Contents

1 A Small-scale Fuel Cell Cogeneration System Considering Partial Load and Load Fluctuation 1
1.1 Introduction 1
1.2 System Configuration 2
1.2.1 System Outline 2
1.2.2 Energy Loss and Mass Loss 4
1.2.3 System Model and Equations 5
1.2.4 Partial Load Operation 7
1.3 Energy Balance and Objective Function 8
1.3.1 Energy Balance 8
1.3.2 Electric Heater Operation 9
1.3.3 Thermal Storage Operation 11
1.4 Energy Output Characteristics 11
1.4.1 System Operation Map 11
1.4.2 Load Fluctuation and Fuel Consumption 12
1.5 Case Study 14
1.5.1 System Outline 14
1.5.2 Results of the Operation Plan 14
1.5.3 Annual Operation Cost of the System 15
1.6 Conclusions 16

2 Equipment Arrangement Planning of a Fuel Cell Energy Network Optimized for Cost Minimization 17
2.1 Introduction 17
2.2 System Scheme 18
2.2.1 The Energy Network 18
2.2.2 Fuel Cell System 19
2.2.3 Heat Source Use Order 20
2.2.4 City Gas Reformer 20
2.2.5 Operation Model of the System 21

2.3 Amount of Heat Release of the Hot Water Piping Network (HWN) ... 22
2.4 Energy Balance ... 24
2.4.1 The Balance of Power ... 24
2.4.2 The Balance of Heat ... 24
2.5 Cost Calculation and Objective Function ... 25
2.5.1 Cost Calculation ... 25
2.5.2 Objective Function ... 26
2.6 Analysis Method and Case Study ... 26
2.6.1 Optimization Using a Genetic Algorithm ... 26
2.6.2 Equipment Characteristics Model ... 27
2.6.3 Operation of the Heat Storage Tank and Boiler ... 29
2.6.4 Specification of Hot Water Piping and a Hot Water Circulating Pump ... 29
2.6.5 Analysis Flow ... 30
2.6.6 Analysis Conditions ... 32
2.7 Analysis Result ... 34
2.7.1 Operation Plan of the Fuel Cell and the Reformer ... 34
2.7.2 Amount of Hot Water Heat Release and the Hot Water Piping Route ... 36
2.7.3 Quantity of Flow of the Hot Water Circulating Pump ... 38
2.7.4 Operation of the Heat Storage Tank and the Boiler ... 39
2.7.5 Cost Analysis Results ... 40
2.7.6 Consideration of Analysis Accuracy ... 41
2.8 Conclusions ... 42

3 Effective Improvement in Generation Efficiency due to Partition Cooperation Management ... 43
3.1 Introduction ... 43
3.2 System Configuration ... 44
3.2.1 Scheme of the FC Micro-grid ... 44
3.2.2 System Configuration ... 45
3.2.3 Operating Method ... 46
3.3 Installation Planning of the FC Micro-grid ... 46
3.3.1 Generation Efficiency of the Micro-grid ... 46
3.3.2 The Power Demand Model ... 49
3.3.3 The Analysis Method ... 50
3.4 Case Study ... 51
3.5 Analysis Results and Discussion ... 52
3.5.1 Generation Efficiency of the Stand-alone System ... 52
3.5.2 Generation Efficiency of the Central System ... 54
3.5.3 Generation Efficiency of the Partition Cooperation System ... 54
3.6 Conclusions ... 59

4 Fuel Cell Network System Considering Reduction in Fuel Cell Capacity Using Load Leveling and Heat Release Loss 61
4.1 Introduction 61
4.2 Load Leveling and the Arrangement Plan of the Fuel Cell 62
4.2.1 The Fuel Cell Network System 62
4.2.2 Power Generation Characteristics of the Fuel Cell 63
4.2.3 Load Leveling Using Water Electrolysis 65
4.2.4 Distribution of the Fuel Cell 65
4.2.5 Energy Balance Equation 66
4.2.6 Operating Method of the System 68
4.3 Analysis Method 68
4.3.1 Procedure of Analysis 68
4.3.2 Solution Parameters 70
4.4 Case Study 71
4.4.1 Energy Demand Pattern and Network System 71
4.4.2 Reduction Effect of the Fuel Cell Facility Capacity 72
4.4.3 Route Planning Result of the Hot Water Piping 73
4.4.4 Result of the Fuel Cell Arrangement Plan 75
4.5 Conclusions 76

5 Equipment Plan of a Compound Interconnection Micro-grid Composed of Diesel Power Plants and a Fuel Cell 77
5.1 Introduction 77
5.2 Compound Interconnection Micro-grid 78
5.2.1 The Micro-grid Model 78
5.2.2 The CIM Model 80
5.2.3 Facility Scheme 80
5.2.4 The CIM Operating Method 82
5.3 Equipment Characteristics 82
5.3.1 Diesel Engine Power Generator 82
5.3.2 The Proton Exchange Membrane-type Fuel Cell 84
5.4 Analysis Method 84
5.4.1 Route Plan of the Compound Interconnection Grid 84
5.4.2 Analysis Flow 85
5.4.3 The Power Demand Model 86
5.5 Case Study 88
5.5.1 The Urban Area Model 88
5.5.2 Complex Community 89
5.5.3 The Residential Area Model 91
5.6 Conclusions 93

6 The Effective-use Method of Exhaust Heat for Distributed Fuel Cells 95
6.1 Introduction 95
6.2 Outline of the Fuel Cell Energy Network System 96
6.2.1 System Outline 96
6.2.2 The Path and the Amount of Heat Release from the Hot Water Piping 98
6.2.3 Heat Energy Balance 100
6.2.4 The Heat Release Amount for a Hot Water Network 101
6.3 Model of the Fuel Cell 102
6.3.1 Characteristics of Electric Power and Heat Output 102
6.3.2 Energy Demand Pattern and Capacity of the Fuel Cell 103
6.4 Case Analysis 104
6.4.1 Weather Conditions in Sapporo 104
6.4.2 Analysis Method 105
6.5 Analysis Results 107
6.5.1 The Optimal Path and the Amount of Heat Release from a Hot Water Piping Network 107
6.5.2 Optimal Path of the Energy Demand Pattern and the Hot Water Piping 108
6.5.3 The Influence of Load Fluctuations 110
6.6 Conclusions 111

7 Load Response Characteristics of the Fuel Cell for Individual Cold-region Houses 113
7.1 Introduction 113
7.2 System Configuration 114
7.2.1 System Outline 114
7.2.2 Method of Power Generation 116
7.2.3 Method of Heat Supply 117
7.2.4 Controller and Auxiliary Machinery 117
7.2.5 Model of Operation Control 118
7.3 The Time Constant of Each Piece of Equipment 119
7.3.1 The Time Constant of the Fuel Cell Stack 120
7.3.2 Town Gas Reformer 123
7.3.3 Inverter and System Interconnection Device 124
7.3.4 The Time Constant of the Heat Pump 124
7.4 Analysis Method 125
7.5 Results and Discussion 126
7.5.1 Control Variables of the Controller 126
7.5.2 Step Response Characteristics of the System 128
7.5.3 Step Response Characteristics with Power Load Fluctuation 130
7.5.4 Application to an Individual Cold-region House 133
7.6 Conclusions 135

8 Load Response Characteristics of a Fuel Cell Micro-grid with Control of the Number of Units 137
8.1 Introduction 137
8.2 The Micro-grid Model 138
8.2.1 Power Quality of the Micro-grid 138
8.3 Response Characteristics of System Configuration Equipment 142
8.3.1 Generation Characteristics of the Engine Generator 142
8.3.2 Generation Characteristics of the Fuel Cell 143
8.3.3 Output Characteristics of the City Gas Reformer 144
8.3.4 Inverter and Interconnection Device 144
8.3.5 Generation Efficiency of the Fuel Cell System 144
8.4 Control Variables and Analysis Method 145
8.5 Load Response Characteristics of the Micro-grid 147
8.5.1 Step Response Characteristics 147
8.5.2 Application of the Electric Power Demand Pattern of a House 148
8.5.3 Generation Efficiency of the Fuel Cell 150
8.6 Conclusions 152

9 Dynamic Characteristics of a PEM-FC/ Woody Biomass Engine Hybrid Micro-grid 153
9.1 Introduction 153
9.2 System Scheme 154
9.2.1 The Hybrid Micro-grid 154
9.2.2 The Micro-grid System Operating Method 157
9.3 Control Response Characteristics of PEM-FC and SEG 157
9.3.1 The Control Block Diagram 157
9.3.2 Response Characteristics of PEM-FC 159
9.3.3 Response Characteristics of SEG 160
9.4 Results of Dynamic Characteristics Analysis of the PWHC Micro-grid 161
9.4.1 Power Response Characteristics of PWHC 161
9.4.2 Response Characteristics of SEG and the PEM-FC Micro-grid Using the Power Load Pattern for Houses 163
9.4.3 Response Characteristics of the PWHC Micro-grid Using the Power Load Pattern for Houses 165
9.5 Conclusions 167

10 A Fuel Cell and Hydrogenation Engine Hybrid System Considering Efficiency Improvement for Partial-load Operation 169
10.1 Introduction 169
10.2 System Scheme 170
10.2.1 The HCGS Model 170
10.2.2 Operation Method of the System 171

10.3 Equipment Characteristics 173
10.3.1 Output Characteristics of NEG 173
10.3.2 Output Characteristics of PEM-FC 177
10.4 Power and Heat Output Characteristics of HCGS 179
10.4.1 Output Characteristics of NEG and PEM-FC 179
10.4.2 Method Operating FC or NEG with the Threshold Value of the Load (OM-C) 180
10.4.3 Operation Method Using PEM-FC Corresponding to a Base Load (OM-D) 181
10.5 Case Study 182
10.5.1 Power and Heat Demand Model 182
10.5.2 Analysis Method 183
10.6 Results and Discussion 184
10.6.1 City Gas Consumption 184
10.6.2 Generation Efficiency and Total Efficiency 185
10.6.3 Carbon Dioxide Emissions 186
10.6.4 Capacity of the Heat Storage Tank 187
10.7 Conclusions 188

11 CO_2 Discharged from a Compound Micro-grid of a Hydrogenation City Gas Engine and a Fuel Cell 189
11.1 Introduction 189
11.2 System Scheme 190
11.2.1 The IMPE Model 190
11.2.2 Operation Method of the Micro-grid 191
11.2.3 Equipment Scheme 191
11.3 Equipment Characteristics 193
11.3.1 Output Characteristics of the Gas Engine Power Generator 193
11.3.2 Carbon Dioxide Emissions of NEG 195
11.3.3 The PEM-FC System 196
11.4 Case Study 197
11.4.1 The Urban Area Model 197
11.4.2 The Power Demand Model 198
11.4.3 Analysis Flow 198
11.5 Results and Discussion 200
11.5.1 Power Load of the Micro-grid 200
11.5.2 Capacity of the Power Plant 202
11.5.3 Power Generation Efficiency 202
11.5.4 Carbon Dioxide Emissions 202
11.5.5 Heat Demand and Exhaust Heat Output 204
11.6 Conclusions 204

12 Development of a Fast Operation Algorithm of a Fuel Cell System with Solar Reforming 207
12.1 Introduction 207
12.2 System Configuration 208
12.2.1 The Fuel Cell System with Bioethanol Solar Reforming (FBSR) 208
12.2.2 Installation Method of FBSR 209
12.2.3 Control of Reformed Fuel 209
12.3 Energy and Mass Balance 210
12.3.1 Energy Balance 210
12.3.2 Mass Balance 210
12.4 Dynamic Operation Prediction of SRF 210
12.4.1 Analysis Procedure of the Operation Prediction Algorithm 210
12.4.2 Structure of the Neural Network 211
12.4.3 Learning Calculation 212
12.4.4 The Operation Prediction Process 214
12.5 Preparation of the Training Signal Using a GA 215
12.5.1 Dynamic Operation Plan of a Representative Day 215
12.5.2 Chromosome Model and Analysis Flow 216
12.5.3 System Operation 217
12.5.4 Objective Function and Adaptive Value 217
12.6 Case Study 218
12.6.1 Analysis System 218
12.6.2 Characteristics of the System 218
12.6.3 Analysis Condition 219
12.7 Results and Discussion 221
12.7.1 Energy Supply by FBSR 221
12.7.2 Analytic Accuracy of the Operation Prediction 222
12.7.3 Analysis Error of the Heat Storage Prediction 225
12.7.4 Relationship Between the Difference in Weather Characteristics and the Operation Prediction Error 227
12.8 Conclusions 230

13 Power Characteristics of a Fuel Cell Micro-grid with Wind Power Generation 231
13.1 Introduction 231
13.2 The Micro-grid Model 232
13.3 Response Characteristics of System Configuration Equipment 233
13.3.1 Power Generation Characteristics of the Fuel Cell 233
13.3.2 Output Characteristics of the City Gas Reformer 233
13.3.3 Power Generation Characteristics of Wind Power Generation 234
13.3.4 Generation Efficiency of the Fuel Cell System 235
13.3.5 Inverter and System Interconnection Device 236

13.4 Control Parameters and Analysis Method 237
13.5 Load Response Characteristics of the Micro-grid 238
13.5.1 Step Response 238
13.5.2 Load Response Characteristics of Cold-region Houses ... 239
13.5.3 Power Generation Efficiency 241
13.6 Conclusions 242

References 245

Index 251