

Contents

Preface — V

Chapter 1

Introduction — 1

- 1.1 Review of the concepts of digital power systems — 1
- 1.2 Definition of smart power system — 2
 - 1.2.1 Smart power systems and smart wide-area robots — 2
 - 1.2.2 SEMS and smart power systems in China — 3
- 1.3 The value of SPS construction — 4
 - 1.3.1 Improvement of disaster prevention capability — 5
 - 1.3.2 Economic operation indices and power quality improvement — 6
- 1.4 Global research: state of the art — 7
 - 1.4.1 IECSA project — 8
 - 1.4.2 The seamless communication architecture of power systems — 9
 - 1.4.3 The advanced control center in PJM — 9
 - 1.4.4 Intelligent utility network of IBM — 10
 - 1.4.5 Advanced distribution automation system — 11
- 1.5 Summary — 12

Chapter 2

Overview of power system hybrid control theory — 13

- 2.1 Introduction — 13
- 2.2 Basic concepts — 13
 - 2.2.1 State variable — 14
 - 2.2.2 State vector — 14
 - 2.2.3 State space — 14
 - 2.2.4 State trajectory — 14
 - 2.2.5 State space and state vector field — 15
 - 2.2.6 Mapping — 15
 - 2.2.7 True state vector and true state vector field — 16
- 2.3 The dichotomy of state space — 16
- 2.4 Optimality-approximating state space — 18
- 2.5 E transform and C transform — 20
- 2.6 Geometrical interpretation of the two-level transform — 21
- 2.7 Events initiate control; control clears events — 22
- 2.8 Time-driven and event-driven control — 23
- 2.9 Structure of a power system hybrid control system and smart energy management system — 24
 - 2.9.1 Data source and mathematical model of a power system hybrid control system — 24

| | | |
|-------|---------------------------------------|----|
| 2.9.2 | Analysis of the structure of a SEMS — | 26 |
| 2.10 | Summary — | 30 |

Chapter 3

Smart power system infrastructures — 32

| | | |
|-------|---|----|
| 3.1 | Introduction — | 32 |
| 3.2 | Digital substations — | 32 |
| 3.2.1 | Definition of digital substations — | 32 |
| 3.2.2 | Fundamentals of constructing a digital substation — | 33 |
| 3.3 | Digital power plants — | 41 |
| 3.3.1 | Definition — | 41 |
| 3.3.2 | Fundamentals of constructing a digital power plant — | 42 |
| 3.4 | Digital transmission lines — | 47 |
| 3.4.1 | Definition — | 47 |
| 3.4.2 | Fundamentals of constructing digital transmission lines — | 48 |
| 3.5 | Summary — | 57 |

Chapter 4

Basic platforms of smart power systems — 58

| | | |
|-------|---|----|
| 4.1 | Introduction — | 58 |
| 4.2 | Basic communication platform — | 58 |
| 4.2.1 | Requirements of the basic communication platform — | 58 |
| 4.2.2 | Architecture and technology of the basic communication platform — | 63 |
| 4.3 | Data-sharing platform — | 73 |
| 4.3.1 | The needs of the data-sharing platform — | 73 |
| 4.3.2 | The structure and technologies of the data-sharing platform — | 74 |
| 4.3.3 | Real-time data sharing with a kernel of advanced state estimation — | 79 |
| 4.4 | Summary — | 80 |

Chapter 5

Standard indexes for smart power system operation — 82

| | | |
|-------|--|----|
| 5.1 | Introduction — | 82 |
| 5.2 | Standard system of operational performance indicators — | 83 |
| 5.2.1 | A standard index system — | 83 |
| 5.2.2 | Components of the standard index system — | 84 |
| 5.2.3 | Workflow of indicator computations — | 88 |
| 5.3 | Safety indicators — | 90 |
| 5.3.1 | Minimum radius of the voltage safety domain and its calculation method — | 91 |

- 5.3.2 Minimum radius of the small-disturbance safety domain and its calculation method — 96
- 5.3.3 Minimum radius of the transient safety domain and its numerical approximation — 98
- 5.3.4 Numerical studies — 101
- 5.4 Coordinated control performance indicator of interconnected power system — 104
- 5.4.1 Interconnected power grid active control performance indicator — 104
- 5.4.2 Research on the reactive power control performance of an interconnected power grid — 107
- 5.5 Summary — 117

Chapter 6

Event analysis and processing technology — 118

- 6.1 Introduction — 118
- 6.2 Advanced State Estimation (ASE) algorithm — 119
 - 6.2.1 Measurement uncertainty — 120
 - 6.2.2 Main idea of ASE — 122
 - 6.2.3 Introduction of the ASE algorithm — 123
 - 6.2.4 Features of the ASE algorithm — 127
 - 6.2.5 Case study — 127
- 6.3 An OPF algorithm based on the constraint transformation technology — 130
 - 6.3.1 OPF model — 131
 - 6.3.2 Workflow of the OPF algorithm — 134
 - 6.3.3 Case studies — 136
- 6.4 Summary — 139

Chapter 7

Smart power system visualization — 140

- 7.1 Introduction — 140
- 7.2 Smart power system visualization content — 141
 - 7.2.1 Operation state visualization — 141
 - 7.2.2 From state visualization to monitoring and control visualization — 144
- 7.3 Automatic generation of topological graphics — 146
 - 7.3.1 Basic concepts — 146
 - 7.3.2 Automatic generation of single-line diagrams — 148
 - 7.3.3 Automatic generation of a main plant wiring diagram — 152
- 7.4 Fast graphic drawing algorithm — 155

- 7.4.1 Interpolation algorithm analysis — 156
- 7.4.2 Grid merging method — 157
- 7.4.3 Application examples — 159
- 7.5 Summary — 162

Chapter 8

SEMS — 163

- 8.1 Introduction — 163
- 8.2 Definition and characteristics of SEMS — 163
 - 8.2.1 Definition of SEMS — 163
 - 8.2.2 Characteristics of the SEMS — 164
 - 8.2.3 SEMS and EMS — 165
- 8.3 Components of SEMS — 165
 - 8.3.1 Event analysis system — 167
 - 8.3.2 Event processing system — 168
 - 8.3.3 Decision-making system for dispatchers — 170
- 8.4 The event analysis model in the SEMS — 172
 - 8.4.1 Evaluation of security and stability events — 172
 - 8.4.2 Evaluation of power quality events — 173
 - 8.4.3 Evaluation of economic operation events — 173
- 8.5 The event processing model in the SEMS — 173
 - 8.5.1 Security and stability event processing — 174
 - 8.5.2 Power quality event processing — 176
 - 8.5.3 Economic event processing — 176
- 8.6 Controllable resources of the SEMS — 178
 - 8.6.1 Classification by the information utilized in system control — 179
 - 8.6.2 Classification by the response time of system control — 179
 - 8.6.3 Classification by power system operation status — 180
- 8.7 The layered hierarchical structure of the SEMS — 180
- 8.8 Conclusions — 181

Chapter 9

Smart grid — 183

- 9.1 Background — 183
- 9.2 Definition of a smart grid — 183
- 9.3 Construction of a modernized distribution grid — 184
- 9.4 Demand-side management for peak load regulation — 185
- 9.5 Two-sided energy management systems for SGs — 186
 - 9.5.1 User-Smart Energy Management System (U-SEMS) — 187
 - 9.5.2 Distribution-Smart Energy Management System — 188
- 9.6 Implementation of new techniques for the development of SGs — 189

| | | |
|-------|---|-----|
| 9.6.1 | Utilization of renewable energy resources — | 190 |
| 9.6.2 | Storage technology — | 199 |
| 9.6.3 | Economic interactive energy-consuming techniques — | 208 |
| 9.6.4 | New operation and control methods for distribution networks — | 213 |
| 9.7 | Conclusions — | 217 |

| | |
|--------------|-----|
| References — | 219 |
|--------------|-----|

| | |
|---------|-----|
| Index — | 225 |
|---------|-----|