
Contents

Foreword	xiv
Preface	xv
Acknowledgements	xvii
List of abbreviations	xviii
1 Distributed generation and Microgrid concept	1
1.1 Distributed generation	1
1.2 Why integration of distributed generation?	2
1.3 Active distribution network	2
1.4 Concept of Microgrid	3
1.5 A typical Microgrid configuration	4
1.6 Interconnection of Microgrids	8
1.7 Technical and economical advantages of Microgrid	8
1.8 Challenges and disadvantages of Microgrid development	10
1.9 Management and operational issues of a Microgrid	11
1.10 Dynamic interactions of Microgrid with main grid	11
1.11 Conclusion	12
2 Distributed energy resources	15
2.1 Introduction	15
2.2 Combined heat and power (CHP) systems	15
2.2.1 Micro-CHP systems	16
2.3 Wind energy conversion systems (WECS)	26
2.3.1 Wind turbine operating systems	27
2.4 Solar photovoltaic (PV) systems	29
2.4.1 Types of PV cell	30
2.5 Small-scale hydroelectric power generation	32
2.6 Other renewable energy sources	32
2.7 Storage devices	33
2.8 Conclusion	33
3 Impacts of Microgrid	35
3.1 Introduction	35
3.2 Impact on heat utilisation	36
3.2.1 Supply of thermal energy	36
3.2.2 Absorption chillers	38

3.2.3	Desiccant dehumidifiers	38
3.2.4	Thermal energy storage	39
3.3	Impact on process optimisation	39
3.3.1	HVAC system optimisation	39
3.3.2	Power quality	41
3.3.3	Power cost considerations	42
3.3.4	Costs of transmission congestion	42
3.3.5	Basic Microgrid cost considerations	42
3.4	Impact on market	43
3.4.1	Possibilities in the electricity market	43
3.4.2	Gas market and its difficulties	44
3.4.3	Necessary market reforms	45
3.5	Impact on environment	46
3.5.1	Minimisation of pollutant deposition	46
3.6	Impact on distribution system	47
3.6.1	Ancillary services	48
3.6.2	Distribution system issues of Microgrid	51
3.7	Impact on communication standards and protocols	52
3.7.1	Protocols, communication procedures and gateways	52
3.7.2	Alternative communications	53
3.8	Conclusion	54
4	Microgrid and active distribution network management system	57
4.1	Introduction	57
4.2	Network management needs of Microgrid	57
4.2.1	Microsource generation control	58
4.2.2	Domestic process control	58
4.2.3	Energy storage	59
4.2.4	Regulation and load shifting	59
4.2.5	Ancillary services	60
4.3	Microsource controller	61
4.3.1	Control functions for microsource controller	61
4.4	Central controller	65
4.4.1	Energy manager module (EMM)	65
4.4.2	Protection co-ordination module (PCM)	68
4.4.3	Information needed for central controller operation	71
4.4.4	Control strategies for central controller design	74
4.5	Conclusion	76
5	Protection issues for Microgrids	77
5.1	Introduction	77
5.2	Islanding: separation from utility	79
5.2.1	Different islanding scenarios	80
5.3	Major protection issues of stand-alone Microgrid	84
5.3.1	Microgrid distribution system protection	84
5.3.2	Protection of microsources	88

5.3.3	NEC requirements for distribution transformer protection	90
5.3.4	Neutral grounding requirements	91
5.4	Conclusion	94
6	Power electronic interfaces	97
6.1	Introduction	97
6.2	Background	97
6.2.1	Standard computer architecture	98
6.2.2	Very large scale integration (VLSI)	98
6.3	Power converter trends	99
6.3.1	Custom design and manufacturing	99
6.3.2	Power module integration and component packaging	99
6.3.3	Power electronic building blocks (PEBB)	100
6.3.4	Packaging framework design	100
6.4	Bricks-Buses-Software (BBS) framework	100
6.4.1	Bricks as modular components	101
6.4.2	Buses as connective links	103
6.4.3	High-level software design environment	104
6.5	BBS framework issues	105
6.5.1	Modularity	105
6.5.2	Aspect ratio	105
6.5.3	Parasitic inductance	106
6.5.4	Cross coupling and loading	106
6.6	Conclusion	106
7	SCADA and active distribution networks	109
7.1	Introduction	109
7.2	Existing DNO SCADA systems	109
7.3	Control of DNO SCADA systems	110
7.3.1	Centralised SCADA systems	110
7.3.2	Distributed SCADA systems	111
7.4	SCADA in Microgrids	111
7.5	Human-machine interface (HMI)	112
7.6	Hardware components	112
7.6.1	Remote terminal unit (RTU)	113
7.6.2	Programmable logic controller (PLC)	114
7.6.3	Master station and HMI computers	115
7.6.4	SCADA communication infrastructure	115
7.7	Communication trends in SCADA	116
7.8	Distributed control system (DCS)	117
7.9	Sub-station communication standardisation	118
7.10	SCADA communication and control architecture	119
7.11	Communication devices	119
7.12	Observations on SCADA and communication	120
7.13	Conclusion	123

8	Impact of DG integration on power quality and reliability	125
8.1	Introduction	125
8.2	Power quality disturbances	126
8.2.1	Transients	127
8.2.2	Voltage sags and swells	127
8.2.3	Over-voltages and under-voltages	127
8.2.4	Outage	128
8.2.5	Harmonic distortion	128
8.2.6	Voltage notching	129
8.2.7	Flicker	130
8.2.8	Electrical noise	130
8.3	Power quality sensitive customers	130
8.4	Existing power quality improvement technologies	132
8.4.1	Alternative power supply technologies	133
8.4.2	Power-conditioning technologies	133
8.5	Impact of DG integration	136
8.5.1	Simple standby generation scheme	137
8.5.2	Secondary DG system with power quality support	138
8.5.3	Primary DG system with power quality support to priority loads	139
8.5.4	Soft grid-connected DG with power quality support to priority loads	139
8.5.5	DG with intermittent solar PV within power quality environment	139
8.5.6	DG with intermittent wind generator within power quality environment	140
8.5.7	Ultra-high reliability scheme using dual link DC bus	141
8.6	Issues of premium power in DG integration	142
8.7	Conclusion	143
9	Microgrid economics	145
9.1	Introduction	145
9.2	Main issues of Microgrid economics	145
9.3	Microgrids and traditional power system economics	146
9.3.1	Joint optimisation of heat and electric power supply	147
9.3.2	Joint optimisation of demand and supply	148
9.4	Emerging economic issues in Microgrids	148
9.5	Economic issues between Microgrids and bulk power systems	149
9.6	Microgrid economics: the UK scenario	149
9.6.1	Microgeneration	149
9.6.2	Regulatory issues and regulation activities	152
9.6.3	Microgeneration technologies: economic perspectives in the UK	152
9.6.4	Potential benefits of Microgrid economics	153
9.6.5	Future developments of Microgrid economics	154
9.7	Conclusion	155

10	Market participation of Microgrids	157
10.1	Introduction	157
10.2	Restructuring models	158
10.2.1	PoolCo Model	158
10.2.2	Bilateral Contracts Model	159
10.2.3	Hybrid Model	159
10.3	Independent System Operator (ISO)	160
10.3.1	Background	160
10.3.2	The role of ISO	161
10.4	Power exchange (PX)	162
10.5	Market clearing price (MCP)	163
10.6	Day-ahead and hour-ahead markets	163
10.7	Elastic and inelastic markets	164
10.8	Market power	164
10.8.1	Vertical market power	165
10.8.2	Horizontal market power	165
10.9	Stranded costs	166
10.10	Transmission pricing	166
10.10.1	Contract path method	167
10.10.2	MW-mile method	167
10.11	Congestion management	167
10.11.1	Congestion pricing	169
10.11.2	Transmission rights	169
10.11.3	Management of inter-zonal and intra-zonal congestions	170
10.12	Role of Microgrid in power market competition	170
10.12.1	Retail wheeling	170
10.12.2	Ancillary services	171
10.12.3	Role of aggregators	172
10.13	Conclusion	175
Appendix A:	Modelling and performance analysis of microturbine in stand-alone and grid-connected modes	177
A.1	Model description	177
A.2	Model parameters	179
A.3	Case studies	179
A.3.1	Stand-alone mode	182
A.3.2	Grid-connected mode	184
A.3.3	MTG performance	190
Appendix B:	Dynamic modelling and performance analysis of a DFIG wind energy conversion system	191
B.1	Model description	191
B.1.1	Wind velocity module	192
B.1.2	Gear model	193
B.1.3	DFIG model	195
B.2	Case study	199

Appendix C: Software simulation of PEM fuel cell system for dynamic performance analysis	201
C.1 PEMFC power generation system	201
C.2 Dynamic model of PEMFC	201
C.3 Reformer model	204
C.4 Power-conditioning unit model	204
C.5 Model parameters	205
C.6 Case study with PI controller	205
C.7 Design of fuzzy logic controller	207
C.7.1 Fuzzy rule base	210
C.8 Case study with fuzzy logic controller	211
Appendix D: Application of solid-oxide fuel cell in distributed power generation	215
D.1 SOFC power generation system	215
D.2 Dynamic model of SOFC	216
D.3 Model of the SOFC power generation system	218
D.3.1 Model parameters	219
D.3.2 Power and voltage control strategy	220
D.4 Case study	221
Appendix E: Modelling and performance evaluation of a stand-alone photovoltaic (PV) plant with maximum power point tracking	227
E.1 Photovoltaic modelling	227
E.2 Double diode model of the polycrystalline cell	228
E.3 Modelling of PV array	229
E.3.1 Calculation of V_{oc}	231
E.3.2 Calculation of P_m , V_{pm} and I_{pm}	231
E.3.3 Calculation of V_{ocar} , P_{mar} and V_{pmar}	231
E.3.4 Calculation of internal resistance R_{inar}	231
E.4 Case studies and results	232
E.4.1 Case 1	232
E.4.2 Case 2	232
E.4.3 Case 3: Modelling of load-shedding scheme	237
Appendix F: Setting of market clearing price (MCP) in Microgrid power scenario	239
F.1 Proposed market structure for Microgrid participation	239
F.2 Bidding procedure	240
F.3 Rules of MCP	241
F.4 Formulation of MCP	241
F.4.1 Single-side bid market	242
F.4.2 Double-side bid market	243

F.5	Case study	244
F.5.1	Case 1: Linear supply bid with fixed demand (i.e. single-sided bid market)	244
F.5.2	Case 2: Linear supply bid with linear demand bid (i.e. double-sided bid market)	247
F.6	Impacts on electricity market	249
Appendix G: Islanding operation of distributed generators in active distribution networks – simulation studies		251
G.1	Background	251
G.2	System configuration	253
G.3	Case studies	255
G.3.1	Case study 1	255
G.3.2	Case study 2	255
G.3.3	Case study 3	258
Bibliography		265
Index		281