

Table of Contents

| | |
|---|----|
| Preface | xi |
| Chapter 1. Introduction to Systemic Design | 1 |
| Stéphan ASTIER, Alain BOUSCAYROL and Xavier ROBOAM | |
| 1.1. The system and the science of systems. | 2 |
| 1.1.1. First notions of systems and systems theory | 3 |
| 1.1.2. A brief history of systems theory and the science of systems | 6 |
| 1.1.3. The science of systems and artifacts. | 9 |
| 1.2. The model and the science of systems | 12 |
| 1.3. Energy systems: specific and shared properties | 15 |
| 1.3.1. Energy and its properties | 15 |
| 1.3.2. Entropy and quality of energy | 19 |
| 1.3.3. Consequences for energy systems | 24 |
| 1.4. Systemic design of energy systems | 26 |
| 1.4.1. The context of systemic design in technology | 26 |
| 1.4.2. The design process: toward an integrated design | 28 |
| 1.5. Conclusion: what are the objectives for an integrated design of energy conversion systems? | 32 |
| 1.6. Glossary of systemic design | 33 |
| 1.7. Bibliography | 36 |
| Chapter 2. The Bond Graph Formalism for an Energetic and Dynamic Approach of the Analysis and Synthesis of Multiphysical Systems | 39 |
| Xavier ROBOAM, Eric BIDEAUX, Genevieve DAUPHIN-TANGUY, Bruno SARENI and Stéphan ASTIER | |
| 2.1. Summary of basic principles and elements of the formalism. | 41 |
| 2.1.1. Basic elements | 41 |

| | |
|---|-----------|
| 2.1.2. The elementary phenomena | 42 |
| 2.1.3. The causality in bond graphs | 45 |
| 2.2. The bond graph: an “interdisciplinary formalism” | 46 |
| 2.2.1. “Electro-electrical” conversion | 47 |
| 2.2.2. Electromechanical conversion | 51 |
| 2.2.3. Electrochemical conversion | 52 |
| 2.2.4. Example of a causal multiphysical model: the EHA actuator | 55 |
| 2.3. The bond graph, tool of system analysis | 56 |
| 2.3.1. Analysis of models properties | 56 |
| 2.3.2. Linear time invariant models | 58 |
| 2.3.3. Simplification of models | 61 |
| 2.4. Design of systems by inversion of bond graph models | 69 |
| 2.4.1. Inverse problems associated with the design approach | 70 |
| 2.4.2. Inversion of systems modeled by bond graph | 72 |
| 2.4.3. Example of application to design problems | 78 |
| 2.5. Bibliography | 84 |
| Chapter 3. Graphic Formalisms for the Control of Multi-Physical Energetic Systems: COG and EMR | 89 |
| Alain BOUSCAYROL, Jean Paul HAUTIER and Betty LEMAIRE-SEMAIL | |
| 3.1. Introduction. | 89 |
| 3.2. Which approach should be used for the control of an energetic system? | 90 |
| 3.2.1. Control of an energetic system | 90 |
| 3.2.2. Different approaches to the control of a system | 91 |
| 3.2.3. Modeling and control of an energetic system | 92 |
| 3.2.4. Toward the use of graphic formalisms of representation. | 93 |
| 3.3. The causal ordering graph | 95 |
| 3.3.1. Description by COG | 95 |
| 3.3.2. Structure of control by inversion of the COG | 100 |
| 3.3.3. Elementary example: control of a DC drive | 105 |
| 3.4. Energetic Macroscopic Representation | 107 |
| 3.4.1. Description by EMR | 108 |
| 3.4.2. Structure of control by inversion of an EMR. | 111 |
| 3.4.3. Elementary example: control of an electrical vehicle. | 114 |
| 3.5. Complementarity of the approaches and extensions | 116 |
| 3.5.1. Differences and complementarities | 117 |
| 3.5.2. Example: control of a paper band winder/unwinder | 117 |
| 3.5.3. Other applications and extensions | 119 |
| 3.6. Bibliography | 120 |

| | |
|---|-----|
| Chapter 4. The Robustness: A New Approach for the Integration of Energetic Systems | 125 |
| Nicolas RETIÈRE, Delphine RIU, Mathieu SAUTREUIL and Olivier SENAME | |
| 4.1. Introduction. | 125 |
| 4.2. Control design of electrical systems | 126 |
| 4.2.1. The control design is an issue of integration | 126 |
| 4.2.2. The nominal control synthesis | 130 |
| 4.2.3. The analysis of robustness. | 135 |
| 4.3. Application to an on-board generation system | 141 |
| 4.3.1. Presentation of a nominal system | 141 |
| 4.3.2. Modeling and dynamical analysis of the nominal system | 141 |
| 4.3.3. Analysis of the robustness. | 147 |
| 4.4. Conclusion | 155 |
| 4.5. Bibliography | 155 |
| Chapter 5. Quality and Stability of Embedded Power DC Networks | 159 |
| Hubert PIQUET, Nicolas ROUX, Babak NAHID-MOBARAKEH, Serge PIERFEDERICI, Pierre MAGNE and Jérôme FAUCHER | |
| 5.1. Introduction. | 159 |
| 5.1.1. Challenges to quality optimization. | 160 |
| 5.1.2. The difficulty of stability | 161 |
| 5.2. Production of DC networks: the quality of the distributed energy. | 165 |
| 5.2.1. Combined and specialized electrical architectures | 165 |
| 5.2.2. AC/DC converters | 167 |
| 5.2.3. Studying AC/DC interactions. | 167 |
| 5.2.4. Simplified modeling of the HVDC network | 169 |
| 5.2.5. Methods of causal analysis of AC/DC interactions | 170 |
| 5.3. Characterization of the input impedances/admittances of equipment. | 172 |
| 5.3.1. Analytical characterization of the input impedance of systems in electrical engineering | 173 |
| 5.3.2. Experimental and simulation characterization | 187 |
| 5.4. Analysis of asymptotic stability via methods, based on impedance specifications | 190 |
| 5.4.1. Introduction | 190 |
| 5.4.2. Principles: the case of a two-body cascading system | 191 |
| 5.5. Analysis of asymptotic stability via the Routh–Hurwitz criterion. | 206 |
| 5.5.1. Overview of the Routh–Hurwitz criterion | 206 |
| 5.5.2. Example, design charts | 207 |
| 5.5.3. Analysis of network architectures with regard to their stability | 210 |

| | |
|--|------------|
| 5.6. Analysis tools for asymptotic global stability – dynamic behavior of an HVDC network subject to large-signal disturbances | 215 |
| 5.6.1. Introduction | 215 |
| 5.6.2. Analysis tools for large signal stability | 216 |
| 5.6.3. Conclusion | 219 |
| 5.7. Conclusion to the chapter | 219 |
| 5.8. Bibliography | 220 |
| Chapter 6. Energy Management in Hybrid Electrical Systems with Storage | 223 |
| Christophe TURPIN, Stéphane ASTIER, Xavier ROBOAM, Bruno SARENI and Hubert PIQUET | |
| 6.1. Introduction to energy hybridization via the example of hybrid automobiles | 224 |
| 6.1.1. General information on the architectures of hybrid automobiles | 224 |
| 6.1.2. Parallel architecture: summation of the mechanical powers | 225 |
| 6.1.3. Series architecture: summation of the electric powers | 226 |
| 6.1.4. Series–parallel architecture | 228 |
| 6.2. Energy management in electric junction hybrid systems with electric energy storage | 229 |
| 6.2.1. Storage, essential properties, power invertibility, losses | 229 |
| 6.2.2. Electric junction hybrid systems, electric node | 233 |
| 6.2.3. Generic hybrid system with an electric node containing storage, energy flow management | 234 |
| 6.2.4. Strategy for frequency splitting of power via active filtering | 236 |
| 6.2.5. Electric node and energy degrees of freedom | 239 |
| 6.2.6. Overview of energy management in electric-junction multisource hybrid systems with storage: energy management strategy | 242 |
| 6.3. Indicators, criteria and data for the design of hybrid systems | 245 |
| 6.3.1. Properties of storage units for hybridization | 245 |
| 6.3.2. Mission properties, energy indicators | 247 |
| 6.4. Examples in various application areas | 250 |
| 6.4.1. Example 1. Simple hybridization: emergency generator for an aircraft based on a wind turbine hybridized by supercapacitors | 250 |
| 6.4.2. Example 2. Simple hybridization: emergency generator for an aircraft based on a fuel cell hybridized with supercapacitors | 256 |
| 6.4.3. Example 3. Double hybridization: power train of a locomotive based on a combustion engine hybridized by batteries and supercapacitors | 266 |

| | |
|--|-----|
| 6.4.4. Example 4. Double hybridization: smoothing of photovoltaic generation via an electrolyzer–fuel cell tandem (H ₂ /O ₂ battery) and a lead acid battery | 275 |
| 6.5. Conclusion for energy management in hybrid systems | 281 |
| 6.6. Bibliography | 283 |
| Chapter 7. Stochastic Approach Applied to the Sizing of Energy Chains and Power Systems. | 287 |
| Patrick GUÉRIN, Geoffroy ROBLOT and Laurence MIÉGEVILLE | |
| 7.1. Introduction. | 287 |
| 7.2. Standard principle of the power report | 289 |
| 7.2.1. Maximum current | 290 |
| 7.2.2. Load factor Ku | 290 |
| 7.2.3. Diversity factor Ks | 291 |
| 7.2.4. Enhancement factor Ka | 292 |
| 7.2.5. Application | 292 |
| 7.3. Stochastic approach | 294 |
| 7.3.1. Observation | 294 |
| 7.3.2. Principle of the stochastic approach | 295 |
| 7.4. Modeling of the loads | 297 |
| 7.4.1. Different types of loads | 298 |
| 7.4.2. Modeling using a specification | 299 |
| 7.4.3. Modeling using experimental readings | 301 |
| 7.5. Simulation of the power flows. | 302 |
| 7.5.1. Analytical method | 302 |
| 7.5.2. Monte Carlo method | 304 |
| 7.5.3. Application to an “on-board” power system | 306 |
| 7.6. Probabilistic and dynamic approach | 312 |
| 7.6.1. Modeling of the loads or associated electrical quantities. | 312 |
| 7.6.2. Simulation of the power flows | 316 |
| 7.6.3. Application to the embedded network. | 317 |
| 7.7. Conclusion | 319 |
| 7.8. Bibliography | 321 |
| Chapter 8. Probabilistic Approach for Reliability of Power Systems | 325 |
| Yvon BÉSANGER and Jean-Pierre ROGNON | |
| 8.1. Contextual elements. | 325 |
| 8.2. Basic concepts of the Monte Carlo simulation | 331 |
| 8.2.1. Monte Carlo method | 331 |
| 8.2.2. Simulation | 331 |
| 8.2.3. Basic statistical concepts and definitions | 331 |
| 8.2.4. Monte Carlo simulation | 333 |

| | |
|--|------------|
| 8.3. Variance reduction | 340 |
| 8.3.1. Justification and principles | 340 |
| 8.3.2. Comparative study of the variance reduction methods | 342 |
| 8.4. Illustrative example | 363 |
| 8.5. Conclusion | 367 |
| 8.6. Bibliography | 368 |
| List of Authors | 371 |
| Index | 373 |