

Table of Contents

Preface	xv
Jean-Claude SABONNADIÈRE	
Chapter 1. The Electrical Distribution Network: From Heritage to Innovation	1
Nouredine HADJSAÏD, Jean-Claude SABONNADIÈRE and Jean-Pierre ANGELIER	
1.1. Introduction	1
1.2. The new power system paradigm	6
1.3. Structure and characteristics of current distribution systems	7
1.3.1. Connections are primarily based on busbars that represent “electrical nodes”	8
1.3.2. Network reliability determines the choice of substation structure	8
1.4. Consumption	11
1.4.1. Concepts and constraints concerning the load	11
1.4.2. Load characteristics	13
1.5. Transmission and distribution systems operators	13
1.5.1. Transmission system operator	14
1.5.2. Distribution system operator	14
1.6. Future challenges for the distribution system	17
1.6.1. Quality and reliability requirements and economical impact	18
1.6.2. The infrastructure heritage	23
1.6.3. Distributed generation	25
1.6.4. Integration of new technologies	27

1.6.5. Energy efficiency and demand response: stakes for the evolution and optimal operation of distribution systems	28
1.6.6. Transfer on the electricity vector	29
1.6.7. Desired evolution of the distribution system towards intelligent systems	29
1.6.8. Impact on education	32
1.7. The link between investment and quality	32
1.8. Financing mechanisms and investment actors of distribution systems.	36
1.9. Conclusion	38
1.10. Glossary	38
1.11. Bibliography	39
Chapter 2. Characteristics of Distribution Networks.	41
Marie-Cécile ALVAREZ-HÉRAULT, Raphaël CAIRE, Sylvain MARTINO, Christophe ANDRIEU and Bertrand RAISON	
2.1. Part 1: the French network	41
2.1.1. Signal characteristics: voltage level and frequency.	42
2.1.2. Distribution networks structures	44
2.1.3. Protection plan	52
2.1.4. Neutral regime.	54
2.1.5. Characteristics of loads	57
2.1.6. Characteristics of faults	58
2.1.7. Rules of connection	59
2.2. The North American network.	61
2.2.1. Regular structure of the North American distribution system	63
2.2.2. Voltage levels and standards relative to proper functioning of North American-type distribution networks.	64
2.2.3. Regimes with neutral	68
2.2.4. Protection of the electrical network	71
2.2.5. Elements specific to the electrical network.	76
2.3. Bibliography	81
Chapter 3. Overview of Decentralized Means of Production.	83
Haizea GAZTAÑAGA, Raphaël CAIRE, Seddik BACHA and Daniel ROYE	
3.1. Introduction	83
3.2. Deregulation	84
3.3. Emergent means of production.	85
3.3.1. Diesel groups	86

3.3.2. Microturbines	90
3.3.3. Means of storage	97
3.3.4. Wind generators.	103
3.3.5. Photovoltaic panels.	108
3.3.6. Combustion engines in cogeneration.	113
3.3.7. Stirling engines	115
3.3.8. Fuel cells	117
3.4. Conclusion: a challenge and a development opportunity for mains power	119
3.5. Bibliography	119
Chapter 4. Connection to the Decentralized Production Network: Regulatory and Economic Aspects	123
Cédric CLASTRES, Philippe MENANTEAU and Lina-Maria RUIZ	
4.1. Introduction	123
4.2. European policies and growth dynamics of REn.	124
4.3. Incentive policies for the deployment of renewable energies	129
4.3.1. Price instruments	130
4.3.2. Quantity tools	136
4.4. Integration and connection of new renewable energy producers to the network	141
4.4.1. Connection costs	142
4.4.2. Spreading connection costs between different operators	144
4.5. The insertion of renewable energies into the electrical market	147
4.5.1. Uncertainty in forecasting production level	147
4.5.2. Impacts on merit order and electricity prices.	149
4.5.3. Regulation of imbalances and adjustment costs	151
4.5.4. Intermittency management	154
4.6. Bibliography	157
Chapter 5. Impacts of Distributed Generation on the Electrical Network.	161
Raphaël CAIRE and Tuan TRAN-QUOC	
5.1. Introduction	161
5.2. Impact of distributed generation on electrical parameters	164
5.2.1. Power flow modification	164
5.2.2. Voltage profile	166
5.2.3. Quality of the voltage and harmonics	170

5.2.4. Flicker	176
5.2.5. Unbalances generated by single-phase connections	179
5.2.6. Voltage dips and short power cuts	181
5.2.7. Overvoltage	183
5.2.8. Transient stability and dynamics	188
5.2.9. Contribution of DG to the short-circuit currents and powers	189
5.3. Impacts on the design, planning and exploitation	191
5.3.1. Voltage profile and operation	191
5.3.2. Protection plan	192
5.3.3. Change in monitoring (operation and supervision) and planning of the MV network	193
5.3.4. Transmission of the ripple control signal	194
5.4. Impacts on network equipment.	197
5.4.1. Transient recovery voltage	197
5.4.2. Currents due to switching the transformers.	199
5.4.3. Impact of the overvoltage on the aging of equipment	199
5.4.4. Impact of the overcurrent on equipment aging	199
5.5. Bibliography	200
Chapter 6. Photovoltaic Systems Connected to the Network	203
Tuan TRAN-QUOC and Seddik BACHA	
6.1. Introduction to grid-connected PV production	203
6.2. Structure of photovoltaic inverters	207
6.2.1. Basic structure.	207
6.2.2. Arrangement of modules	208
6.2.3. Topologies of the most common inverters	210
6.3. Control/command of the grid side converter	217
6.4. Anti-islanding protection of PV systems.	221
6.5. Impact on the voltage and harmonics of grid connected PV systems	225
6.5.1. Case study	225
6.5.2. Voltage signals and input/output inverter currents	227
6.6. Impact on the voltage.	230
6.6.1. P/Q control.	230
6.6.2. Auto-adaptive voltage control (AVC)	232
6.7. Impact on voltage unbalance	233
6.8. Conclusion	234
6.9. Bibliography	235

Chapter 7. Voltage Control in Distribution Systems with Dispersed Generation	237
Yvon BÉSANGER and Tuan TRAN-QUOC	
7.1. Introduction: problems of voltage control	237
7.1.1. Quality of supply: figures and norm	238
7.1.2. Voltage adjustment for network safety	239
7.1.3. Voltage control for normal exploitation of the networks	239
7.2. Voltage control in today's distribution systems	241
7.2.1. Compensation of reactive power at the substation	241
7.2.2. On-load tap changers (OLTC)	241
7.3. Voltage control in distribution systems with DG	242
7.3.1. Coordinated voltage control	242
7.3.2. The local auto-adaptive voltage control (AVC)	254
7.3.3. Comparison of local and coordinated voltage control strategies	267
7.3.4. A new application program: mixed control.	269
7.4. Conclusion	270
7.5. Bibliography	271
Chapter 8. Grid Integration of Wind Turbine Systems and their Ancillary Services Participation	273
Alexandre TENINGE, Daniel ROYE and Seddik BACHA	
8.1. Wind energy: context.	273
8.1.1. Status of wind energy in 2010.	273
8.1.2. Favorable factors in the development of wind energy	274
8.1.3. Assessment.	276
8.2. Integration of wind energy in electrical systems	276
8.2.1. DGs impact on voltage	277
8.2.2. DGs impact on frequency.	280
8.3. Grid code requirements and wind farms	282
8.3.1. Voltage/reactive power requirements	283
8.3.2. Low voltage ride-through (LVRT) requirements	286
8.3.3. Frequency/active power requirements	288
8.3.4. Conclusion	290
8.4. Wind turbines: principles and modeling aspect.	290
8.4.1. Wind energy conversion principle	290
8.4.2. The turbine	291
8.4.3. Mechanical transmission	295

8.4.4. Fixed speed wind turbine	295
8.4.5. Variable speed wind turbine	297
8.4.6. Conclusion on various wind turbine structures	301
8.5. Study of mixed wind farm integration in an islanded grid	301
8.5.1. Sizing of a mixed wind farm (IG/PMSG).	301
8.5.2. Participation in voltage control	304
8.5.3. Low voltage ride-through (LVRT)	305
8.5.4. Participation in frequency control	307
8.5.5. Conclusion on mixed wind farms.	311
8.6. Bibliography	311
8.7. Manufacturers websites	313
8.8. List of symbols.	314
Chapter 9. Reliability of Distribution Systems with Dispersed Generation	315
Yvon BÉSANGER	
9.1. New considerations and challenges for the reliability of distribution systems	315
9.1.1. Quality of the electricity product	316
9.1.2. Costs of reliability	317
9.1.3. Probability criteria and techniques	317
9.2. Basic concepts of electrical network reliability.	319
9.2.1. Definition of reliability	319
9.2.2. Quantities of security	319
9.2.3. Distribution functions	322
9.2.4. Methodology of a study of reliability: assessment of reliability criteria	323
9.3. Objectives and use of probabilistic reliability studies.	330
9.3.1. . . .in the development of distribution systems	330
9.3.2. . . .and in the exploitation of distribution systems	332
9.4. Basic concepts of Monte Carlo simulation	333
9.4.1. Monte Carlo method	333
9.4.2. Simulation	334
9.4.3. Concepts and basic definition of the statistics	334
9.4.4. Monte Carlo simulation	337
9.5. Some results of Monte Carlo method application	343
9.6. Conclusion	348
9.7. Bibliography	349

Chapter 10. Protection, Detection and Isolation of Faults in MV Networks in the Presence of Decentralized Production	351
Bertrand RAISON, Olivier CHILARD, Delcho PENKOV and Duc CONG PHAM	
10.1. Introduction	351
10.2. Characteristics of faults in HVA distribution systems.	353
10.2.1. Various types of faults	353
10.2.2. Characteristics of polyphase faults	355
10.2.3. Characteristics of single-phase faults.	355
10.2.4. Neutral grounding modes of the distribution systems . . .	356
10.2.5. Impact of decentralized production on faults.	357
10.3. Functioning of protection in MV networks in the presence of decentralized production.	361
10.3.1. General principles of the HVA protection plan	362
10.3.2. MV protection plan on the level of source stations	362
10.3.3. Impact of decentralized production on the functioning of protective relays in the feeder	365
10.3.4. Protection of generators	369
10.4. Detection of faults	373
10.4.1. What are FPIs?	373
10.4.2. Isolation of faults using FPIs.	376
10.4.3. Impact of decentralized production FTI functioning and fault isolation.	377
10.4.4. FPIs of the future	379
10.5. Localization of faults in the presence of decentralized production.	380
10.5.1. General principle of existing methods	380
10.5.2. Calculation of fault distance using the calculation of impedance: an example	382
10.5.3. Impact of decentralized production on localization methods	385
10.5.4. Some research prospects	392
10.6. Bibliography	392
Chapter 11. Load Control in the Management of Distribution Systems	395
Didier BOËDA, Christophe KIENY and Daniel ROYE	
11.1. Objectives of load control for the distributor	395
11.2. Controlled loads	397
11.2.1. Description of the houses thermal model	398
11.2.2. Load control strategy: typical cycle	400

11.2.3. Load control strategies	402
11.3. Results for real-time control	403
11.3.1. Impact of the time-step; performances of the communication system	405
11.3.2. Impact of the load shedding duration	405
11.3.3. Impact of the ensured supply back	406
11.3.4. Load control length time and amount of power to reduce	406
11.4. Real-time load control with knowledge of houses' characteristics	406
11.5. Optimized load control	407
11.5.1. Implementation of the algorithm	408
11.5.2. Results for the optimized approach	408
11.6. Conclusion	413
11.7. Bibliography	414
Chapter 12. Power Electronics in the Future Distribution Grid	415
Seddik BACHA, David FREY, Erwan LEPELLETER and Raphaël CAIRE	
12.1. Introduction	415
12.2. New context of distribution systems	416
12.2.1. Evolution	416
12.2.2. Electrical networks today and tomorrow	417
12.3. PE systems in the context of existing networks	420
12.3.1. Various types of FACTS and DFACTS	420
12.3.2. Some manufacturers' offerings	423
12.4. Current state of development	425
12.4.1. Examples concerning the transmission system	426
12.4.2. Examples concerning the distribution system	427
12.4.3. Examples concerning the architecture of FACTS	431
12.5. Conclusion	434
12.6. Bibliography	436
Chapter 13. Virtual Power Systems for Active Networks	439
Guillaume FOGGIA, Christophe KIENY and Joseph MAIRE	
13.1. General context: towards an active network	439
13.2. Objectives	440
13.3. Concept of a virtual power plant (project FENIX)	442
13.3.1. Structure	442
13.3.2. Commercial virtual power plant (CVPP)	443
13.3.3. Technical virtual power plant (TVPP)	448
13.3.4. Information exchange and relation between actors	450
13.4. Other developments: the Alp energy project	452

13.5. Prospects for virtual power plants on active network	454
13.5.1. Obstacles and guidelines	454
13.5.2. Future prospects	455
13.6. Bibliography	457
Chapter 14. Towards Smart Grids	459
Nouredine HADJSAÏD and Jean-Claude SABONNADIÈRE	
14.1. Introduction	459
14.1.1. The new energy paradigm	459
14.1.2. Information and communication technologies serving the electrical system	464
14.1.3. The French context in the European energy prospective	466
14.1.4. Main triggers of the development of smart grid	470
14.2. Definitions of the smart grid	471
14.3. Objectives addressed by the smart grid concept	472
14.3.1. Technical objectives	473
14.3.2. Socio-economic and environmental objectives	473
14.4. Stakeholders involved in the implementation of the smart grid concept.	474
14.5. Research and scientific aspects of the smart grid.	476
14.5.1. Examples of innovative concepts in development.	476
14.5.2. Scientific, technological, commercial and sociological challenges	481
14.6. Conclusion.	483
14.7. Bibliography	484
List of Authors	487
Index	489