INDEX

active stall control, 417
AC-to-DC Conversion, 166–9
advanced metering infrastructure, 567, 570–71
air conditioning demand, 24
air density, 426–9
air mass ratio, 189–91, 213–15, 230, 260
alkaline fuel cells (AFCs), 618
Altamont Pass, 452
altitude angle of the sun, 193–6
AM 1.5 (air-mass ratio 1.5), 260
amorphous silicon, 259, 272–4, 333–4
amortizing costs, 39, 340–42, 483–5, 638–9
anaerobic digestors, 554–5
ancillary services, 19–21, 146–8, 575, 579–80
Andasol power station, 509
anemometers, 442–3
apparent power, s, 127–31
appliance energy consumption, 360–63
area required for wind farms, 470–74
Atlantic wind connection, 479–80
attenuators, wave power, 526
automated distribution systems, 566
automatic generation control (AGC), 19
average power in the wind, 451
azimuth angle of the sun, 196–200
back-to-back voltage-source converters, 177–8
balancing authorities, 16
band-gap energy, 256–2
and PV efficiency, 261–2
in tandem cells, 273–4
Banki turbine, 544
batteries, 366–78
flow batteries, 576–7
for grid storage, 575–7
i-v curves, 358–60
lead-acid batteries, 367–72, 577
lithium batteries, 366–7, 575–8
sizing, off grid, 375–8
sodium-sulfur batteries, 577
for vehicles, 577–80
Betz efficiency, 433–5, 534
binary cycle, geothermal, 556–7
biomass for electricity, 553–5
biomass gasification, 622
INDEX

bipolar junction transistors, 169
blackbody radiation, 186–8, 260
blackouts, 16, 21, 568
boost converters, 174
Brayton cycle, 26
buck-boost converters, 302–5
buck converter, 170–74
building energy efficiency, 588–91
buoy data, 523–4, 527
bypass diodes and blocking diodes, 299–301
cadmium telluride (CdTe), 255, 259, 262, 275–6
california energy,
AB 1890, 10
conservation achievements, 585
deregulation, 9–12, 568
summer load profile, 24
California solar initiative, 329, 326
capacitive reactance, 117
capacitors, 78–81
idealized, 115–19
for power factor correction, 129–31
capacity factors, 30–31
for concentrating solar power, 504, 510
for photovoltaics, 334–5
for tidal power, 538
for wind, 461–8
capital recovery factor, 39, 638–9
carbon emissions,
abatement curves, 588–91
costs and emissions, 48–50
emission rates, 29, 592
Carnot efficiency, 499–502, 517–18, 591
cash flow analysis, 344–7, 643–4
central receiver systems, 499, 506–8, 511–12, 518–21
centrifugal pumps, 390–91
collectors, 169–70
CIS, copper indium gallium selenide, 255, 259, 262, 268–9, 276
clearness index, 238
clear sky insolation, 210–27
beam radiation, 210, 216–17
calculator, 222
equation summary, 230–32
hour-by-hour, 226–7, 653–62
monthly, 227–32, 663–6
clock (civil) time, 206–8
ccoal-fired steam power plants, 26–30
cogeneration, see combined heat and power
combined-cycle power plants, 32–5, 40
combined heat and power, 565, 591–9
biomass, 553
economics, 593–6
efficiency measures, 591–8
fuel cells, 603–15
microturbines, 598–9
reciprocating engines, 600–601
combiner box, 318
combustion turbines, 31–2
complex algebra, 123–5
concentrating solar power systems (CSP), 498–521
central receiver systems, 499, 506–8, 511–12, 518–21
collection, 519
cooling systems, 504–6
dish-Stirling power systems, 499, 514–21
levelized cost of energy, 511–12
linear fresnel reflectors, 499, 513–14, 518–21
parabolic trough systems, 499, 506–11, 518–21
resource assessment, 520
thermal energy storage, 506–9
conversion factors (Appendix B), 645–8
converters, 166–78
AC - DC, 499, 506–8
back-to-back, 177–8
DC - DC, 169–75
copper indium gallium selenide (CIGS), 255, 259, 262, 268–9, 276
Coulomb efficiency, 373–5
critical peak pricing, 349
crystalline silicon PV technologies, 269–72
cumulative distribution function, 454–8
current gulps, 167–8
cut-in and cut-out wind speed, 437
Czochralski process, 254
Darrieus rotor, 413, 436
day numbers, 191
DC-to-AC Inverters, 175–7, 318
DC-to-DC converters, 169–75
debt and equity financing, 39, 489–90
INDEX

depletion region, 264–5
derating factors for PVs, 323–9
deregulation, 9–12, 568
DFIG (doubly-fed induction generator), 422–3
diesel generators, 356, 385–6, 642–3
diffuse horizontal irradiance (DHI), 236–8
diffuse radiation, 217–19
diffuse sky factor, 214, 218
diodes, 265–7
  blocking diodes, 300
  bypass diodes, 299–300
  ideal, 166
  p-n junction diode, 265–7
  in rectifiers, 166–9
  Shokley equation, 266–7
direct band-gap materials, 257
direct methanol fuel cells (DMFCs), 617
direct normal irradiance (DNI), 236–8, 502–4
dirt on PVs, 324–5
discount rate, 631, 644
dish-Stirling power systems, 499, 514–21
dispatching, 47–8, 506, 572–5
distributed generation, 149
distribution systems, 13–14, 148–54, 566
DNI direct-normal irradiance, 236–238, 502–4
doubly-fed induction generator, 422–3
dry cooling, 504
duty cycle of switches, 171–5
dynamic head, water, 394–6, 545–6
economics of energy systems,
  combined heat and power, 593–596
  conventional generation, 38–48
  diesel generators, 385–386, 642–643
energy efficiency, 585–588
  fuel cells, 595–596, 619–620
  geothermal systems, 558
  photovoltaic grid systems, 338–356
  photovoltaic stand-alone systems, 384–387
  retail prices of electricity, 24
  wave energy systems, 529
  wind systems, 474–5, 481–91
eddy current losses, 98–100
Edison, Thomas Alva, 3–5, 166
electricity milestones, 13
electric rate adjustment mechanism (ERAM), 582
electric vehicles, 565, 578–80
  charging, 565, 578–80
  for frequency response, 573–5
electrolysis of water, 622
  electromagnetism, 81–5
  electromotive force (mmf), 2, 31–3, 124–5, 388
  electron drift velocity, 59
  end-use energy, 23–5
  Energetech oscillating WEC system, 527–8
  energy chargeable to power, 593–5
  energy economics tutorial (Appendix A), 629–44
  energy Policy Act of 1992 (EPAct), 8–10
  energy service companies (ESCOs), 580
  enhanced geothermal systems, 556
  Enron, 12
  enthalpy, 605–9
  entropy, 609–12
  environmental impacts of wind, 491
  equation of time, 207–08
  equinox, 192
  equivalent circuits for PV cells, 277–84
  exempt wholesale generators, 8
  experience curves, 254–5, 269–70, 309
  extraterrestrial solar flux, 187–91, 212–14, 236–8
  Faraday’s law of magnetic induction, 81–2
  faults, 21, 133–5, 318, 566
  federal energy regulatory commission (FERC), 7–9
  feed-in tariffs, 321–2
  fill factor, 290
INDEX

financial calculations,
capital recovery factor, 39, 638–9
cash flow analysis, 344–7, 643–4
fixed charge rate, 38–40
flip financing of wind, 489
fossil fuel costs, 25
fuel escalation, npv, 635–8
initial rate of return, 630
internal rate of return (irr), 347–51
tutorial (Appendix A), 629–44
weighted average cost of capital, 38–9
firm capacity, 506
fixed charge rate, 38–40
flip financing of wind, 489
flow batteries, 576–7
fossil fuel costs, 25
Fourier series analysis, 158–60
Francis turbine, 545, 550
frequency regulation, 16–21, 573–5
friction loss in pipes, 395, 545–6
fuel cells, 602–23
economics, 595–6, 619–20
electrical characteristics, 613–15
thermodynamics, 605–12
types of fuel cells, 616–20
fuel escalation, NPV, 635–8
furling windspeed, 437
gallium arsenide cells (GaAs), 255, 259,
262, 268–9, 274–5
gas turbines, 31–2
general rate case, 581
generators,
circuit models, 124–5, 146–8
doubly fed induction (DFIG), 422–3
fixed-speed synchronous, 143–8, 418–19
induction, 419–23
permanent magnet, synchronous, 419,
423, 441
squirrel-cage induction, 419–22
variable-speed synchronous, 423–24
geothermal power, 555–8
GE wind turbine, 424, 460
Gibbs free energy, 606–7, 612–3
Gildea anniversary, 427
global horizontal irradiance (GHI), 236–8
greenhouse gas abatement curves, 588–91
grid-connected PV systems, 317–54
grid stability, 16–22, 568–9
ground-cover ratio, 326
ground-fault interrupter (GFI), 133–4, 318
harmonics, 158–65
gulps of current, 167–68
overloaded neutrals, 162–64
total harmonic distortion, 161–62
transformers impacts, 165
heat engines, 499–502
heat rates, 28, 44
heat transfer fluid, 507, 509, 512
heliostats, 511
high heating value of fuel (HHV), 596–8,
608
high-voltage DC (HVDC), 15, 177–8,
476–9, 529
hill-climbing algorithm, 305–6
hole-electron pairs, 257–60, 263–6
home area networks (HAN), 570
horizontal axis wind turbines, 413–14
hot dry rock, 556
hour angle, 197–9
hourly clear-sky insolation tables, 653–62
household electrical loads, 362
hybrid cooling systems, 504–06
hybrid electric vehicles, 2
hybrid PV modules, 313
hydraulic system curves, 390–96
hydroelectric power, 22, 538–50
hydrogen production, 620–3
hydrothermal regions, 556
hysteresis losses, 96–8

IEC 61400-1 Wind classifications, 442
IGBT transistors, 169
impedance, 121–5
impulse transistors, 543
incremental conductance algorithm, 306–9
independent power producers (IPPs), 8
independent system operators (ISOs), 9, 19
indirect band-gap materials, 257
inductance, 85–92
inductive reactance, 120
INDEX

inductors, idealized, 119–21
initial rate of return, 630
instant costs, 38
Insull, Samuel, 3–5
integrated gasification combined cycle (IGCC), 33–5
integrated resources planning (IRP), 580
internal combustion engines, 600–602
internal rate of return (IRR), 345–7, 633–5
inverters, derating factors, 324
electronic systems, 175–7
microinverters, 319–20
investor owned utilities (IOUs), 7, 39
islanding of PV systems, 319
isolation transformers, 324
Ivanpah central receiver, 512
Kaplan turbines, 545
Kempton, Willett, 574
Kirchhoff’s current and voltage laws, 60–64
La Rance River tidal plant, 530
LCOE of concentrating solar power, 511–12
LCOE of wind turbines, 482–9
lead-acid batteries, 367–72, 577
learning rates, 254–5, 309, 529
least-cost planning, 580
Lenz’s law, 82
levelized cost of energy (LCOE), 40–43, 481–4, 639–43
levelizing factor for fuel escalation, 41–2, 641
light-emitting diodes (LEDs), 257, 356
linear Fresnel reflectors, 499, 513–14, 518–21
linear power supplies, 173
line voltages, 138–42
lithium batteries, 366–7, 575–8
load duration curves, 44–8
low heating value of fuel (LHV), 596–8, 608

MACRS Modified accelerated cost recovery system, 351–352, 485–9
magnetic fields and flux density, 83–5
magnetomotive force (mmf), 83–4
Makani windpower, 494
marginal tax brackets, 342–4
maximum power point, 290–91
maximum power point trackers, 301–9, 335–7, 364
McKinsey GHG abatement curves, 588–91
merchant power plants, 8, 39
metallurgical-grade silicon, 271
methane steam reforming, 621–2
micro-hydro power, 546–50
microinverters, 319–20, 332
microturbines, 598–600
Milankovitch oscillations, 192
mixed tides, 536
modified accelerated cost recovery system (MACRS), 351–2, 485–9
module mismatch factors, 323–5
molten-carbonate fuel cells (MCFCs), 618
molten salt storage, 507–8, 512
monthly clear-sky insolation tables, 663–6
MOSFET transistors, 169
motor dc I-V curves, 389–90
MPPT controllers, 305–9
multicrystalline silicon, 271–2
multijunction solar cells, 273–5

national solar radiation data base (NSRDB), 233–5
natural gas combined cycle, 32–5
neap tides, 532–3
neighborhood area networks (NAN), 570
net metering, 317–19, 321–2
net present value (NPV), 346–7, 630–33
nominal operating cell temperature (NOCT), 293–4, 327–9, 333
North American electric reliability corporation (NERC), 15–16
North American power grid, 14–16
Northeast power blackout, 16, 21, 568
nuclear power, 22, 35–8

off-grid PV systems, 356–99
offshore cables, 476–9
offshore wind farms, 475–80, 529–30
once-through cooling, 504
one-line diagrams, 14
onshore wind potential, 468–75
optical depth, 214
optimum band gap, 261–2
overnight costs, 38
overtopping devices, wave power, 526
parabolic dish reflectors, 275, 514–15
parabolic trough systems, 499, 506–11, 518–21
partial oxidation, 622
peak-hours approach to PV performance, 330–33
peak-hours for stand alone systems, 380–81
peak-wave period, 523–4
Pelamis wave converter, 527
Pelton wheel, 543–4
permanent magnet synchronous generator, 419, 423, 441
phase voltages, 138–42
phasor measurement units (PMUs), 569
phasors, 117, 123, 146–8
phosphoric acid fuel cells (PAFCs), 617–18
photon energy, 257–9
photovoltaic materials and characteristics, equivalent circuits, 277–84
I-V curves, 288–98
materials, 267–77
module performance data, 292
parallel and series leakage resistance, 280–87
semiconductor physics, 255–67
shading impacts, 294–300
temperature impacts, 291–4, 327–9
photovoltaic systems, grid-connected system sizing, 336–8
off-grid systems with battery storage, 356–87
predicting performance, 322–36
system economics, behind the meter, 338–56
utility system economics, 353–6
water pumping, 387–99
physics of shading, 294–9
pico-scale PV systems, 316
Pierson-Moskowitz spectrum, 523
piping friction loss, 395, 545–6
pitch-controlled wind turbines, 417, 437
Planck’s constant, 187, 259
Planta Solar, Seville, Spain, 512
plug-in hybrid electric vehicles (PHEVs), 578–80
p-n junctions, 263–7
point absorbers, wave power, 526
polycrystalline silicon, 269
polymer electrolyte fuel cells (PEMs), 616–17
positive-displacement pumps, 390–91
power conditioning unit, 317–18, 330
power electronics, 166–78
power factor, 125–7
power factor correction, 129–31, 141
power purchase agreements (PPAs), 352–3, 489
power quality, 157–65
power towers, 499, 506–8, 511–12, 518–21
power triangle, 127–9
present value calculations, 346, 631–2
pressure-volume diagram, 518
probability density functions (PDFs), 447–50
production tax credit (PTC), 485–9
proton exchange membrane (PEM) fuel cells, 604–5
publicly owned utilities (POUs), 8, 39
public utilities commissions, 581
public utility holding company act (PUHCA), 5–6
public utility regulatory policies act (PURPA), 5–7
Puerto Erado linear fresnel system, 513–14
pulse-width modulation, 173–6, 303
pumped storage hydro, 550–52, 575
pump hydraulic and I-V curves, 390–94
PVUSA test conditions, 329
PVWATTS, 323–9
pyranometer, 233–4
pyrhiometer, 233–5
pyrolysis, 554
qualifying facilities (QFs), 7
Q volt-amps reactive, 127–31
ramp rates, 18–20
Rankine cycle, 26, 504
rare earth elements, 84, 424
rated windspeed, 437
rate structures, 347–51
Rayleigh probability density function, 449–52, 454–8
reactance, 117, 120
reaction turbines, 543
reactive power, Q, 127–31
real power, W, 127–31
real-time pricing, 349, 352
INDEX

rear-contact solar cell, 270
reciprocating engines, 600–602
rectifiers, 15, 166–9, 173
reflected radiation, 220–21
regional transmission organizations (RTOs), 9, 19
regulation services, 19–21, 573–5
renewable portfolio standards (RPS), 485, 540
residential wiring, 131–4
reverse saturation current, 265–7
root mean square (rms), 110–13
Rosenfelds, the unit, 31
rotating magnetic field, 144–6
rotor spacing, wind farms, 471–3
roughness classifications, 430
Ruths accumulator, 508–9
SCADA (Supervisory control and data acquisition), 566
screening curves, 43–7
sea state scatter diagrams, 523–4
second law of thermodynamics, 609
self-regulating modules, 358–60, 379
semiconductor physics, 255–67
shading analysis,
derate factors, 315–26
impacts on I-V curves, 294–301
losses in PV systems, 325–6
maximum power point trackers, 308–9
shadow diagrams, 203–6, 667–9
sun path diagrams, 200–203, 649–552
shared savings program, 583
Shockley diode equation, 265–7
Shockley-Queisser efficiency limit, 261–2, 268
Siemens wind turbine, 460
significant wave height, 522–3
simple payback period, 629–30
single-axis trackers, 222–7, 245
single-phase residential power, 131–4
slip speed, 421
smart grid, 564–75
smart meters, 567, 570–71
sodium-sulfur batteries, 577
solar advisor model, 323
solar angles summary, 211
solar declination, 194–6
solar electric generating system (SEGS), 509–10
solar irradiation,
average monthly, by city, 238–43, 670–81
clear sky calculations, 210–30
equations summary, 230–32
hourly clear sky tables, 653–62
measurements, 233–5
monthly clear sky tables, 663–6
NREL radiation data manual, 243–6
solar one and solar two, 511
solar spectrum, 186–93, 260
solar time and clock time, 206–8
SolFocus concentrators, 275
solid oxide fuel cells (SOFCs), 619–20
solsite, 192–3
sonic anemometers, 442–3
sonic detection and ranging (SODAR), 443
spring tides, 532–3
squirrel-cage induction generator, 419–20
stall-controlled wind turbines, 417, 437
standard test conditions (STCs) for PVs, 288–91, 322
standby power, 174, 357, 361–3
state of charge, 357
Stefan-Boltzmann law of radiation, 187
stirling engines, 515–18
storage battery, grid, 575–80
storage, pumped hydro, 551
storage thermal, grid, 506–9, 511–12
submarine cables, 476–9
sun path diagrams, 200–203, 649–52
sunrise and sunset times, 209–10
Sunshot Program, 255, 339
sunspots, 213
tandem solar cells, 273–5
terminators, wave power, 526
thermal energy storage for CSP, 506–9
tacoma Narrows, WA tides, 537–8
temperature derating of PVs, 291–4, 327–9
tandem solar cells, 273–5
terminators, wave power, 526
INDEX

thermal stratification, 507–8
Three Gorges dam, 539
three-phase rectifiers, 168–9
three-phase systems, 12, 134–43
  balanced, wye-connected, 134–42
  delta-connected, 142–3
  overloaded neutrals, 162–4
  rectifiers, 168–9
tidal in-stream energy conversion, 530–9
tides, origin, 531–3
tilt angle impact on PVs, 227–9
time of delivery factors (TOD), 353–5
time of use (TOU) rate structure, 347–9, 489
tip-speed-ratio (TSR), 436, 439–40, 535
total harmonic distortion, 161–4
tracking systems, 222–7, 503
transformers, 13–15, 92–100, 166
  battle over AC vs DC, 13–15
  harmonics, 165
  idealized, 93–6
  isolation, 324
  magnetization losses, 96–100
transmission systems, 12–16, 148–52
  AC - DC links, 14–16, 177–8
  FERC Order 888, 8–9
  HVDC, 15, 177–8, 476–9, 529
  losses, 22, 149–52
  North American grid, 14–16
  offshore wind and wave farms, 476–9, 529
  reactive power in T&D, 152–7
  voltage loss, 154–7
  transparent conducting oxide (TCO), 270
  turgo wheel, 544
typical meteorological year (TMY) data, 236–8, 327
utility rate structures,
  commercial-building rates, 349–50
  critical peak pricing, 329
  feed-in tariffs, 321–2
  ratemaking disincentives, 581–2
  real-time pricing, 349, 352
  residential rate structures, 347–9
  time of use (TOU), 347–9, 489
vampire loads, 174, 361–3
vanadium redox batteries, 576–7
variable-speed synchronous generators, 423–4
vehicle to grid (V2G), 564, 573–5, 577–80
Vergnet wind turbine, 460
Vestas wind turbine, 460–461
voltage loss in transmission lines, 154–7
volt-amps reactive (VARs), 127–31
volt/VAR optimization, 566–8
water pumping PV systems, 387–99
wave energy conversion systems,
  predicting performance, 527–9
  resource assessment, 525–6
  scatter diagrams, 524
  technologies, 526–7
Weibull probability density function, 448–450
weighted average cost of capital, 38–9
western electricity coordinating council, 16
Westinghouse, George, 3–5, 166
wet cooling, 504–6
wide area networks (WAN), 570
Wien’s displacement rule, 187
wind power systems,
  economics, 481–9
  environmental impacts, 489–90
  estimating capacity factors, 463–8
  generators, 418–23
  historical development, 410–14
  IEC classifications, 441
  offshore wind farms, 475–81
  rotors, 415–18
  turbine power curves, 433–41
  turbine specifications, 460
  with wave power, 529–30
wind resources,
  air density, 426–32
  measuring the wind, 442–3
  onshore wind potential, 468–75
  probability density functions, 444–51
  windshear exponent, 430
  windspeed classifications, 452–4
  wire losses, 73–8, 149–52
  wound-rotor induction generator, 420
  wound-rotor synchronous generator, 419
wye connected 3-phase power, 134–42