

Table of Contents

Preface	xvii
Chapter 1. Photovoltaic Electricity Production	1
Jean-Claude MULLER	
1.1. Introduction	2
1.2. Photovoltaic conversion	3
1.2.1. I-V characteristics of a cell and conversion output	4
1.3. Cells with a crystalline silicon base.	5
1.3.1. Raw silicon	5
1.3.2. Monocrystalline silicon	5
1.3.2.1. Techniques for growing monocrystals	5
1.3.2.2. Record for cells on monocrystals	5
1.3.3. Multicrystalline silicon	6
1.3.3.1. Techniques for growing multicrystals.	6
1.3.3.2. Improvement in performance of cells created from multicrystals	7
1.3.4. Silicon in self-supported ribbon	9
1.3.4.1. Growing techniques	9
1.3.4.2. Prospects	9
1.4. Cells in thin films	10
1.4.1. Polycrystalline silicon	10
1.4.2. Nanocrystalline and amorphous silicon	12
1.4.2.1. State of the art and new prospects	12
1.4.2.2. Industrial applications	13
1.4.3. Marriage of crystalline and amorphous technologies	14

1.4.4. Other emerging thin-film materials	15
1.4.4.1. Materials with a cadmium–tellurium base	15
1.4.4.2. Materials with a base of indium–copper–selenium (CIS) (copper selenate)	15
1.4.5. Prospects for thin films	16
1.5. Photovoltaic market	17
1.5.1. Stimulation of production by political intervention	18
1.5.2. First beneficial effects on production and power of the installations	19
1.5.3. Adaptation of the product to the market: cost of watt and kilowatt hour PV	21
1.6. Prospects for photovoltaic electricity development	22
1.7. Bibliography	23
Chapter 2. Photovoltaic Systems Connected to the Grid	25
Seddik BACHA and Daniel CHATROUX	
2.1. Problems of photovoltaic power generation connected to the grid	25
2.2. General remarks on connection	28
2.2.1. Interfacing with the grid.	28
2.2.2. General remarks on control.	30
2.3. Physical architectures	30
2.3.1. Central inverter	32
2.3.2. Individual inverter	32
2.3.3. Row inverters	32
2.3.4. Multiple row inverters.	32
2.3.5. Conclusion.	33
2.4. Constraints related to supplying energy to the utility grid	34
2.4.1. Quality of the energy supplied	34
2.4.2. Security	34
2.4.2.1. Security regarding the grid	35
2.4.2.2. Security with respect to installation	35
2.5. Algorithmic architectures	38
2.5.1. The search for MPPT	38
2.5.2. Control of the inverter grid and the global chain	41
2.6. Conclusion	42
2.7. Bibliography	43

Chapter 3. Solar Heating	45
Christophe MARVILLET	
3.1. Introduction	45
3.1.1. Some history	45
3.1.2. Some basic calculations	47
3.1.3. The performance of solar heating devices	48
3.2. Available energy from the sun	49
3.2.1. The apparent motion of the sun	49
3.2.2. Evaluation of sunlight received by a collector	52
3.3. Flat solar panels	53
3.3.1. Different technologies of thermal solar collectors	54
3.3.2. Evaluation of the performance of solar collectors	55
3.3.3. Selective coatings for collectors and glazing	58
3.4. Solar heating systems	58
3.4.1. Individual and collective solar water heaters	58
3.4.2. Combined solar systems for the heating of buildings	61
3.5. Bibliography	62
 Chapter 4. Solar Thermodynamic Power Stations	 63
Alain FERRIÈRE	
Introduction	63
4.1. Concentrating solar power technologies	65
4.1.1. Why concentrate solar radiation?	65
4.1.2. Concentrating systems	67
4.1.2.1. The parabolic concentrator (or dish)	68
4.1.2.2. The tower concentrator	71
4.1.2.3. The cylindrical-parabolic concentrator (or trough concentrator)	72
4.1.3. Components for production of heat and conversion into electricity	75
4.1.3.1. The solar receiver	76
4.1.3.2. Heat transfer fluid	77
4.1.4. Storage and hybridization	82
4.2. The state of the art	84
4.2.1. First generation solar stations and exploratory work	84
4.2.2. Second generation solar power stations: precommercial prototypes	90
4.3. Prospects	94
4.3.1. Strategy for penetrating the market	94
4.3.1.1. Power stations of the future and research efforts	98
4.3.1.2. Conclusions	101
4.4. Bibliography	102

Chapter 5. Wind Systems Technology	103
Régine BELHOMME, Daniel ROYE and Nicolas LAVERDURE	
5.1. Introduction: wind power today	103
5.2. Description of a wind generator	104
5.2.1. Principle	104
5.2.2. Constitution	105
5.3. Operation of a wind turbine	106
5.3.1. Controls of energy conversion	106
5.3.2. Control at the turbine level	108
5.3.2.1. Action of the wind on the turbine blades	108
5.3.2.2. Control methods at the turbine level	111
5.3.3. Mechanical system – transmission of the power	116
5.3.4. Controls at generator and transmission network levels – different types of wind power generator systems	119
5.3.4.1. Fixed speed systems – squirrel cage asynchronous machines	119
5.3.4.2. Variable speed systems	123
5.4. Bibliography	136
Chapter 6. Integration of Wind Turbine Generators into the Grid	143
Régine BELHOMME, Daniel ROYE and Nicolas LAVERDURE	
6.1. Connection to the grid	143
6.1.1. Voltage at the point of connection	144
6.1.2. Currents in steady state	145
6.1.3. Short circuit currents	145
6.1.4. Voltage profile	147
6.1.5. Voltage quality	148
6.1.5.1. Slow variations in voltage	148
6.1.5.2. Sudden changes in voltage	148
6.1.5.3. Flicker	149
6.1.5.4. Harmonics	149
6.1.5.5. Disturbances of signals transmitted on the grid	151
6.1.6. Stability and protection design	151
6.1.6.1. Management in normal and abnormal regimes	152
6.1.6.2. Managing voltage sags (FRT “fault-ride-through” or LVRT)	152
6.1.6.3. Interaction with the protection design	155
6.1.7. Auxiliary system	156
6.1.7.1. Regulation of voltage and reactive compensation	157
6.1.7.2. Regulation of frequency	159
6.1.7.3. Operating on a separate grid and reconstitution of grids	161
6.1.8. Variability and unpredictability of production	162

6.1.9. Other solutions for connection problems	162
6.1.9.1. Reinforcement of the grid	162
6.1.9.2. Power shedding	163
6.1.9.3. Coordination with other production methods	163
6.1.9.4. Load control	164
6.1.9.5. Systems of reactive compensation and of voltage control	165
6.1.9.6. Systems for managing voltage sags	167
6.1.9.7. Systems for energy storage	168
6.1.9.8. Short circuit current limiting devices	168
6.1.9.9. Other equipment	169
6.2. Comparison of technologies and conclusion	169
6.3. Bibliography	171
6.4. Appendix: symbol table	177
6.4.1. Parameters and physical variables	177
6.4.1.1. Time variable	177
6.4.1.2. Turbine, blades	178
6.4.1.3. Mechanical system	178
6.4.1.4. Induction and synchronous generators	178
6.4.1.5. DC bus	180
Chapter 7. Marine Energy Resources Conversion Systems	181
Bernard MULTON, Alain CLÉMENT, Marie RUELLAN, Julien SEIGNEURBIEUX and Hamid BEN AHMED	
7.1. Introduction.	181
7.2. Electricity productivity from marine resources	183
7.2.1. Energy sources from the sea	183
7.2.1.1. Solar heat.	183
7.2.1.2. Wind energy	183
7.2.1.3. Ocean wave energy.	184
7.2.1.4. Tidal currents	184
7.2.1.5. Continuous ocean currents	185
7.2.1.6. Osmotic energy	185
7.2.1.7. Ocean biomass	186
7.2.1.8. Evaluation	186
7.2.2. General technical-economic aspects	186
7.3. Ocean wave generator systems (WEC: wave energy converters)	188
7.3.1. Wave energy characteristics	188
7.3.2. Diversity in conversion systems	192
7.3.3. Systems with breakwater ramps	193
7.3.4. Oscillating water column (OWC) systems	195
7.3.5. Systems with wave activated bodies.	198

7.4. Tidal energy converters (TEC)	202
7.4.1. Characteristics of tides and other marine currents	202
7.4.2. Tidal power production systems with dams	203
7.4.3. Systems for recovering energy from marine currents	206
7.5. Other conversion systems	214
7.5.1. Offshore wind power generators	214
7.5.2. Ocean thermal energy converter (OTEC).	218
7.6. Conclusion	221
7.7. Bibliography	223
Chapter 8. Small Hydropower	227
Raymond CHENAL, Aline CHOULOT, Vincent DENIS and Norbert TISSOT	
8.1. Introduction.	227
8.2. What is small hydropower?	229
8.3. Hydraulic energy	231
8.4. The exploitation of hydraulic force	233
8.4.1. Description of a typical scheme	234
8.4.2. Different types of schemes encountered	234
8.4.3. Different kinds of turbines	236
8.4.3.1. The Pelton turbine	236
8.4.3.2. The Francis turbine	237
8.4.3.3. The diagonal turbine	238
8.4.3.4. The Kaplan turbine	238
8.4.3.5. The waterwheel for water from above.	239
8.4.3.6. The Banki or crossflow turbine.	240
8.4.3.7. The inverted Archimedes screw	240
8.4.4. Particular applications of small hydro	240
8.4.4.1. Turbines in drinking water networks	241
8.4.4.2. Turbines in wastewater networks	242
8.4.4.3. Recovery of energy in desalination plants	244
8.5. Potential	244
8.5.1. Worldwide small hydropower	244
8.5.2. European-wide small hydropower	244
8.5.3. Possibilities for development of small hydropower in Europe	245
8.6. Research & Development in small hydropower	245
8.6.1. Development of equipment adapted to each site.	246
8.6.2. Development of variable speed.	246
8.6.3. Development in generators	247
8.6.4. Development in control-command.	247
8.6.5. Inflatable weirs	248
8.6.6. Water intake	248

8.7. Environmental aspects of small hydropower	249
8.7.1. Initial state of the milieu	249
8.7.2. Setting phase.	249
8.7.2.1. Setting of a small power plant for its integration into the ecosystem	249
8.7.2.2. Flow of materials and equipment	253
8.7.3. Principal inputs and outputs during the operating phase	253
8.7.3.1. Water	254
8.7.3.2. Materials carried by the watercourse	254
8.7.3.3. Noise	254
8.7.3.4. Electricity production	254
8.8. Policies favoring small hydropower	254
8.8.1. R & D program	255
8.8.2. Rate measures	256
8.9. Conclusions.	257
8.10. Bibliography	258
Chapter 9. Geothermal Energy Production	261
Florence JAUDIN and Laurent LE BEL	
9.1. Introduction.	261
9.2. Geothermal energy: why, for whom and how?	262
9.2.1. The types of resources used.	262
9.2.1.1. Fissured and/or porous volcanic formations	264
9.2.1.2. Aquifers of sedimentary basins.	265
9.2.1.3. Superficial formations	266
9.2.1.4. Deep formations (with low permeability).	266
9.2.2. End-use.	266
9.2.2.1. Heat network system.	267
9.2.2.2. Heat pump (HP) system	267
9.2.2.3. Electricity production	268
9.2.3. Other uses	268
9.3. Geothermal heat pump systems	269
9.3.1. Current situation and tendencies	269
9.3.2. The principle of the heat pump	270
9.3.2.1. Classification of heat pumps	270
9.3.2.2. Coefficient of performance (COP).	273
9.3.3. Extracting heat from the ground	275
9.3.3.1. Drawing calories from groundwater.	276
9.3.3.2. Horizontal and vertical in-ground heat exchangers	277
9.3.4. Development prospects and potential	285

9.4. Direct production of heat	286
9.4.1. Current situation	286
9.4.2. Geothermal heating networks	288
9.4.2.1. The theoretical doublet and the associated heating network	288
9.4.2.2. Geothermy experience in the Paris basin	289
9.4.2.3. Technological developments	291
9.4.3. Prospects and potential for development	300
9.4.3.1. The objectives of the revival in Ile-de-France	301
9.5. Electricity production	301
9.5.1. Current contribution of geothermal energy to the production of electricity	301
9.5.2. Exploitation of geothermal resources	302
9.5.2.1. Naturally producing reservoirs	302
9.5.2.2. Enhanced geothermal systems	312
9.5.3. Development potential	318
9.6. Glossary	320
9.7. Bibliography	325
Chapter 10. Biofuels	329
Frédéric MONOT, Jean-Luc DUPLAN, Nathalie ALAZARD-TOUX and Stéphane HIS	
10.1. The place of biofuels in the energy environment	329
10.1.1. A favorable environment	330
10.1.2. Principal characteristics of systems today	331
10.1.3. Main advantages and disadvantages associated with biofuel use	333
10.1.4. The situation of biofuels in the world	335
10.1.4.1. The influence of the Common Agricultural Policy (CAP)	343
10.1.5. Prospects	345
10.2. Current systems	345
10.2.1. Biodiesel systems	345
10.2.1.1. Raw materials	345
10.2.1.2. Production processes	346
10.2.2. The bioethanol system	352
10.2.2.1. Raw materials	352
10.2.2.2. Production procedures	353
10.3. Future systems: use of lignocellulose	358
10.3.1. Characteristics of components in vegetable lignocellulose	358
10.3.2. The BtL system	361
10.3.2.1. Main constraints of the process	361
10.3.2.2. Conditioning of biomass	362
10.3.2.3. Gasification	366
10.3.2.4. Treatment of syngas	370

10.3.2.5. Fuel synthesis: Fischer–Tropsch and hydrocracking	371
10.3.2.6. Conclusion	372
10.3.3. The bioethanol system	373
10.3.3.1. Main constraints of the process	373
10.3.3.2. Pretreatment	374
10.3.3.3. Enzyme hydrolysis	375
10.3.3.4. Ethanol fermentation	377
10.3.3.5. Conclusion	379
10.4. Economic and environmental balance of biofuel production systems	380
10.4.1. Economic aspects	380
10.4.1.1. The competitiveness of biofuels	380
10.4.1.2. The ethanol system	382
10.4.1.3. Cost of ETBE production	387
10.4.1.4. Biodiesel	387
10.4.1.5. New fuel systems	389
10.4.2. Results of analyses of life cycle of biofuels.	390
10.5. Bibliography	394
Chapter 11. Biogas.	397
Pierre LABEYRIE	
11.1. Introduction: biogas, “the renewable natural gas”	397
11.2. Naturally occurring biogas	397
11.3. Production organized by humans	398
11.4. History of anaerobic digestion	399
11.5. Anaerobic digestion	400
11.5.1. Management of the anaerobic digestion process	401
11.5.1.1. The effect of temperature	402
11.5.1.2. Effect of pH	403
11.5.1.3. Dynamics of the bacteria populations	403
11.5.1.4. Mixtures of substrates or codigestion	403
11.6. Anaerobic digestion installations or biogas units	405
11.6.1. Techniques	405
11.6.1.1. Digesters functioning with a continuous introduction of substrates	405
11.6.1.2. Discontinuously functioning digesters (batch)	408
11.6.2. Examples of recent agricultural anaerobic digestion installations	408
11.6.2.1. Mr Claudepiere’s installation: liquid system	408
11.6.2.2. The GAEC Oudet installation: liquid system.	411

11.6.2.3. GAEC of the Chateau installation (under completion): mixed system	413
11.6.2.4. Pierre Lebbe installation: solid system	414
11.7. Uses of biogas	419
11.7.1. Thermal engine cogeneration	419
11.7.2. Exclusively thermal use	421
11.7.2.1. Use of a boiler	421
11.7.2.2. Use of a production system for cooling	422
11.7.3. Fuel production	422
11.7.3.1. PSA (pressure swing adsorption) purification	423
11.8. Conclusion: renewable natural gas and its challenges	424
11.9. Bibliography	425
Chapter 12. Energy Production from Wood.	427
Frédéric DOUARD	
12.1. Introduction: what is wood energy?	427
12.2. Overview of wood fuels.	429
12.2.1. Logs	429
12.2.2. Densified wood logs or compacted logs.	430
12.2.3. Briquettes.	431
12.2.4. Wood pellets	432
12.2.5. Wood chips.	434
12.2.6. Industrial chips	435
12.2.7. Grindings from recycled wood	436
12.2.8. Ground bark	438
12.2.9. Sawdust and wood chips.	439
12.2.10. Wood powder	440
12.2.11. Roasted wood	440
12.2.12. Wood charcoal	440
12.2.13. Spent pulping liquors and paper mill sludge	441
12.3. Principles of conversion of wood into energy.	442
12.3.1. Combustion	442
12.3.2. Pyrolysis	445
12.3.3. Gasification	447
12.4. Generators of thermal energy from wood	450
12.4.1. Domestic technologies	450
12.4.1.1. Hearths, ovens and other open fireplaces	450
12.4.1.2. Closed hearth fireplaces	451
12.4.1.3. Heating and cooking stoves	453
12.4.1.4. Wood-fired boilers	455
12.4.1.5. Pellet stoves	457

12.4.1.6. Pellet boilers	459
12.4.1.7. Domestic wood chip boilers	460
12.4.2. Housing complexes or industrial technologies	461
12.4.2.1. Hot air boilers and generators with fixed grilles	461
12.4.2.2. Boilers with moving or mobile grilles	463
12.4.2.3. Boilers with rotating conical grilles	464
12.4.2.4. Boilers with vibrating grilles	466
12.4.2.5. Boilers with rolling grilles	466
12.4.2.6. Bottom draft or air injection boilers	467
12.4.2.7. Boilers with boiling fluidized beds	468
12.4.2.8. Boilers with circulating fluidized beds	469
12.5. Conclusion	470
12.6. Bibliography	471
List of Authors	473
Index	475