Contents

	Biographies of the editors Preface		
1	Smart energy – smart grid research and projects overview Ilias Lamprinos, Nikos Hatziargyriou and Hongjian Sun		
	1.1	The Smart Grid	1
		1.1.1 Introduction	1
		1.1.2 Smart metering and data privacy	3
		1.1.3 Smart grid communications, networking and security	4
		1.1.4 Smart grid modelling, control and optimization	5
	1.2	Smart grid research: mapping of ongoing activities	6
		1.2.1 Europe	6
		1.2.2 United States of America	12
		1.2.3 Asia-Pacific	14
		Smart grid research in Europe: what comes next?	17
	1.4	The SmarterEMC2 project	18
		1.4.1 Stakeholders involved in SmarterEMC2	19
		1.4.2 Conceptual architecture of the SmarterEMC2	
		ICT ecosystem	19
		nowledgements	24
	Bib	liography	24
Pa	rt I	Smart metering	
2		vacy-preserving data aggregation in smart metering systems <i>io Borges</i>	29
	2.1	Introduction	29
	2.2	Definitions	31
		2.2.1 List of acronyms	31
		2.2.2 List of symbols	32
	2.3	Background	33
	2.4	State-of-the-art protocols	36
		2.4.1 Homomorphic encryption	36
		2.4.2 Commitments	38
		2.4.3 Symmetric DC-Net (SDC-Net)	39
		2.4.4 Asymmetric DC-Net (ADC-Net)	42

	2.5	An in	nproved ADC-Net	44
	2.6	Comp	parison with related work	45
		2.6.1	Privacy	45
		2.6.2	Communication	46
		2.6.3	Processing time	47
		2.6.4	Techniques	48
	2.7	Simu	lations	49
			Real-world data set	49
			Software and hardware	49
			Simulation parameters	49
			Simulation results	50
			lusions	54
			lgements	54
	Bibl	iograp	hy	55
3	Sma	art pri	ce-based scheduling of flexible residential appliances	59
		-	Papadaskalopoulos and Goran Strbac	
	Non	nenclat	ture	60
			luction	60
			Context – emerging challenges for low-carbon electrical	
			power systems	60
		3.1.2	Role of residential demand in addressing emerging	
			challenges	61
		3.1.3	Challenges in scheduling residential appliances	62
			Overview of alternative approaches for smart scheduling	
			of residential appliances	63
	3.2	Mode	elling operation and price response of flexible residential	
		applia		64
			Appliances with continuously adjustable power levels –	
			EV with smart charging capability	65
		3.2.2	Appliances with shiftable cycles – WA with delay	
			functionality	67
	3.3	Meas	ures against demand response concentration	68
			Flexibility restriction	69
		3.3.2	Non-linear pricing	69
			Randomised pricing	70
		3.3.4	Tuning the parameters of smart measures	71
	3.4	Case	studies	72
		3.4.1	Scheduling of flexible residential appliances in	
			electricity markets	72
		3.4.2	Scheduling of flexible residential appliances for	
			management of local distribution networks	77
	3.5	Conc	lusions and future work	85
	Bibl	iograp	hy	87

<i>a</i>	••
Contents	V11
contentis	* * * *

4	plat	art tariffs for demand response from smart metering tform nghong Gu, Zhimin Wang and Furong Li	89
	4.1	Introduction	89
	4.2	Electricity tariff review	90
		4.2.1 Current energy tariff products	91
		4.2.2 Variable electricity tariffs	92
	4.3	Variable ToU tariff design	95
		4.3.1 Introduction	95
		4.3.2 Rationale of proposed tariff design	96
		4.3.3 ToU tariff design by equal interval grouping	100
		4.3.4 ToU tariff development by hierarchical clustering	102
	4.4	Results and discussion	104
		4.4.1 Results of RTP tariffs	104
		4.4.2 ToU tariffs by equal interval grouping	104
		4.4.3 ToU tariffs by hierarchical clustering	109
	4.5	Impact analysis of ToU tariffs	111
		4.5.1 Flexible load modelling	113
		4.5.2 Impact analysis of designed ToU tariffs	114
		4.5.3 Benefit quantification	116
		4.5.4 Cooperation with energy storage	116
		4.5.5 Case study	117
	4.6	Impact of networks on tariff design	119
		4.6.1 Quantification of DSR on network investment	119
		4.6.2 Tariff design in response to network conditions	120
	4.7	Discussion and conclusion	121
		4.7.1 Discussion	121
		4.7.2 Conclusion	122
	Bib	liography	124

Part II Smart grid modeling, control and optimization

5	Decentralized models for real-time renewable integration in future grid <i>Kiyoshi Nakayama</i>		
	5.1	Introduction to future smart grid	129
	5.2	Hybrid model of centralized resource management	
		and decentralized grid control	129
		5.2.1 Centralized resource management	130
		5.2.2 Decentralized grid control	132
	5.3	Graph modeling	132
	5.4	Maximizing real-time renewable integration	133

5.5 General decentralized approaches	135
5.6 Distributed nodal approach	136
5.6.1 Initialize	136
5.6.2 Send	137
5.6.3 Receive	137
5.6.4 Compare	137
5.6.5 Optimize	138
5.6.6 Notify	138
5.6.7 Confirm	138
5.6.8 StandBy	138
5.7 Distributed clustering approach	139
5.7.1 Tie-set graph theory and its application to distributed	
systems	140
5.7.2 Tie-set Based Optimization Algorithm	142
5.8 Case study of decentralized grid control	145
5.9 Simulation and experiments	146
5.9.1 Energy stimulus response	147
5.9.2 Convergence with different renewable penetration rates	149
5.9.3 Comparison of TBO and DLP	150
5.10 Summary	152
Bibliography	152
Distributed and decentralized control in future power systems	157
Emmanouil Loukarakis and Chris Dent	
6.1 Introduction	157
6.2 A look into current power systems control	158
6.3 Identifying the role of distributed methods	160
6.4 Distributed optimization definitions and scope	161
6.4.1 Distributed optimization fundamentals	162
6.4.2 Simple price-based decomposition	163
6.4.3 From optimization to control using prices	164
6.4.4 Making prices work	166
6.5 Decomposition methods	167
6.5.1 Improving price-undates	167

	6.5.1 Improving price-updates	16/
	6.5.2 Decomposing an augmented Lagrangian	168
	6.5.3 Proximal decomposition methods	169
	6.5.4 Optimality Condition Decomposition	170
	6.5.5 On other distributed methods	172
6.6	OPF insights	173
	6.6.1 Decomposition structure considerations	174
	6.6.2 Practical application considerations	177
6.7	The UC time frame	177
6.8	The ED time frame	179

	6.9	Closer to real time	181		
	6.10	Conclusions	183		
	Bib	iography	184		
7	Mu	ltiobjective optimization for smart grid system design	193		
,		Kang Hsieh and Wei-Yu Chiu	1)5		
		Introduction	193		
	7.2	Problem formulation	195		
		7.2.1 Model of MOP	195		
		7.2.2 Design examples	197		
		Solution methods	201		
		Numerical results	202		
		Conclusion	204		
		nowledgments	204		
	Bib	iography	204		
8	Fre	quency regulation of smart grid via dynamic demand control			
	and battery energy storage system				
	Qi 2	Thu, Chuan-Ke Zhang, Wei Yao and Lin Jiang			
	8.1	Introduction	210		
	8.2	Dynamic model of smart grid for frequency regulation	212		
		8.2.1 Structure of frequency regulation	212		
		8.2.2 Wind farm with variable-speed wind turbines	214		
		8.2.3 Battery energy storage system	216		
		8.2.4 Plug-in electric vehicles	217		
		8.2.5 Controllable air conditioner based DDC	219		
		8.2.6 State-space model of closed-loop LFC scheme	220		
	8.3	Delay-dependent stability analysis	224		
		8.3.1 Delay-dependent stability criterion	225		
		8.3.2 Delay margin calculation	227		
	8.4	Delay-dependent robust controller design	228		
		8.4.1 Delay-dependent H_{∞} performance analysis	229		
	o r	8.4.2 Controller gain tuning based on the PSO algorithm	231		
	8.5	Case studies	233		
		8.5.1 Robust controller design	234		
		8.5.2 Contribution of the DDC, BESS, and PEV to frequency	224		
		regulation	234		
		8.5.3 Robustness against to load disturbances	237		
		8.5.4 Robustness against to parameters uncertainties	238 239		
	0 <i>C</i>	8.5.5 Robustness against to time delays	239 240		
	8.6 Bib				
	D10	iography	240		

9			frequency control and demand-side management	245
	<i>E</i> . <i>D</i>	evane, 1	4. Kasis, C. Spanias, M. Antoniou and I. Lestas	
	9.1	Introd	uction	245
		9.1.1	Frequency control in the power grid	245
			Optimality in frequency control	247
			Demand-side management	248
	9.2		g equation dynamics	249
	9.3	-	ry frequency control	251
			Historical development	251
			Passivity conditions for stability analysis	251
			Economic optimality and fairness in primary control	252
		9.3.4		254
	9.4	Secon	dary frequency control	258
			Historical development	258
			Economic optimality and fairness in secondary	
			control	259
		9.4.3	Stability guarantees via a dissipativity framework	261
	9.5	Future	e challenges	262
	Bibli	ograph	6	263
		<mark>e smar</mark> gia Asii	t grid makopoulou and Nikos Hatziargyriou	269
		Introd		269
	10.1		Related bibliography	209
			Overview	273
	10.2		el decision framework for optimal energy procurement	2/4
	10.2	of DE	· ••• ·	274
			Nomenclature	274
			Model	276
			Solution methodology	278
			Implementation	279
			Results	282
	10.3		el decision framework for optimal energy management	
		of DE	· · · ·	286
		10.3.1	Nomenclature	288
			Model	289
			Solution methodology	292
			Implementation	295
			Results	296
	10.4	Concl	usions	299
	Bibli	ograph	V	300

Bibliography

Part III Smart grid co		Smart grid communications and networking	
11	Cybe and Jinpi Woon	305	
		Hau Chin and Zhong Fan	
	11.1	Power system state estimation and FDIAs	306
		11.1.1 State estimation	307
	11.0	11.1.2 Malicious FDIAs	308
	11.2	Stealth attack strategies 11.2.1 Random attacks	309 310
		11.2.1 Random attacks	310
		11.2.3 Target attacks	313
		11.2.4 Numerical results	317
	113	Defense mechanisms	319
	11.5	11.3.1 Strategic protection	320
		11.3.2 Numerical results	325
		11.3.3 Robust detection	328
		11.3.4 Numerical results	330
	11.4	Conclusions	332
	Bibli	ography	332
	Rube Juan	o Angjelichinoski, Mirsad Cosovic, Charalampos Kalalas, n Lliuyacc, Mehdi Zeinali, Jesus Alonso-Zarate, Manuel Mauricio, Petar Popovski, Cedomir Stefanovic, S. Thompson and Dejan Vukobratovic	
		* v	
		Introduction	335
	12.2	Cellular-enabled D2D communication for smart grid	
		neighbourhood area networks	336
		12.2.1 Limitations of LTE technology	337
		12.2.2 A promising approach: LTE-D2D communication	338
		12.2.3 State of the art – open challenges 12.2.4 Conclusions and outlook	339 343
	123	Power talk in DC MicroGrids: merging primary control	545
	12.3	with communication	344
		12.3.1 Why power talk?	344
		12.3.2 Embedding information in primary control loops	345
		12.3.3 One-way power talk communication	346
		12.3.4 Conclusions and outlook	351
	12.4	Compression techniques for smart meter data	352
		12.4.1 Introduction	352
		12.4.2 Basic concepts of data compression	353
		12.4.3 Smart meter data and communication scenario	354

	12.5	State estimation in electric power distribution system	
		with belief propagation algorithm	358
		12.5.1 Introduction	358
		12.5.2 Conventional state estimation	358
		12.5.3 Belief propagation algorithm in electric power	
		distribution system	359
	12.6	Research and design of novel control algorithms needed	
		for the effective integration of distributed generators	362
		12.6.1 Overview	362
		12.6.2 Hierarchical control of a microgrid	363
		12.6.3 Conclusions and outlook	368
		Chapter conclusions	368
		nowledgements	370
	Bibli	ography	370
13	Big (lata analysis of power grid from random matrix theory	381
		rt C. Qiu, Xing He, Lei Chu and Qian Ai	
	13.1	Background for conduct SA in power grid with big	
		data analytics	382
		13.1.1 Smart grid—an essential big data system	
		with 4Vs data	382
		13.1.2 Smart grid and its stability, control, and SA	383
		13.1.3 Approach to SA—big data analytics and	
		unsupervised learning mechanism	383
		13.1.4 RMM and probability in high dimension	384
	13.2	Three general principles related to big data analytics	384
		13.2.1 Concentration	385
		13.2.2 Suprema	385
		13.2.3 Universality	385
	13.3	Fundamentals of random matrices	386
		13.3.1 Types of matrices	386
		13.3.2 Central limiting theorem	387
		13.3.3 Limit results of GUE and LUE	388
		13.3.4 Asymptotic expansion for the Stieltjes transform	
		of GUE	392
		13.3.5 The rate of convergence for spectra of GUE	
		and LUE	394
		From power grid to RMM	396
	13.5	LES and related research	399
		13.5.1 Definition of LES	399
		13.5.2 Law of Large Numbers	399
		13.5.3 CLTs of LES	399
		13.5.4 CLT for covariance matrices	400

	13.5.5 LES for Ring law	400
	13.5.6 LES for covariance matrices	401
13.6	Data preprocessing—data fusion	401
	13.6.1 Augmented matrix method for power systems	402
	13.6.2 Another kind of data fusion	403
13.7	A new methodology and epistemology for power systems	403
	13.7.1 The evolution of power systems and group-work mode	403
	13.7.2 The methodology of SA for smart grids	406
	13.7.3 Novel indicator system and its advantages	408
13.8	Case studies	410
	13.8.1 Case 1: anomaly detection and statistical indicators	
	designing using simulated 118-bus system	410
	13.8.2 Case 2: correlation analysis for single factor using	
	simulated 118-bus system	414
	13.8.3 Case 3: advantages of LES and visualization using	
	3D power-map	416
	13.8.4 Case 4: SA using real data	421
Bibli	ography	421
Emad	nunication protocols for smart grid l Ebeid, Sergi Rotger-Griful, Søren Aagaard Mikkelsen and Hylsberg Jacobsen	427
1/1	Introduction	427
	State of the art	429
	Background	431
14.5	14.3.1 Demand response reference architecture	431
	14.3.2 Demand response programs	432
	14.3.3 Demand response protocols	433
	14.3.4 Modeling languages and tools	436
	14.3.5 Evaluation metrics	439
14.4	The methodology	440
	14.4.1 Describing household scenarios, demand response	
	strategy, and protocol	440
	14.4.2 Platform-independent and executable descriptions	441
	14.4.3 Evaluating demand response strategy and protocol	442
14.5	Proof of concept	444
	Experimental results	446
	14.6.1 Case 1: individual household	446
	14.6.2 Case 2: load aggregation	451
14.7	Conclusion	456
Ackn	lowledgments	456
Bibli	ography	456

15	Energy-efficient smart grid communications Shengrong Bu and F. Richard Yu		461
	15.1	Introduction	462
	15.2	Energy-efficient wireless smart grid communications	463
	15.3	System model	465
	15.4	Problem transformation	467
	15.5	Non-cooperative game formulation	468
		15.5.1 Utility function of each DAU in the multicell OFDMA	
		cellular network	468
		15.5.2 Game formulation within each time slot	468
	15.6	Analysis of the proposed EE resource allocation game	
		with fairness	469
		15.6.1 Subchannel assignment algorithm	469
		15.6.2 Non-cooperative EE power allocation game	470
		15.6.3 Properties of the interference pricing function factors	471
		15.6.4 Existence of the NE in the proposed game	471
		15.6.5 Proposed parallel iterative algorithm	472
	15.7	EE resource allocation iterative algorithm	472
	15.8	Simulation results and discussions	473
	15.9	Conclusions	477
	Appendix		478
		A. Proof of Theorem 15.1	478
		B. Proof of Proposition 15.5	478
		C. Proof of Proposition 15.3	479
	Bibli	ography	479

Index

483