545
  computer-based simulation example 534–41
cost-parity 546
drive train configuration 493–6, 545
dynamic model 468–91
  anti-slip control 484–91, 492
  braking 489–91, 492
  forces actuating on the vehicle 469, 470–5
  four driving wheels on a dry surface 479–80, 481, 482
  four driving wheels on an icy surface 481–2, 483, 484
  four-wheel drive car 475–6
  load characteristic 478, 479
  simulation performance 479–83
  traction 486–9
  two driving wheels on a dry surface 483, 485, 487
  two driving wheels on an icy surface 492
  two-wheel drive car 476–8
energy storage systems 525–9
historical evolution 546, 547–8
  new trends and future challenges 546, 548
variable speed drive 506–24
  electric motors 508–11, 535
  inverter control 515
  power converters 511–15, 546
  torque capability 506–7
electrical braking see regenerative braking
electrical fault protection 426–34
  circuit breakers 431
  fault currents 428, 430
  fuses 430–1
  ground faults 427
  grounding (electrical) 426–7
  protection coordination 431–4
  types of fault 427–8, 429
electrical resistance of a conductor 424
elevators 550–615
  classification 551–4
  components 556–65
    cars 560
    control system 565
    door opening/closing mechanisms 610–11
    doors and accesses 561, 563
    elevation system 556–60, 565–9
    guides 563, 564
    ropes 558–9, 560
    safety elements 564, 565
    traction system 561
  computer-based simulation 599–602, 603, 604, 605,
    606, 607
electric drive 577–99
  classic configuration 581–2
  control strategy 581, 582–4
  dimensioning 594–8
elevators (cont’d)
  electric brakes 593–4, 595
  electric machine 584–8
  energy storage systems 590, 591, 617
  power converters 581, 588–93
  trajectory generation 579–81
  historical evolution 612–16, 613
  manufacturers 602, 608–9
  new trends and future challenges 616–18
  physical approach: model differential
    equations 569–77, 577
  rescue systems 611–12
  standards and norms 609
  technical parameters 554–5, 557
  traffic controlling algorithms 612
EN 50163 223, 224, 316, 322
EN 62864-1 332, 333
EN 81.1 and EN 81.2 609
EN 81-20 and EN 81-50 609
energy efficiency
  elevators 553–4, 617
  light rail vehicles (LRVs) 312, 313, 317
  ship propulsion 370, 464
energy management strategies
  diesel-electric shunting locomotives 305–7
  hybrid electric vehicles 500–3
  light rail vehicles (LRVs) 308–18
see also battery management systems (BMSs)
energy sources 9
energy storage systems
  electric vehicles 525–9
  elevators 590, 591, 617
  metros 297
see also batteries; on-board energy storage;
  supercapacitors; trackside energy storage
extended range electric vehicles (EREVs) see plug-in
  hybrid electric vehicles (PHEVs)
fall pipe and rock dumping ship 450–2
fast-charging strategy 524
fault currents 428, 430
fault protection see electrical fault protection
feedback based field weakening 78, 123–4
field support vessels 453–4
field weakening regions 69, 70–1, 76, 108, 115–16, 121
feedback based strategy 78, 123–4
field-oriented control see rotor flux oriented vector control
film separator capacitors (PP-film) 237–8
filter inductors 235–6, 237, 237, 344
see also L filters
filters see harmonic filters; LC filters; LCL filters
finite state machines (FSMs) 515
fixed-pitch propellers 370–1, 380
flux weakening see field weakening regions
flyback converters 520–1
forces acting on a vehicle 469, 470–5
forces affecting a train 248–50, 263–4
forward converters 521
four-wheel drive cars 475–6
  on a dry surface 479–80, 481, 482
  on an icy surface 481–2, 483, 484
frequency and rotational speed 416, 417
frequency control 418–19, 420, 421
friction forces 249
frictional resistance 376–7
FSMs (finite state machines) 515
fuel cells 513
fuses 430–1
galvanic isolation 323, 338
gate turn-off (GTO) thyristor 27
gate-commutated thyristors (GCTs) 23, 27
gearboxes
  elevators 561, 585, 586
  vehicle traction 493, 494, 506
gearless drives
  electric vehicles 496, 506
  elevators 561, 562, 582, 586, 608, 616
gavity force 470
Greentech 320
grid side filters 152–7, 162–4
grid voltage oriented vector control (GVOVC) 176–7
grid-connected converters 148–220
configurations 149
control 175–85
  alignment with the grid voltage space vector 175–6
  simulation-based example 183–5
  synchronization method 179
  tuning of the current regulators 179–83
  vector control strategy 176–7
control under unbalanced voltage conditions 185–207
  power expressions 196–9
  simulation-based example 205–6
  synchronization method 202–5
  tuning of the current regulators 205
  vector control 198, 199–202
  voltage equations 192–6
  elevators 592, 617
output voltage combinations 152
representative parameters 217, 217, 218, 219, 220
single-phase
  control 212–20
interior permanent magnet synchronous machines (IPMSMs) (cont’d)
constant torque and constant current contours 108
constant voltage, current and torque contours 120, 122
maximum capability curves 122
maximum torque per ampere (MTPA) 109–11
operating regions 121
torque equation 108
vehicle traction 509
inverters see DC/AC power converters
in-wheel drives 495–6, 506
IPMSM see interior permanent magnet synchronous machines (IPMSMs)
L filters 153–4, 162–3, 164–7, 179–81, 192–5
see also filter inductors
LC filters 232–5, 405
LCL filters
analysis and design 169–74
ship propulsion 405
transfer functions 171, 172, 173
lead acid (Pb) batteries 526
lifts see elevators
light rail vehicles (LRVs)
on-board energy storage 288, 307–21
catenary-free sections 315–16, 320
control strategies 314–15
energy management strategies 308–18
energy savings 312, 313
hybrid electric vehicles 317–18
lithium-ion batteries 307, 317
manufacturers 318–20, 322
operating modes 314
power converters 322–32
powertrain configuration 309–10, 316
supercapacitors 306, 308–17, 318
tramways 307–8
see also metros; trams
limiter ropes 564
linear motors (LIMs) 335, 336, 557
lithium-air batteries 357
lithium-ion batteries 288–95, 299, 357
cells management system 294–5
chemistries 290–1
classification 288–90
compared to supercapacitors 295, 296, 302
degradation factors 292–4
depth of discharge (DOD) 292, 293–4, 317
electric vehicles 527, 528
lifecycle 293
manufacturers 294
on-board energy storage 307, 317
packaging technologies 290
trackside energy storage 301
working temperature 292–3
working voltage 292
lithium-sulfur batteries 357
locomotives 225–7, 347–8
low frequency transformers 338–9, 354–5
low-floor trams 279–80, 315, 316–17, 340–3
LRVs see light rail vehicles (LRVs)
machine-room-less elevators 553, 556
magnet polarity detection 138–9
magnetic levitation railways 335
magnetic materials 518, 587
magnetic sheets 587–8
materials classification 34
matrix converters 23, 24
maximum capability curves
elevator drives 598
induction machines 88–91, 89–90, 92
railway traction 263
ship propulsion 399, 442, 443
synchronous machines 119, 140–4, 141, 143
vehicle traction 506, 536
maximum torque per ampere (MTPA) 108–9
IPMSMs 120, 121, 122
SPMSMs 117
SynRMs 123
mechanical load 9
medium frequency transformers (MFTs) 258–9, 339, 340, 351–3, 356
metros 224, 225
commercial examples 343–4, 346–7
energy storage systems 297
linear motors (LIMs) 335
third rail system 333
MFTs (medium frequency transformers) 258–9, 339, 340, 351–3, 356
MITRACTM 319–20
model reference adaptive systems (MRAS) 85–6, 130
model-based control methods
induction machines 84–5
synchronous machines 127–30
modulation techniques 32
grid-connected converters 159–62, 209–11
traction motors 264, 266
see also pulse width modulation (PWM); space vector modulation (SVM)
MOSFET (metal-oxide semiconductor field-effect transistor) 27, 513
MRAS (model reference adaptive systems) 85–6, 130
MTPA see maximum torque per ampere (MTPA)
multilevel converters 27, 28
AC/DC/AC converter 19, 20, 21
DC/AC converter 14–15, 15
DC/DC/AC converter 17
parallelization 22
multi-pole permanent based synchronous motors 398, 496, 561
multisystem traction vehicles 260–1
neutral point clamped (NPC) converters 14, 29, 256, 403, 404, 405, 440, 442
nickel cadmium (NiCd) batteries 526
nickel metal hydride (NiMH) batteries 288, 321, 500, 526
non-salient synchronous machines
control under voltage constraints 117–19
maximum capability curves 140, 141
vector control 112–13
see also surface permanent magnet synchronous machines (SPMSMs)
normal forces 474–5
NPC (neutral point clamped) converters 14, 29, 256, 403, 404, 405, 440, 442
on-board energy storage 302–21
AC/AC shunting locomotives 307, 308
battery and supercapacitor voltage profiles 323
diesel-electric shunting locomotives 302–5, 303–7
light rail vehicles (LRVs) 288, 307–21
catenary-free sections 315–16, 320
control strategies 314–15
energy management strategies 308–18
energy savings 312, 313
hybrid electric vehicles 317–18
lithium-ion batteries 307, 317
manufacturers 318–20, 322
operating modes 314
power converters 322–32
powertrain configuration 309–10, 316
supercapacitors 306, 308–17, 318
tramways 307–8

Pacejka tire model 473, 473
 pantographs 229–31, 275
 parachutes (elevators) 564
 parallel hybrid electric vehicles 503–5
 parasitic capacitances 24–5
 permanent magnet synchronous machines (PMSMs) 101–2
 elevators 496, 586, 608–9
 magnets 587–8
 modeling 125–7
 railway traction 262
 sensorless control
 model-based 127–30
 rotor speed estimation using the stator flux 129
 saliency-tracking-based methods 130–3
 ship propulsion 397
 stator voltage equation at high speeds 115–16
 vector control 111–14
 vehicle traction 508, 509
 see also interior permanent magnet synchronous machines (IPMSMs); surface permanent magnet synchronous machines (SPMSMs)
 phase-locked loops (PLLs) 179, 202
 phasor diagrams 163, 164
 PHEVS (plug-in hybrid electric vehicles) 498–500
 planetary gears 504–5, 543, 561
 PLLs (phase-locked loops) 179, 202
 plug-in hybrid electric vehicles (PHEVS) 498–500
 podded propulsors 372
 position sensors, elevators 558, 583–4
 positioning system, elevators 581
 power cables 423–5, 426, 436
 power converter boxes 244, 246, 247, 341, 342, 345, 347, 349
 power converters 11, 322–32
 AC voltage output 12
 current and voltage limits 115
 elevators 581
 inductor cores 326–7
 interaction with the energy source 11
 low frequency 338–9, 354–5
 medium frequency 339, 340
 output AC voltages 12
 railway traction 255–61, 351–5
 schematic representation 13
 semiconductor devices 26–8
 series cascaded 259
 ship propulsion 392, 400, 403–6
 topologies 13–26, 27, 28
 vehicle traction 511–15, 546
 power factor correction 499, 500, 518–20
 power film capacitors (PP-film) 237–8
 power management systems (PMS) 422–3
 power semiconductors 238–42, 355–7
 power sign convention 165
 PP-film capacitors 237–8
 predictive control 32
 propeller propulsion 378–85
Index

propellers 370–5
pulse width modulation (PWM) 32
  common mode currents 24–6
  grid-connected converters 209–11
  sinusoidal PWM with third harmonic injection 159–60, 161, 162, 266

railway traction 221–361
catenaries and converters 255–61
  AC catenaries 257–9, 277–8
  DC catenaries 255–7, 276
  diesel electric traction vehicles 259–60
  medium frequency transformers (MFTs) 258–9
  multisystem traction vehicles 260–1
  pantograph disconnection 275
  voltage sources 32
control strategy 264–75
  anti-slip control 275
  DC bus voltage maintenance 275, 276
  electro-magnetic torque and rotor flux 271–2
  jerk and force limitation 272–3
  levels of control 264
  modulation techniques 266–70
  speed and acceleration 272
  torque and flux references limitations 274
  transformation from force to torque 273–4
electric machines 261–4
  direct drive 261–2
  IM versus PMSM 263
  torque capability 263–4
electrical components 229–48
  braking resistors 242–4, 245, 246
  catenary wire 231
  DC-link capacitors 237–8
  filter inductors 235–6, 237, 237
  HSCBs (high-speed circuit breakers) 232, 233
  input filters 232–5
  main elements location 230
  pantographs 229–31
  power converter boxes 244, 246, 247
  power semiconductors 238–42
  regenerative converters in 148–9
  surge arresters 231, 232
  traction motors 246, 247
  energy storage systems 278–332
  battery management systems (BMSs) 294–5, 296
  energy storage technologies 282–95
  on-board energy storage 302–21, 296, 322, 357
  power converters 322–32
  tracksode applications 295–302
  traction and braking processes 280, 281

  ground level power supply systems 332–8
  contact type 333–5
  contact-less type 335–6
  historical evolution 350, 351
  new trends and future challenges 531–7
  physical approach
    forces affecting the train 248–50, 263–4
    model of the train 253–5
    traction diagram 263
    train adhesion 251–3
  power supply systems
    AC 16.7Hz supply systems 277–8
    AC 50Hz supply system 276–7
    DC supply systems 276–8
  power systems
    AC power systems 223, 229
    architecture 227–9
    auxiliary systems 338–9
    DC power systems 223, 228, 276
    supply voltages 222–3, 224
  railway systems in Europe 221–3
  railway vehicles 224–7, 279–80
  traction axle with gear unit and braking disks 248
  see also light rail vehicles (LRVs)
ramps (control) 407
range-extended electric vehicles (ReEVs) see plug-in
  hybrid electric vehicles (PHEVS)
rare earth magnets 508, 509, 518
reactive power
  grid-connected converters 164, 176–7, 184–5, 201–2
  railway traction 329
  ship propulsion 417, 421
  rectifiers 233–4
ReEVs (range-extended electric vehicles) see plug-in
  hybrid electric vehicles (PHEVS)
regenerative braking 19, 277, 280, 281, 297–8, 300
  elevators 590–1
  railway traction 243
  light rail vehicles (LRVs) 308–14
  road vehicles 490–1
  regenerative converters see bi-directional converters;
    grid-connected converters
reluctance torque 107, 108, 109
rescue systems, elevators 611–12
residual resistance 377
resins 236
reversible converters see bi-directional converters;
  grid-connected converters
ride comfort 578–9, 596
ring gears 505
RLC filters 437–8
rolling resistance 470–1
ropes, elevator 558–9, 560, 568, 608, 609, 618–19
roping arrangements 566–9, 577
rotor flux control loop 82–3
rotor flux oriented vector control 31, 52–69
railway traction 264
rotor flux estimation
  closed-loop flux observers 69
  parameter sensitivity 69
  using the current model 64–5, 66
  using the voltage model 66–9
rotor flux selection 71–8
rotor position and speed estimation 85–6, 136
rotor voltage equations 39, 46, 48
saliency-tracking-based methods
  induction machines 88
  synchronous machines 130–3
salient synchronous machines
  control under voltage constraints 119–21
  maximum capability curves 142–4, 143
  steady-state operation 144, 145, 146
  vector control 113, 114
see also interior permanent magnet synchronous machines (IPMSMs); synchronous reluctance machines (SynRMs)
scalar-based control 31
SCRs (silicon-controlled rectifiers) see thyristors
secondary saliencies 136
second-order generalized integrator (SOGI) 202
selective harmonic elimination (SHE) 270
self-inductance 424
semiconductor devices 26–7
see also power semiconductors
sensorless control
induction machines 84–8
  model-based methods 84–7
  saliency-tracking-based methods 88, 139–40
  ship propulsion 407
synchronous machines 125–40
  high-frequency signal-injection-based methods 133–7
  magnet polarity detection 138–9
  model-based 127–30
  saliency-tracking-based methods 130–3
series hybrid electric vehicles 497–503
  energy management control strategies 500–3
series parallel hybrid electric vehicles 505–6
series hybrid locomotives 304, 305–6, 307, 308, 332
SGCT (symmetric gate-commutated thyristor) 27
shock absorbers 564
ship propulsion 362–467, 443
  commercial examples 450–5
  components 365–9
  computer-based simulation example 439–47
  design procedure 448–50
  dynamic positioning (DP) 358, 455–7
  efficiency 370
  historical evolution 458–63, 459–60
  hybrid mechanical-electrical propulsion 464–5
  new trends and future challenges 463–6
  operation quadrants 392, 392
physical approach 376–91
  dynamic model 385–7
  propeller propulsion 378–85
  ship resistance 376
  steady-state analysis 387–91
power generation and distribution system 409–39
  configurations 409–10, 411, 412
  DC distribution networks 463–4
  energy storage systems 465–6
  fault protection 426–34
  fault types 427–8
  frequency and voltage control 418–22
  generators 416–18, 436
  grounded or ungrounded 426–7
  harmonic distortion analysis and reduction 435–9
  hybrid generation 465–6
  power cables 423–5, 426, 436
  power management system (PMS) 422–3
  prime movers 413–16
  redundancy 409–10
  voltage droop analysis 435
  voltage levels 411–13
propellers 370–5
torque capability
  maximum capability curves 399, 442, 443
  torque and power equations 392, 398, 399, 441
  types of ship 363, 364, 366
variable speed drive 367–9, 392–409
  acceleration and deceleration 407, 408
  control strategy 406–9
  drive configurations 394–7
  electric machine 339, 397–8, 442
  power converters and transformers 400–6
  redundancy 394
  reference converters and transformers 400–6
  redundancy 394
  reference generations of power and rotational speed 407–8
  torque and power equations 392, 398, 399, 441
  shock absorbers 564
shore tanker 450
SiC diodes 242, 355
silicon-controlled rectifiers (SCRs) see thyristors
Simon Stevin fall pipe and rock dumping vessel 450–2
sinusoidal PWM with third harmonic injection 159–60, 161, 162, 266
SITRAS MES/HES 317–19
six-pulse generation modulation 269
six-pulse rectifiers
railway traction 233, 234, 276
ship propulsion 400, 401, 402, 403
slip see wheel slip
slip (propellers) 391
slip (rotating machines) 54, 70, 91
SMC (stacked multi-cell) topologies 28
SOGI (second-order generalized integrator) 202–3
space vector modulation (SVM) 32, 267–8
space vector theory 40–2
speed control
diesel engines 419, 420
elevators 583, 615–16
induction machines 79–82
ship propulsion 407–8
synchronous machines 124–5
see also variable speed drives
speed coupling 504–5
speed droop control 419–20
speed limiters, elevators 564
SPMSMs see surface permanent magnet synchronous machines (SPMSMs)
squirrel cage induction motors 246
SRF-PLL (synchronous reference frame phase-locked loop) 179, 191–2, 204
SRMs (switched reluctance motors) 508, 511, 512
stacked multi-cell (SMC) topologies 28
standards
catenary voltages 223, 224, 316, 322
elevators 609
on-board energy storage 332, 333
stator voltage constraints 117–19
stator voltage equations
induction machines 38, 45, 46, 48, 56–8, 89, 90, 93, 94
synchronous machines 103, 104, 105, 106, 115–16, 141, 143, 145
steel ropes 558–9
step-down converters 261, 521
see also DC/DC converters
step-down transformers 18, 21, 257
submersible induction motor 30
sun gears 305
supercapacitors 283–6, 357, 513, 617
compared to batteries 285, 295, 296, 302
cycling current 286, 287
depth of discharge (DOD) 315
energy storage capacity 283, 311, 312
internal structure 284
manufacturers 285
materials 34
on-board energy storage 306, 308–17, 318
sizing 308–14
storage conditions 286
working temperature 286
working voltage 285, 311, 312
surface permanent magnet synchronous machines (SPMSMs) 30, 101
constant torque and constant current contours 107
constant voltage, current, and torque contours 117
control under voltage constraints 119
maximum capability curves 119
modeling 126
regions of operation 118
sensorless control
model-based 127–30
saliency-tracking-based methods 130
stator voltage equation at high speeds 115, 116
torque equation 107–8
surge arresters 231, 232
switched reluctance motors (SRMs) 508, 511, 512
symmetric gate-commutated thyristor (SGCT) 27
synchronous current regulators
induction machines 58–64
digital implementation 64
tuning using a second-order equivalent system 62–4
tuning using pole-zero cancellation 60–2
synchronous machines 113–14, 205
synchronous generators 416–18
synchronous machines
dynamic models 103–6
numerical calculation of the steady-state 140–6
operation under voltage and current constraints 115–24
control of non-salient machines under voltage constraints 117–19
control of salient machines under voltage constraints 119–21
current and voltage limits 115
feedback-based flux weakening 123–4
stator voltage equation at high speeds 115–16
rotor position and speed estimation 136
sensorless control
high-frequency signal-injection-based methods 133–7
magnet polarity detection 138–9
model-based 127–30
saliency-tracking-based methods 130–3
speed control 124–5
steady-state operation 141
torque capability
maximum capability curves 119, 140–4, 141, 143
torque equation 106–11
type 29, 100–3
typical electric parameters 146
vehicle traction 508
see also brushless DC motors (BLDCs); permanent magnet synchronous machines (PMSMs); synchronous reluctance machines (SynRMs); wound rotor synchronous machines
synchronous reference frame phase-locked loop (SRF-PLL) 179, 191–2, 204
synchronous reluctance machines (SynRMs) 102, 122–3
constant torque and constant current contours 109
constant voltage, current, and torque contours 123
sensorless control 125, 130
vehicle traction 508
synthetic ropes 558, 560
third harmonic injection 159–60, 161, 162
third rail system 333
3L-NPP (neutral point piloted) 28, 256
thyristors 26–7
gate-commutated (GCTs) 23, 27
integrated gate-commutated (IGCTs) 277, 278
tire model 473, 473
tire-ground adhesion 472–3
see also wheel slip
torque and power equations
induction machines 49–52, 89, 90, 93, 94
ship propulsion 392, 398, 399, 441
synchronous machines 106–11, 141, 143, 145
torque capability
electric vehicles 506–7
induction machines 69–71
maximum capability curves 88–91, 89–90, 92, 265
railway traction 263–4
ship propulsion 399, 442, 443
synchronous machines 106–11, 109–11, 120, 121
maximum capability curves 119, 122, 140–4, 141, 143
torque coupling 503–4
torque ripple 511, 588
torque-speed behavior 8–9, 91, 95
electric vehicles 508
railway traction 570–7, 581–2, 583
propellers 393
see also torque capability
Toyota Prius 543–6
trackside energy storage 295–302
traction (adhesive) effort coefficients 472–3
traction applications 3–9
examples 7–8
traction motors (railways) 246, 247, 247
traffic controlling algorithms 612
trains 225
adhesion 251–3
dynamics 248–50
modeling 253–5
see also railway traction
trams 224, 225
acceleration and deceleration profiles 342, 343
catenary nominal voltage 322
commercial example 340–3
driving cycles 309
energy losses and recovery 281
ground level power supply systems 334–5
low-floor 279–80, 315, 316–17, 340–3
on-board energy storage 288, 307–21, 322
power converter boxes 246, 247
speed profiles 343
see also light rail vehicles (LRVs)
transformers
AC/DC/AC power converters 18
core materials 329, 330
railway traction 148, 228–9, 257, 258–9
resonant topologies 331
ship propulsion 400–3, 405, 436
tunnel thrusters 374
twelve-pulse rectifiers
railway traction 233–4, 234, 276
ship propulsion 401, 402, 403, 440, 442
twenty-four-pulse rectifiers 401, 402, 403
tyre see tire
ultracapacitors see supercapacitors
unbalanced three-phase systems 185–92
vacuum pressure impregnation (VPI) 236
variable frequency controls 31
variable pitch propellers 371, 380
variable reluctance machines 29, 380
variable speed drives
railway traction 255–75
ship propulsion 392–409
vehicle traction 506–15
see also speed control
varnishes 236
vector control 31
electric vehicles 515, 516
elevators 581, 583–4
grid-connected converters 176–7
under unbalanced voltage conditions 198, 199–202
permanent magnet synchronous machines (PMSMs) 111–14
ship propulsion 407
synchronous machines 123–4
see also rotor flux oriented vector control
vehicle traction see electric vehicles
vertical axis propellers 374–5
vibration in elevators 578–9
voltage control
DC bus 176, 183, 201, 212, 216, 275, 316
ship electric systems 420–2
voltage droop
analysis 425, 426, 435
control 420–1
voltage harmonics 174, 401, 436
see also harmonic filters
voltage source converters (VSC) see power converters
voltage transients 435
VPI (vacuum pressure impregnation) 236
VSC (voltage source converters) see power converters
‘wave wall’ 378, 379
wheel dynamic equation 473–4
wheel hub motors 499
wheel slip
anti-slip control 275, 484–91, 492
railway traction 252, 275
vehicle traction 472–3, 480, 481, 482, 483, 484–6, 488
wind turbines 21, 30
wireless charging 518, 548
worm gearboxes 561, 562
wound rotor induction machine (WRIM) 30
wound rotor synchronous generators 416–18
wound rotor synchronous machines 101, 397, 443, 508
WRIM (wound rotor induction machine) 30
zebra sodium (Na-NiCl2) batteries 526