

IEEE Smart Grid Research
IEEE Vision for Smart Grid Communications: 2030 and Beyond

Table of Contents

Foreword	xi
Acronyms and Abbreviations	xiii
PART I	
Introduction and Background	1
Chapter 1	
Smart Grid of the Future: Vision for Year 2030	3
1.1 Abstract.....	3
1.2 Introduction.....	3
1.3 Overview of how the power grid works today.....	4
1.4 Drivers for enhancing communication in the electric grid.....	8
1.5 Smart Grid communications: Impediments and realities.....	8
1.6 Current and future visions of the Smart Grid.....	9
1.7 The objectives of the Smart Grid	11
1.8 Role of communication in the Smart Grid.....	14
1.9 Communications vision.....	15
1.10 Layout of this document	16
1.11 Summary	21
1.12 Citations.....	22
Chapter 2	
How Power Grids Operate	24
2.1 Abstract.....	24
2.2 Introduction	24
2.3 System overview	26
2.4 Synchronous generator	27
2.5 Interconnected grids	29
2.6 Transmission and distribution.....	31
2.7 The substation	33
2.8 Operating principles of an interconnected grid.....	35
2.9 Managing the network	37
2.10 Protective relaying	38
2.11 The control center.....	39
2.12 Planning (operational and long-term)	41
2.13 Learning from blackouts	41
2.14 Regulatory framework in the United States.....	43
2.15 New technologies	44
2.16 Citations.....	45
Chapter 3	
Control, Communications, and Signal Processing	46
3.1 Abstract.....	46
3.2 Introduction	46

3.3	Control technology.....	49
3.4	Vision	62
3.5	Challenges and issues	68
3.6	Chapter summary	70
3.7	Citations.....	71
PART II		
Enabling Technologies for Smart Grid Communications	75	
Chapter 4		
Smart Grid Communication Technologies	77	
4.1	Abstract.....	77
4.2	Introduction	77
4.3	Technologies for Smart Grid communications systems	78
4.4	Power line communication.....	85
4.5	Power line–borne optical fiber	92
4.6	Wireless media	101
4.7	Other media	119
4.8	Summary	123
4.9	Recommendations and the future	123
4.10	Citations.....	125
Chapter 5		
Information Theory and Network Science for Power Systems.....	128	
5.1	Abstract.....	128
5.2	Introduction	129
5.3	Relevance of the theory to the Smart Grid	134
5.4	Information theory and network science	141
5.5	Vision	151
5.6	Challenges and issues	157
5.7	Summary	159
5.8	Acknowledgments	161
5.9	Citations.....	161
PART III		
Networking Support of Smart Grid	167	
Chapter 6		
Networking Technologies for Smart Grid	169	
6.1	Abstract.....	169
6.2	Introduction	170
6.3	Smart microgrid communication scenario	172
6.4	Communication paradigms and architectures	174
6.5	Communication technologies	180
6.6	Smart Grid communication technology evolution	186
6.7	The role of future Smart Grid communication	189
6.8	Conclusions	191
6.9	Citations.....	192
Chapter 7		
Quality of Service Mechanisms and Traffic Characteristics.....	195	
7.1	Abstract.....	195
7.2	Introduction	195

7.3	Smart Grid model	196
7.4	Data traffic sources in the Smart Grid	197
7.5	Quality of service metrics	199
7.6	Quality of service mechanisms.....	201
7.7	Trends and vision	212
7.8	Summary	217
7.9	Citations.....	217
PART IV		
Chapter 8	Data-Level Communication Technologies for the Smart Grid.....	221
	Overlay Networks for Smart Grids	223
8.1	Abstract.....	223
8.2	Introduction	224
8.3	Technology	226
8.4	Vision	232
8.5	Challenges and issues	238
8.6	Summary	240
8.7	Recommendations.....	241
8.8	Acknowledgments	244
8.9	Citations.....	244
Chapter 9	Espousing Peer-to-Peer Communication for the Smart Grid	250
9.1	Abstract.....	250
9.2	Introduction	250
9.3	Communication requirements for the Smart Grid: the Internet of Energy (IoE)	252
9.4	P2P technologies.....	256
9.5	A proposed architecture for a P2P-enabled Smart Grid.....	257
9.6	Related approaches	263
9.7	Summary	264
9.8	The future P2P-enabled Smart Grid: challenges, opinions, and suggestions for its rollout	264
9.9	Citations.....	266
PART V		
Chapter 10	Security, Standards, and Regulation	269
	Smart Grid Security.....	271
10.1	Abstract.....	271
10.2	Introduction	271
10.3	Understanding the risks.....	282
10.4	Vision	287
10.5	Citations.....	296
Chapter 11	Standards for the Smart Grid.....	299
11.1	Abstract.....	299
11.2	Introduction	299
11.3	Current state of standardization	301
11.4	Recommendations.....	306

11.5	Citations.....	307
PART VI		
Emerging Technologies and Applications (Disruptive Technologies) .	309	
Chapter 12		
The Emerging Solid State Transformer and its Impact on the Electric Power Grid		311
12.1	Introduction	311
12.2	Solid state transformer	312
12.3	Communications aspects	318
12.4	DC Distribution networks and stability.....	322
12.5	Citations.....	323
Chapter 13		
Wireless Beamed Power		327
13.1	Abstract.....	327
13.2	Introduction to wireless beamed power.....	327
13.3	Preview of implications for Smart Grid communications	328
13.4	The technology of wireless power beaming	329
13.5	Expected evolution of millimeter wave power beaming	331
13.6	Summary: Smart Grid implications	334
13.7	Recommendations.....	337
13.8	Citations.....	339
Chapter 14		
Quantum Key Distribution for the Smart Grid		345
14.1	The need for quantum key distribution	345
14.2	Quantum key distribution basics	346
14.3	Quantum key distribution schemes	348
14.4	Limitations.....	350
14.5	The future of quantum key distribution on the Smart Grid	350
14.6	Citations.....	351

PART VII		
Author Biographies	353	