

Contents

1	Introduction to Energy Generation Principles	1
1.1	Fluid Mechanics	1
1.1.1	Mass, Momentum, and Energy Balance	1
1.1.2	Stress Rate of Strain Relations and Viscosity	4
1.1.3	Perfect Gases and Acoustic Waves	5
1.1.4	Reference States	8
1.1.5	Normal Shock Relations	9
1.1.6	One-Dimensional Flow: Rayleigh Flow	11
1.1.7	One-Dimensional Flow: Fanno Flow	16
1.1.8	Quasi-One-Dimensional Flows	19
1.1.9	Oblique Shocks	23
1.1.10	Prandtl–Meyer Flow	26
1.2	Thermodynamics	29
1.2.1	The Zeroth Law of Thermodynamics	31
1.2.2	The First Law of Thermodynamics	31
1.2.3	The Second and Third Laws of Thermodynamics	31
1.2.4	Heat Required to do Work in Real Gases	32
1.2.5	Spontaneous Processes and Thermodynamic Potentials	33
1.2.6	Reversibility, Energy, and Cycles	36
1.2.7	Application of the Second Law	37
1.2.8	Basic Power Generation Cycles	38
1.2.9	Heat Transfer: Conduction, Radiation, Convective Heat Transfer	41
1.3	Electrochemistry: Introduction	44
1.3.1	Fuel Cell Thermodynamics	45
1.3.2	Electrode Electrochemistry	47
1.3.3	Relationship to the Change in the Gibbs Potential	50
1.3.4	Fuel Cell Efficiency	51
1.3.5	Electrode Overpotentials	51
1.3.6	Examples of Half-Cell Electrodes	53

1.3.7	The Salt Bridge	55
1.3.8	Types of Electrodes and Cells	55
1.3.9	Examples of Batteries and Fuel Cells	56
	References	60
2	Principles of Energy Conversion.	61
2.1	Preliminary Concepts of Electric Generator and Electric Motor Action.	61
2.1.1	Introduction.	61
2.1.2	Principles of Electric Generator and Motor Operation	61
2.2	Electric Motors: DC Motors	63
2.2.1	Loading a DC Motor	66
2.2.2	Types of DC Motors	67
2.3	AC Motors	68
2.3.1	Synchronous Motors.	68
2.3.2	Types of Synchronous Motors	69
2.3.3	Operation of a Synchronous Motor	69
2.3.4	Loading the Synchronous Motor	72
2.3.5	Induction Motors	74
2.3.6	AC Servomotors	76
2.3.7	AC Tachometer	78
2.4	Brushless DC Motors	78
2.5	Stepper Motors	80
2.6	The Design and Development of High Performance Electric Actuators	81
2.7	Driving a DC Motor: Speed Control of a DC Motor	83
2.7.1	Controlling a DC Motor: Position Control Servo	84
2.8	Driving and Controlling AC motors	89
2.9	Stability of Electric Servo-Actuators	91
2.9.1	Routh's Tabular Method	95
2.10	Electric Generators.	95
2.10.1	Synchronous AC Generators	96
2.10.2	Dynamic Modeling of the Synchronous AC Generators.	97
2.10.3	Induction AC Generators	100
2.11	Power Systems	103
2.11.1	Power Systems Stability	103
2.11.2	Transmission Lines	106
2.11.3	Transformers	110
2.11.4	Power Factor Improvement	111
	References	112

3	Modelling of Synchronous and Induction Machines	113
3.1	Generic Principles of Modelling: Park Transformation and Applications	113
3.2	Exciting a Synchronous Generator	118
3.3	Equivalent Circuit Modelling	119
3.4	The Electromechanical Model of a Permanent Magnet Synchronous Generator with Field Orientation	119
3.5	Application to a Wound-Field Synchronous Generator	123
3.5.1	Modelling a Typical Exciter	126
3.5.2	Model Parameter Estimation	126
3.6	Performance Characteristics of Synchronous Generators	128
3.7	Dynamic Modelling of Induction Generators	129
3.7.1	Equivalent Circuit Modelling	130
3.7.2	Parameter Estimation of Induction Generators model	131
3.7.3	Characteristics of Induction Generators and Experimental Determination of Parameters	133
3.8	Doubly Fed Induction Generator (DFIG): A Case Study	133
3.8.1	The Steady-State Electromechanical Model	137
3.8.2	The Nonlinear Perturbation Dynamics	137
	References	139
4	Wind Power Generation and Control	141
4.1	Introduction	141
4.2	Wind Turbine Components	141
4.3	Wind Turbine Aerodynamics: Momentum Theory	142
4.3.1	Actuator Disc Theory	143
4.3.2	The Betz Limit	144
4.3.3	Effects of Flow Rotation	145
4.4	Blade Element Momentum Theory	147
4.4.1	The Power Coefficient: The BEM Theory Expression	150
4.5	Aerodynamic Design of the Blade	150
4.6	Blade Structural Dynamics	153
4.7	Rotor Aeroelastic Dynamic Modelling	163
4.7.1	Multiblade Coordinates	167
4.7.2	Equations of Motion in Multiblade Coordinates	168
4.7.3	Centrifugal Stiffening of the Torsion Modes	169
4.7.4	The Aerodynamic Moments Based on Blade Element Theory	170
4.7.5	The Inflow Dynamics	173
4.7.6	The Inflow Driving Hub Moments	173
4.7.7	The Rotor Torque Coefficient: The General Expression	177

4.7.8	The Rotor Torque Coefficient: The Case Constant Inflow and Rigid Blades with Steady Root Pitch	178
4.8	The Actual Power Coefficient and its Dependence on the Blade Setting Angle	180
4.9	Maximum Power Point Tracking and Protection Against Excessive Wind Torque	183
4.10	Quasi-steady Aerodynamic Loads on Flexible Rotor Blades . . .	186
4.11	Dynamics and Aeroelasticity of Flexible Rotor Blades	190
4.12	Wind Field Velocity Distributions and Spectrum	193
4.13	Support Structures	195
4.13.1	Tower Dynamics and Aeroservoelasticity	195
4.13.2	Offshore and Floating Support Structures	196
4.13.3	Hydrodynamic and Subsea Ice Loading	198
4.13.4	Floater Dynamics and Wave Hydrodynamics	203
4.13.5	Floater–Rotor Passive and Active Decoupling Control	206
	References	207
5	Dynamic Modeling of Gas Turbines and Compressors.	211
5.1	Gas Turbines: Typical Components and Dynamic Modeling . . .	211
5.2	Axial Flow Compressor Systems: Modeling as a One-Dimensional Duct.	217
5.2.1	Actuator Disk Theory	218
5.3	The Moore–Greitzer Model.	218
5.3.1	Compressor Surge and Rotating Stall	219
5.3.2	Derivation of the Moore–Greitzer Model Equations . . .	223
5.3.3	The Moore–Greitzer Model Equations	226
5.3.4	Steady Flow Analysis.	228
5.3.5	Unsteady Non-Linear Extended Moore–Greitzer Model.	230
5.3.6	Application to Rotating Stall Vibrations	232
5.3.7	Model Response and Instability	234
5.3.8	Control Law for Throttle Setting	236
5.3.9	Control of the Rotating Stall Vibration Amplitude . . .	239
5.3.10	Stability of Controlled Equilibrium	240
5.3.11	Control of Compressor Rotating Stall	241
5.4	Combustion.	244
5.4.1	Combustion Chambers	245
5.4.2	Aeroacoustics of Combustion Chambers	247
5.4.3	Flow-Coupled and Thermoacoustic Instabilities: POGO, Buzz, Chugging and Screech	251
5.5	Overall Jet Engine Volume Dynamics Modeling	252
5.5.1	Compressor Modeling.	255
5.5.2	Combustion Systems Modeling	258

5.5.3	Turbine Dynamics Modeling	260
5.5.4	Turbine Power and Torque Outputs	262
5.5.5	One-Dimensional Variable Area Ducts: The Afterburner and Nozzle	263
5.5.6	The Spool Dynamics Modeling	265
5.5.7	Typical Simulation Results	265
5.6	Full-Authority Digital Engine Control Systems	266
	References	267
6	Modelling and Simulation of Fuel Cells	271
6.1	Fuel Cell Systems	271
6.2	Thermodynamics and Electrochemistry of Fuel Cells	273
6.2.1	Thermodynamics of Fuel Cells	273
6.2.2	Fuel Cell Electrochemistry and Electrocatalysis	275
6.3	Hydrogen Production, Storage, and Distribution.	277
6.4	Stack Configurations and Fuel Cell Systems	277
6.5	Control-Oriented Modelling and Dynamics	279
6.6	Reduced-Order Modelling of PEMFCs	280
6.6.1	The PEMFC Model	282
6.6.2	Membrane Humidification Model	284
6.6.3	The Cell Output Electrode Polarizations	286
6.7	Flow-based Modelling of Proton Exchange Membrane Fuel Cells (PEMFCs)	289
6.7.1	Modelling the Flow Dynamics within the PEM Fuel Cell	289
6.7.2	The Cell Output Equations	296
6.8	Solid Oxide Fuel Cells (SOFCs)	299
6.9	Cogeneration Applications of SO Fuel Cells	306
6.10	Simulation of Fuel Cells	308
6.11	Estimation of the Parameters of a Fuel Cell	309
6.12	Controller Design for Fuel Cells	311
	References	317
7	Batteries: Modeling and State of Charge Estimation	323
7.1	Introduction.	323
7.2	Battery Electrochemistry.	324
7.3	The Capacity and State of Charge	325
7.3.1	Peukert's Equation	326
7.3.2	Performance Plots	327
7.4	Battery Modelling	328
7.5	SOC Estimation.	335
7.6	System and Parameter Identification.	335

7.7	The KF and the Extended KF	338
7.7.1	The Unscented KF	340
7.7.2	Adaptive Kalman filters	342
7.7.3	Adaptive UKF-Based Parameter Identification.	345
	References	345
8	Non-Conventional Energy Generation: Solar, Wave, and Tidal Energy Generation	349
8.1	Introduction.	349
8.2	Solar Cells: Overview of Solar Cell Properties	351
8.2.1	Types and Characteristics	351
8.2.2	PhotoSensitive Devices: Principles of Operation	352
8.2.3	Modeling the Power Output of a Solar Cell	360
8.2.4	Maximum Power Point Tracking Control	364
8.3	Wave Energy Generation	364
8.3.1	Wave Power Transfer Devices.	367
8.3.2	Wave Potentials Due to a Floating Body	368
8.3.3	Conditions for Optimum Power Take-Off	369
8.3.4	The Wells Turbine	371
8.4	Tidal Energy	371
	References	372