

Green Energy and Technology

Said Al-Hallaj
Kristofer Kiszynski

Hybrid Hydrogen Systems

Stationary and
Transportation
Applications



Springer

Contents

1	The Role of Renewable Energy in a Sustainable Energy Future	1
1.1	Fossil Fuel Based Economy and Climate Change Challenges	1
1.2	Review of World Energy Production and Consumption	3
1.3	The Decarbonization Pathway and the Role of Renewable Energy	4
1.4	State of Renewable Energy	6
	References	7
2	Renewable Energy Sources and Energy Conversion Devices	9
2.1	Solar Energy	9
2.1.1	The Solar Constant	9
2.1.2	Variation of Extraterrestrial Radiation	11
2.1.3	Extraterrestrial Radiation on a Horizontal Surface	11
2.1.4	Atmospheric Attenuation of Solar Radiation	12
2.1.5	Estimating Monthly Average Solar Radiation	13
2.1.6	Beam and Diffuse Components of Monthly Radiation	13
2.1.7	Radiation on Sloped Surfaces	14
2.1.8	The Isotropic Diffuse Model I	16
2.1.9	The Hay and Davies Model	16
2.1.10	The HDKR Model	17
2.2	Photovoltaic Cells	17
2.2.1	PV Cell Electrical Performance	18
2.2.2	Types of PV Cell	19
2.2.3	Inorganic Solar Cell Operation	20
2.2.4	Organic Solar Cell Operation	21
2.2.5	The Current State and Future of Solar Cells	21
2.2.6	Solar Concentrators and Trackers	22
2.2.7	Economics	23

2.3	Wind Energy	24
2.3.1	Wind Generation	24
2.3.2	Wind Data Collection and Siting	24
2.3.3	Wind Turbine Types and Operation	25
2.3.4	Determining Wind Turbine Power Output	26
	References	28
3	Hydrogen Production, Storage and Fuel Cells	31
3.1	Hydrogen Production Methods	31
3.1.1	Steam Methane Reformation	31
3.1.2	Water-Gas Shift Reaction	32
3.1.3	Partial Oxidation of Methane	33
3.1.4	Autothermal Reformation of Methane	33
3.1.5	Hydrogen Production from Heavy Oil and Coal	33
3.1.6	Separation of Product Gases	34
3.1.7	Water Electrolysis	34
3.2	Hydrogen Storage	37
3.2.1	Compressed Hydrogen Storage	37
3.2.2	Hydrogen Liquefaction and Storage	41
3.2.3	Metal Hydrides	42
3.2.4	Complex Hydrides	43
3.2.5	Carbon Based Storage	43
3.2.6	Liquid Carrier Storage	44
3.3	Fuel Cells	44
3.3.1	Fuel Cell Structure and Theory of Operation	45
3.3.2	Thermodynamics of Fuel Cells	46
3.3.3	Cell Efficiency and Polarization	47
3.3.4	Fuel Cell Types	50
3.3.5	Summary Table of Fuel Cell Characteristics	53
	References	53
4	Operation and Control of Hybrid Energy Systems	55
4.1	Renewable Hybrid Energy Systems: System Configuration and Theory of Operation	55
4.1.1	Factors Influencing RHES	56
4.1.2	System Simulation for Component Sizing Purposes and Determination of System Cost	56
4.1.3	Explanation of Energy System Simulation	57
4.2	Storage of Excess Energy	57
4.2.1	Battery Constraints	58
4.2.2	Electrolyzer Constraints	59
4.2.3	Hydrogen Storage Constraints	60
4.2.4	Energy Storage Logic	60
4.3	Utilization of Stored Energy	61

Contents

4.3.1	Battery Constraints	61
4.3.2	Fuel Cell Constraints	62
4.3.3	Hydrogen Utilization Constraint	63
4.3.4	Energy Utilization Logic	63
4.4	System Update	66
4.4.1	Excess Energy: System Update	66
4.4.2	Energy Deficit: System Update	68
4.5	Financial Analysis and Sorting of Systems	68
4.6	Simulation of Hybrid Energy Systems for a Case study in Rockford, Illinois	70
4.6.1	Wind alone versus Hybrid wind-solar system	70
4.6.2	Hybrid Hydrogen System	73
4.7	Conclusions	79
	References	79
5	Control of Hybrid Energy Systems	81
5.1	Hybrid Fuel Cell/Battery Controller Logic	81
5.2	Controller Design	84
5.2.1	DC/DC Converters	86
5.2.2	Open-Loop Modeling	86
5.2.3	Tuning the Controller	88
5.2.4	Controller Logic with Battery State-of-Charge Considerations	90
5.2.5	Simulation Results	91
	References	94
6	Case Study: Hybrid PEM Fuel Cell/Li-ion Battery System for a Non-Idling Airport Ground Support Vehicle	95
6.1	Chapter Objectives	95
6.2	Problem Definition and Motivation	95
6.3	Selection of Appropriate Hybrid System	96
6.3.1	PEM Fuel Cell/Li-ion Battery Hybrid System	98
6.4	Project Goals	99
6.5	Design Specifications	99
6.6	Design Strategy	99
6.7	Design Components	100
6.7.1	Li-ion Battery Pack Design	100
6.7.2	Fuel Cell	101
6.7.3	Hydrogen Storage Tanks	101
6.7.4	DC/DC Converters	101
6.7.5	Battery Charger	102
6.7.6	Control System: Control Panel and Controller	102
6.8	Results	103
6.8.1	Data Acquisition Methods	103

6.8.2	Results and Discussion	104
6.8.3	Calculations.	105
6.9	Limitations and Pitfalls.	106
6.10	Plans for Future Work	106
6.11	Conclusion	106
	References	107
7	Case Study: A Hybrid Fuel Cell/Desalination System for Caye Caulker	109
7.1	Chapter Objectives.	109
7.2	Motivation	109
7.3	Problem Definition: Water Shortage in Caye Caulker.	110
7.4	Tools for Selecting Appropriate Hybrid System.	110
7.4.1	Hybrid Fuel Cell/Desalination (HFCD) Systems: An Attractive Solution	110
7.4.2	System Integration Configurations	111
7.4.3	Control Strategy.	116
7.4.4	Comparison of Possible HFCD Technologies Using Methodology	116
7.5	Proposed Solution and Justification	123
7.6	Economic Feasibility	124
7.6.1	Tools for Economic Analysis.	124
7.6.2	Economic Feasibility of Caye Caulker HFCD	126
7.7	Concluding Remarks	128
	References	128
	Index	131