

CONTENTS

PREFACE	xxi
CONTRIBUTORS	xxvii
PART 1 THEORY OF MODERN HEURISTIC OPTIMIZATION	1
1 Introduction to Evolutionary Computation	3
<i>David B. Fogel</i>	
1.1 Introduction, 3	
1.2 Advantages of Evolutionary Computation, 4	
1.2.1 Conceptual Simplicity, 4	
1.2.2 Broad Applicability, 6	
1.2.3 Outperform Classic Methods on Real Problems, 7	
1.2.4 Potential to Use Knowledge and Hybridize with Other Methods, 8	
1.2.5 Parallelism, 8	
1.2.6 Robust to Dynamic Changes, 9	
1.2.7 Capability for Self-Optimization, 10	
1.2.8 Able to Solve Problems That Have No Known Solutions, 11	
1.3 Current Developments, 12	
1.3.1 Review of Some Historical Theory in Evolutionary Computation, 12	
1.3.2 No Free Lunch Theorem, 12	
1.3.3 Computational Equivalence of Representations, 14	
1.3.4 Schema Theorem in the Presence of Random Variation, 16	
1.3.5 Two-Armed Bandits and the Optimal Allocation of Trials, 17	
1.4 Conclusions, 19	
Acknowledgments, 20	
References, 20	

2 Fundamentals of Genetic Algorithms

25

Alexandre P. Alves da Silva and Djalma M. Falcão

- 2.1 Introduction, 25
 - 2.2 Modern Heuristic Search Techniques, 25
 - 2.3 Introduction to GAs, 27
 - 2.4 Encoding, 28
 - 2.5 Fitness Function, 30
 - 2.5.1 Premature Convergence, 32
 - 2.5.2 Slow Finishing, 32
 - 2.6 Basic Operators, 33
 - 2.6.1 Selection, 33
 - 2.6.1.1 Tournament Selection, 34
 - 2.6.1.2 Truncation Selection, 34
 - 2.6.1.3 Linear Ranking Selection, 34
 - 2.6.1.4 Exponential Ranking Selection, 34
 - 2.6.1.5 Elitist Selection, 34
 - 2.6.1.6 Proportional Selection, 35
 - 2.6.2 Crossover, 36
 - 2.6.3 Mutation, 38
 - 2.6.4 Control Parameters Estimation, 38
 - 2.7 Niching Methods, 38
 - 2.8 Parallel Genetic Algorithms, 39
 - 2.9 Final Comments, 40
- Acknowledgments, 41
References, 41

3 Fundamentals of Evolution Strategies and Evolutionary Programming

43

Vladimiro Miranda

- 3.1 Introduction, 43
- 3.2 Evolution Strategies, 46
 - 3.2.1 The General $(\mu, \kappa, \lambda, \rho)$ Evolution Strategies Scheme, 47
 - 3.2.2 Some More Basic Concepts, 50
 - 3.2.3 The Early $(1 + 1)$ ES and the $1/5$ Rule, 51
 - 3.2.4 Focusing on the Optimum, 53
 - 3.2.5 The $(1, \lambda)$ ES and σ SA Self-Adaptation, 54
 - 3.2.6 How to Choose a Value for the Learning Parameter?, 56
 - 3.2.7 The (μ, λ) ES as an Extension of $(1, \lambda)$ ES, 57
 - 3.2.8 Self-Adaptation in (μ, λ) ES, 58

3.3	Evolutionary Programming, 60
3.3.1	The $(\mu + \lambda)$ Bridge to ES, 60
3.3.2	A Scheme for Evolutionary Programming, 61
3.3.3	Other Evolutionary Programming Variants, 63
3.4	Common Features, 63
3.4.1	Enhancing the Mutation Process, 63
3.4.2	Recombination as a Major Factor, 65
3.4.3	Handling Constraints, 67
3.4.4	Starting Point, 67
3.4.5	Fitness Function, 67
3.4.6	Computing, 68
3.5	Conclusions, 68
	References, 69

4 Fundamentals of Particle Swarm Optimization Techniques

71

Yoshikazu Fukuyama

4.1	Introduction, 71
4.2	Basic Particle Swarm Optimization, 72
4.2.1	Background of Particle Swarm Optimization, 72
4.2.2	Original PSO, 72
4.3	Variations of Particle Swarm Optimization, 76
4.3.1	Discrete PSO, 76
4.3.2	PSO for MINLPs, 77
4.3.3	Constriction Factor Approach (CFA), 77
4.3.4	Hybrid PSO (HPSO), 78
4.3.5	Lbest Model, 79
4.3.6	Adaptive PSO (APSO), 79
4.3.7	Evolutionary PSO (EPSO), 81
4.4	Research Areas and Applications, 82
4.5	Conclusions, 83
	References, 83

5 Fundamentals of Ant Colony Search Algorithms

89

Yong-Hua Song, Haiyan Lu, Kwang Y. Lee, and I. K. Yu

5.1	Introduction, 89
5.2	Ant Colony Search Algorithm, 90
5.2.1	Behavior of Real Ants, 90
5.2.2	Ant Colony Algorithms, 91
5.2.2.1	The Ant System, 94
5.2.2.2	The Ant Colony System, 95
5.2.2.3	The Max-Min Ant System, 95

5.2.3 Major Characteristics of Ant Colony Search Algorithms, 98	
5.2.3.1 Distributed Computation: Avoid Premature Convergence, 98	
5.2.3.2 Positive Feedback: Rapid Discovery of Good Solution, 98	
5.2.3.3 Use of Greedy Search and Constructive Heuristic Information: Find Acceptable Solutions in the Early Stage of the Process, 98	
5.3 Conclusions, 99	
References, 99	

6 Fundamentals of Tabu Search

101

Alcir J. Monticelli, Rubén Romero, and Eduardo Nobuhiro Asada

6.1 Introduction, 101	
6.1.1 Overview of the Tabu Search Approach, 101	
6.1.2 Problem Formulation, 103	
6.1.3 Coding and Representation, 104	
6.1.4 Neighborhood Structure, 105	
6.1.5 Characterization of the Neighborhood, 108	
6.2 Functions and Strategies in Tabu Search, 110	
6.2.1 Recency-Based Tabu Search, 110	
6.2.2 Basic Tabu Search Algorithm, 112	
6.2.2.1 Candidate List Strategies, 114	
6.2.2.2 Tabu Tenure, 114	
6.2.2.3 Aspiration Criteria, 115	
6.2.3 The Use of Long-Term Memory in Tabu Search, 115	
6.2.3.1 Frequency-Based Memory, 116	
6.2.3.2 Intensification, 116	
6.2.3.3 Diversification, 117	
6.2.4 Other TS Strategies, 118	
6.2.4.1 Path Relinking, 119	
6.2.4.2 Strategic Oscillation, 119	
6.3 Applications of Tabu Search, 119	
6.4 Conclusions, 120	
References, 120	

7 Fundamentals of Simulated Annealing	123
<i>Alcir J. Monticelli, Rubén Romero, and Eduardo Nobuhiro Asada</i>	
7.1 Introduction, 123	
7.2 Basic Principles, 125	
7.2.1 Metropolis Algorithm, 125	
7.2.2 Simulated Annealing Algorithm, 126	
7.3 Cooling Schedule, 127	
7.3.1 Determination of the Initial Temperature T_0 , 128	
7.3.2 Determination of N_k , 129	
7.3.3 Determination of Cooling Rate, 130	
7.3.4 Stopping Criterion, 130	
7.4 SA Algorithm for the Traveling Salesman Problem, 131	
7.4.1 Problem Coding, 131	
7.4.2 Evaluation of the Cost Function, 132	
7.4.3 Cooling Schedule, 133	
7.4.4 Comments on the Results for the TSP, 134	
7.5 SA for Transmission Network Expansion Problem, 134	
7.5.1 Problem Coding, 136	
7.5.2 Determination of the Initial Solution, 136	
7.5.3 Neighborhood Structure, 138	
7.5.4 Variation of the Objective Function, 139	
7.5.5 Cooling Schedule, 140	
7.6 Parallel Simulated Annealing, 140	
7.6.1 Division Algorithm, 141	
7.6.2 Clustering Algorithm, 142	
7.7 Applications of Simulated Annealing, 143	
7.8 Conclusions, 144	
References, 144	
8 Fuzzy Systems	147
<i>Germano Lambert-Torres</i>	
8.1 Motivation and Definitions, 147	
8.1.1 Introduction, 147	
8.1.2 Typical Actions in Fuzzy Systems, 148	
8.2 Integration of Fuzzy Systems with Evolutionary Techniques, 150	
8.2.1 Integration Types of Hybrid Systems, 150	
8.2.1.1 Stand-alone Systems, 150	
8.2.1.2 Weak Integration Systems, 150	
8.2.1.3 Fused Systems, 151	

8.2.2	Hybrid Systems in Evolutionary Techniques,	151
8.2.3	Evolutionary Algorithms and Fuzzy Logic,	152
8.3	An Illustrative Example of a Hybrid System,	152
8.3.1	Parking Conditions,	153
8.3.2	Creation of the Fuzzy Control,	154
8.3.3	First Simulations,	156
8.3.4	Problem Presentation,	156
8.3.5	Genetic Training Modulus Description,	158
8.3.6	The Option to Define the Starting Positions,	158
8.3.7	The Option Genetic Training,	158
8.3.7.1	Genetic Representation of Solutions,	160
8.3.7.2	Evaluation Function,	160
8.3.7.3	Genetic Operators: Crossover and Mutation,	161
8.3.7.4	Renovation and Selection Criteria,	161
8.3.7.5	Stop Criteria,	162
8.3.7.6	Algorithm Presentation,	162
8.3.8	Tests,	163
8.4	Conclusions,	167
	References,	168
9	Differential Evolution, an Alternative Approach to Evolutionary Algorithm	171
	<i>Kit Po Wong and ZhaoYang Dong</i>	
9.1	Introduction,	171
9.2	Evolutionary Algorithms,	172
9.2.1	Basic EAs,	172
9.2.2	Virtual Population-Based Acceleration Techniques,	174
9.3	Differential Evolution,	176
9.3.1	Function Optimization Formulation,	176
9.3.2	DE Fundamentals,	177
9.3.2.1	Initial Population,	178
9.3.2.2	Mutation and Recombination to Create New Vectors,	178
9.3.2.3	Selection and the Overall DE,	180
9.4	Key Operators for Differential Evolution,	181
9.4.1	Encoding,	181
9.4.2	Mutation,	181
9.4.3	Crossover,	183
9.4.4	Other Operators,	183
9.5	An Optimization Example,	184
9.6	Conclusions,	186

Acknowledgments,	186
References,	186
10 Pareto Multiobjective Optimization	189
<i>Patrick N. Ngatchou, Anahita Zarei, Warren L. J. Fox, and Mohamed A. El-Sharkawi</i>	
10.1	Introduction, 189
10.2	Basic Principles, 190
10.2.1	Generic Formulation of MO Problems, 191
10.2.2	Pareto Optimality Concepts, 191
10.2.3	Objectives of Multiobjective Optimization, 193
10.3	Solution Approaches, 194
10.3.1	Classic Methods, 194
10.3.1.1	Weighted Aggregation, 194
10.3.1.2	Goal Programming, 195
10.3.1.3	ϵ -Constraint, 195
10.3.1.4	Discussion on Classic Methods, 195
10.3.2	Intelligent Methods, 196
10.3.2.1	Background, 196
10.3.2.2	Structure of Population-Based MOO Solvers, 196
10.3.2.3	Common Population-Based MO Algorithms, 200
10.3.2.4	Discussion on Modern Methods, 202
10.4	Performance Analysis, 202
10.4.1	Objective of Performance Assessment, 202
10.4.2	Comparison Methodologies, 203
10.4.2.1	Quality Indicators, 203
10.4.2.2	Attainment Function Method, 204
10.4.2.3	Dominance Ranking, 204
10.5	Conclusions, 205
Acknowledgments, 205	
References, 205	
11 Trust-Tech Paradigm for Computing High-Quality Optimal Solutions: Method and Theory	209
<i>Hsiao-Dong Chiang and Jaewook Lee</i>	
11.1	Introduction, 209
11.2	Problem Preliminaries, 210
11.3	A Trust-Tech Paradigm, 213
11.3.1	Phase I, 213
11.3.2	Phase II, 214

11.4	Theoretical Analysis of Trust-Tech Method, 218
11.5	A Numerical Trust-Tech Method, 221
11.5.1	Computing Another Local Optimal Solution, 222
11.5.1.1	Method for Computing Exit Point, 222
11.5.1.2	Method for Computing Dynamic Decomposition Point (DDP), 222
11.5.1.3	Trust-Tech Method for Computing Another Local Optimal Solution, 223
11.5.2	Computing Tier-One Local Optimal Solutions, 223
11.5.2.1	Trust-Tech Method for Computing Tier-One Local Optimal Solutions, 224
11.5.3	Computing Tier-N Solutions, 224
11.6	Hybrid Trust-Tech Methods, 225
11.7	Numerical Schemes, 227
11.8	Numerical Studies, 228
11.9	Conclusions Remarks, 231
	References, 232

PART 2 SELECTED APPLICATIONS OF MODERN HEURISTIC OPTIMIZATION IN POWER SYSTEMS 235

12	Overview of Applications in Power Systems 237
<i>Alexandre P. Alves da Silva, Djalma M. Falcão, and Kwang Y. Lee</i>	
12.1	Introduction, 237
12.2	Optimization, 237
12.3	Power System Applications, 238
12.4	Model Identification, 239
12.4.1	Dynamic Load Modeling, 239
12.4.2	Short-Term Load Forecasting, 240
12.4.3	Neural Network Training, 241
12.4.3.1	Pruning Versus Growing, 241
12.4.3.2	Types of Approximation Functions, 242
12.5	Control, 242
12.5.1	Examples, 243
12.6	Distribution System Applications, 244
12.6.1	Network Reconfiguration for Loss Reduction, 245
12.6.2	Optimal Protection and Switching Devices Placement, 246
12.6.3	Prioritizing Investments in Distribution Networks, 247

12.7	Conclusions, 249	
	References, 250	
13	Application of Evolutionary Technique to Power System Vulnerability Assessment	261
	<i>Mingoo Kim, Mohamed A. El-Sharkawi, Robert J. Marks, and Ioannis N. Kassabalis</i>	
13.1	Introduction, 261	
13.2	Vulnerability Assessment and Control, 263	
13.3	Vulnerability Assessment Challenges, 264	
13.3.1	Complexity of Power System, 264	
13.3.2	VA On-line Speed, 265	
13.3.3	Feature Selection, 265	
13.3.3.1	Fisher's Linear Discriminant: Selection Criteria, 266	
13.3.3.2	Neural Network Feature-Extraction (NNFE), 268	
13.3.3.3	Support Vector Machine Feature-Extraction, 270	
13.3.4	Vulnerability Border, 270	
13.3.4.1	Gradient Method, 272	
13.3.4.2	Evolutionary Computation Method, 272	
13.3.4.3	Enhanced Particle Swarm Optimization Method, 274	
13.3.5	Selection of Vulnerability Index, 276	
13.3.5.1	Vulnerability Index Based on Distance from a Border, 277	
13.3.5.2	Vulnerability Index Based on Anticipated Loss of Load, 278	
13.4	Conclusions, 281	
	References, 281	
14	Applications to System Planning	285
	<i>Eduardo Nobuhiro Asada, Youngjae Jeon, Kwang Y. Lee, Vladimiro Miranda, Alcir J. Monticelli, Koichi Nara, Jong-Bae Park, Rubén Romero, and Yong-Hua Song</i>	
14.1	Introduction, 285	
14.2	Generation Expansion, 286	
14.2.1	A Coding Strategy for an Improved GA for the Least-Cost GEP, 288	
14.2.2	Fitness Function, 288	
14.2.3	Creation of an Artificial Initial Population, 289	
14.2.4	Stochastic Crossover, Elitism, and Mutation, 291	
14.2.5	Numerical Examples, 292	
14.2.6	Parameters for GEP and IGA, 293	

14.2.7	Numerical Results, 295
14.3	Transmission Network Expansion, 297
14.3.1	Overview of Static Transmission Network Planning, 297
14.3.2	Solution Techniques for the Transmission Expansion Planning Problem, 300
14.3.3	Coding, Problem Representation, and Test Systems, 302
14.3.4	Complexity of the Test Systems, 304
14.3.5	Simulated Annealing, 306
14.3.6	Genetic Algorithms in Transmission Network Expansion Planning, 307
14.3.7	Tabu Search in Transmission Network Expansion Planning, 309
14.3.8	Hybrid TS/GA/SA Algorithm in Transmission Network Expansion Planning, 310
14.3.9	Comments on the Performance of Meta-heuristic Methods in Transmission Network Expansion Planning, 311
14.4	Distribution Network Expansion, 311
14.4.1	Dynamic Planning of Distribution System Expansion: A Complete GA Model, 312
14.4.2	Dynamic Planning of Distribution System Expansion: An Efficient GA Application, 316
14.4.3	Application of TS to the Design of Distribution Networks in FRIENDS, 317
14.5	Reactive Power Planning at Generation–Transmission Level, 320
14.5.1	Benders Decomposition of the Reactive Power Planning Problem, 321
14.5.2	Solution Algorithm, 323
14.5.3	Results for the IEEE 30-Bus System, 324
14.6	Reactive Power Planning at Distribution Level, 326
14.6.1	Modeling Chromosome Repair Using an Analytical Model, 326
14.6.2	Evolutionary Programming/Evolution Strategies Under Test, 327
14.7	Conclusions, 330
	References, 330
15	Applications to Power System Scheduling
	337
	<i>Koay Chin Aik, Loi Lei Lai, Kwang Y. Lee, Haiyan Lu, Jong-Bae Park, Yong-Hua Song, Dipti Srinivasan, John G. Vlachogiannis, and I. K. Yu</i>
15.1	Introduction, 337
15.2	Economic Dispatch, 337
15.2.1	Economic Dispatch Problem, 337
15.2.2	GA Implementation to ED, 339
15.2.2.1	Encoding Method, 340
15.2.2.2	Constraints Handling, 341

- 15.2.2.3 Genetic Operations, 342
 - 15.2.2.4 Fitness Function, 344
 - 15.2.2.5 Multistage Method and Directional Crossover, 345
 - 15.2.3 PSO Implementation to ED, 346
 - 15.2.3.1 Constraints Handling, 346
 - 15.2.3.2 Dynamic Space Reduction Strategy, 348
 - 15.2.4 Numerical Example, 348
 - 15.2.4.1 GA Implementation to ED with Smooth Cost Function, 348
 - 15.2.4.2 PSO Implementation to ED with Smooth/Nonsmooth Cost Function, 349
 - 15.2.5 Summary, 354
- 15.3 Maintenance Scheduling, 354
- 15.3.1 Maintenance Scheduling Problem, 354
 - 15.3.2 GA, PSO, and ES Implementation, 355
 - 15.3.2.1 Optimization Function, 355
 - 15.3.2.2 Total Operating Cost, 356
 - 15.3.2.3 Maintenance Cost, 356
 - 15.3.2.4 Penalty Cost, 356
 - 15.3.2.5 Overall Objective Function, 359
 - 15.3.2.6 Problem Representation, 360
 - 15.3.3 Simulation Results, 365
 - 15.3.4 Summary, 366
- 15.4 Cogeneration Scheduling, 366
- 15.4.1 Cogeneration Scheduling Problem, 367
 - 15.4.2 IGA Implementation, 370
 - 15.4.3 Case Study, 373
 - 15.4.4 Summary, 374
 - 15.4.5 Nomenclature, 379
 - 15.4.5.1 Thermal and Electric Variables, 379
 - 15.4.5.2 Data, 379
 - 15.4.5.3 Parameters, 379
- 15.5 Short-Term Generation Scheduling of Thermal Units, 380
- 15.5.1 Short-Term Generation Scheduling Problem, 380
 - 15.5.2 ACSA Implementation, 382
 - 15.5.3 Experimental results, 385
- 15.6 Constrained Load Flow Problem, 385
- 15.6.1 Constrained Load Flow Problem, 385
 - 15.6.2 Heuristic Ant Colony Search Algorithm Implementation, 386
 - 15.6.2.1 Problem Formulation, 386
 - 15.6.2.2 Construction Graph (AS-graph), 387
 - 15.6.2.3 ACSA for the CLF Problem, 387

15.6.3	Test Examples, 390	
15.6.4	Summary, 399	
References,	399	
16	Power System Controls	403
<i>Yoshikazu Fukuyama, Hamid Ghezelayagh, Kwang Y. Lee, Chen-Ching Liu, Yong-Hua Song, and Ying Xiao</i>		
16.1	Introduction, 403	
16.2	Power System Controls: Particle Swarm Technique, 404	
16.2.1	Problem Formulation of VVC, 405	
16.2.1.1	State Variables, 405	
16.2.1.2	Problem Formulation, 406	
16.2.2	Expansion of PSO for MINLP, 406	
16.2.3	Voltage Security Assessment, 407	
16.2.4	VVC Using PSO, 408	
16.2.4.1	Treatment of State Variables, 408	
16.2.4.2	VVC Algorithm Using PSO, 408	
16.2.5	Numerical Examples, 409	
16.2.5.1	IEEE 14 Bus System, 409	
16.2.5.2	Practical 112 Bus Model System, 412	
16.2.5.3	Large-Scale 1217 Bus Model System, 415	
16.2.6	Summary, 416	
16.3	Power Plant Controller Design with GA, 417	
16.3.1	Overview of the GA, 417	
16.3.2	The Boiler-Turbine Model, 419	
16.3.3	The GA Control System Design, 420	
16.3.3.1	PI Controller Design, 420	
16.3.3.2	LQR Controller Design, 423	
16.3.4	GA Design Results, 423	
16.3.4.1	GA/PI Controller Results, 423	
16.3.4.2	GA/LQR Controller Results, 425	
16.3.4.3	Summary, 427	
16.4	Evolutionary Programming Optimizer and Application in Intelligent Predictive Control, 427	
16.4.1	Structure of the Intelligent Predictive Controller, 428	
16.4.2	Power Plant Model, 430	
16.4.3	Control Input Optimization, 431	
16.4.4	Self-Organized Neuro-Fuzzy Identifier, 435	
16.4.5	Rule Generation and Tuning, 438	
16.4.6	Controller Implementation, 442	
16.4.7	Summary, 444	

16.5 An Interactive Compromise Programming-Based MO Approach to FACTS Control, 444	
16.5.1 Review of MO Optimization Techniques, 446	
16.5.1.1 Weighting Method, 447	
16.5.1.2 Goal Programming, 447	
16.5.1.3 ϵ -Constraint Method, 447	
16.5.1.4 Compromise Programming, 447	
16.5.1.5 Fuzzy Set Theory Applications, 448	
16.5.1.6 Genetic Algorithm, 448	
16.5.1.7 Interactive Procedure, 449	
16.5.2 Formulated MO Optimization Model, 449	
16.5.2.1 Formulated MO Optimization Model for FACTS Control, 450	
16.5.3 Power Flow Control Model of FACTS Devices, 450	
16.5.3.1 Control Variables, 450	
16.5.3.2 Applied Power Flow Control Model, 453	
16.5.4 Proposed Interactive DWCP Method, 453	
16.5.4.1 Applied Fuzzy Compromise Programming, 453	
16.5.4.2 Operation Cost Minimization, 454	
16.5.4.3 Local Power Flow Control, 454	
16.5.5 Proposed Interactive Procedure with Worst Compromise Displacement, 455	
16.5.5.1 Phase 1: Model Formulation, 456	
16.5.5.2 Phase 2: Noninferior Solution Calculation, 456	
16.5.5.3 Phase 3: Scenario Evaluation, 456	
16.5.6 Implementation, 457	
16.5.7 Numerical Results, 457	
16.5.8 Summary, 462	
References, 464	
17 Genetic Algorithms for Solving Optimal Power Flow Problems	471
<i>Loi Lei Lai and Nidul Sinha</i>	
17.1 Introduction, 471	
17.2 Genetic Algorithms, 473	
17.2.1 Terms Used in GA, 473	
17.2.1.1 Search Space, 473	
17.2.1.2 Chromosome, 474	
17.2.1.3 Gene, 474	
17.2.1.4 Population Size, 474	
17.2.1.5 Fitness, 475	
17.2.1.6 Initialization, 475	

17.2.1.7	Creation of Offspring, 476
17.2.1.8	Heuristic Crossover, 476
17.2.1.9	Nonuniform Mutation, 477
17.2.1.10	Normalized Geometric Selection, 477
17.2.1.11	Crossover Probability, 478
17.2.1.12	Mutation Probability, 478
17.2.1.13	Stopping Rule, 478
17.3	Load Flow Problem, 478
17.4	Optimal Power Flow Problem, 483
17.4.1	Application Examples, 485
17.4.1.1	Optimal Power Flow Under Contingent Condition with Line Capacity Limit, 488
17.4.1.2	Optimal Power Flow for Loss Minimization, 488
17.5	OPF with FACTS Devices, 488
17.5.1	FACTS Model, 492
17.5.1.1	Phase Shifter, 492
17.5.1.2	Series Compensator, 495
17.5.2	Problem Formulation, 495
17.5.3	Numerical Results, 496
17.6	Conclusions, 499
	References, 499

18 An Interactive Compromise Programming-Based Multiobjective Approach to FACTS Control

501

Ying Xiao, Yong-Hua Song, and Chen-Ching Liu

18.1	Introduction, 501
18.2	Review of Multiobjective Optimization Techniques, 503
18.2.1	Weighting Method, 503
18.2.2	Goal Programming, 504
18.2.3	ϵ -Constraint Method, 504
18.2.4	Compromise Programming, 504
18.2.5	Fuzzy Set Theory Applications, 505
18.2.6	Genetic Algorithm, 505
18.2.7	Interactive Procedure, 506
18.3	Formulated MO Optimization Model, 506
18.3.1	Formulated MO Optimization Model for FACTS Control, 507
18.3.2	Power Flow Control Model of FACTS Devices, 508
18.3.2.1	Control Variables, 508
18.3.2.2	Applied Power Flow Control Model, 509

18.4	Proposed Interactive Displaced Worst Compromise Programming Method, 511	
18.4.1	Applied Fuzzy CP, 511	
18.4.2	Operation Cost Minimization, 512	
18.4.3	Local Power Flow Control, 512	
18.5	Proposed Interactive Procedure with WC Displacement, 513	
18.5.1	Phase 1: Model Formulation, 513	
18.5.2	Phase 2: Noninferior Solution Calculation, 514	
18.5.3	Phase 3: Scenario Evaluation, 514	
18.6	Implementation, 516	
18.7	Numerical Results, 516	
18.8	Conclusions, 521	
	References, 521	
19	Hybrid Systems	525
	<i>Vladimiro Miranda</i>	
19.1	Introduction, 525	
19.2	Capacitor Sizing and Location and Analytical Sensitivities, 527	
19.2.1	From Darwin to Lamarck: Three Models, 528	
19.2.2	Building a Lamarckian Acquisition of Improvements, 529	
19.2.3	Analysis of a Didactic Example, 531	
19.3	Unit Commitment, Fuzzy Sets, and Cleverer Chromosomes, 538	
19.3.1	The Deceptive Characteristics of Unit Commitment Problems, 538	
19.3.2	Similarity Between the Capacitor Placement and the Unit Commitment Problems, 539	
19.3.3	The Need for Cleverer Chromosomes, 540	
19.3.4	A Biological Touch: The Chromosome as a Program, 541	
19.3.5	A Real-World Example: The CARE Model in Crete, Greece, 542	
19.3.5.1	General Comments, 544	
19.3.5.2	Evolutionary Process Techniques: Chromosome Compression Technique, 544	
19.3.5.3	Evolutionary Process Techniques: Selection and Deterministic Crowding, 544	
19.3.5.4	Evolutionary Process Techniques: Dynamic Mutation Rate, 544	
19.3.5.5	Evolutionary Process Techniques: Crossover, 545	
19.3.5.6	Evolutionary Process Techniques: Chromosome Repair, 545	

19.3.5.7	Evolutionary Process Techniques: A Lamarckist Adaptation, 545
19.3.5.8	Fitness Evaluation: Dispatch with Fuzzy Wind Model, 545
19.3.5.9	Fitness Evaluation: Ramping Rules, 547
19.3.6	Fitness Evaluation: Reliability (Spinning Reserve as a Fuzzy Constraint), 547
19.3.7	Illustrative Results, 547
19.4	Voltage/Var Control and Loss Reduction in Distribution Networks with an Evolutionary Self-Adaptive Particle Swarm Optimization Algorithm: EPSO, 550
19.4.1	Justifying a Hybrid Approach, 550
19.4.2	The Principles of EPSO: Reproduction and Movement Rule, 551
19.4.3	Mutating Strategic Parameters, 552
19.4.4	The Merits of EPSO, 553
19.4.5	Experiencing with EPSO: Basic EPSO Model, 554
19.4.6	EPSO in Test Functions, 554
19.4.7	EPSO in Loss Reduction and Voltage/VAR Control: Definition of the Problem, 557
19.4.8	Applying EPSO in the Management of Networks with Distributed Generation, 558
19.5	Conclusions, 559
	References, 560