



# **Electric Energy Systems**

## **Analysis and Operation**

Edited by

**Antonio Gómez-Expósito**

**Antonio J. Conejo**

**Claudio Cañizares**



# Electric Energy Systems

Analysis and Operation



---

# Contents

|   |      |
|---|------|
| Foreword .....  | ix   |
| Editors .....   | xiii |
| Contributors .....  | xv   |
| <br>  |      |
| <b>Chapter 1</b> Electric Energy Systems—An Overview .....                                | 1    |
| <i>Ignacio J. Pérez-Arriaga, Hugh Rudnick, and Michel Rivier Abbad</i>                    |      |
| <br>  |      |
| <b>Chapter 2</b> Steady-State Single-Phase Models of Power System Components .....        | 51   |
| <i>Edmund Handschin, Antonio F. Otero, and José Cidrás</i>                                |      |
| <br>  |      |
| <b>Chapter 3</b> Load Flow .....  | 95   |
| <i>Antonio Gómez-Expósito and Fernando L. Alvarado</i>                                    |      |
| <br>  |      |
| <b>Chapter 4</b> State Estimation .....   | 127  |
| <i>Antonio Gómez-Expósito and Ali Abur</i>  |      |
| <br>  |      |
| <b>Chapter 5</b> Economics of Electricity Generation .....                                | 165  |
| <i>Francisco D. Galiana and Antonio J. Conejo</i>   |      |
| <br>  |      |
| <b>Chapter 6</b> Optimal and Secure Operation of Transmission Systems .....               | 211  |
| <i>José Luis Martínez Ramos and Víctor Hugo Quintana</i>                                  |      |
| <br>  |      |
| <b>Chapter 7</b> Three-Phase Linear and Nonlinear Models of Power System Components ..... | 265  |
| <i>Enrique Acha and Julio Usaola</i>  |      |
| <br>  |      |
| <b>Chapter 8</b> Fault Analysis and Protection Systems .....                              | 303  |
| <i>José Cidrás, José F. Miñambres, and Fernando L. Alvarado</i>                           |      |
| <br>  |      |
| <b>Chapter 9</b> Frequency and Voltage Control .....                                      | 355  |
| <i>Göran Andersson, Carlos Álvarez Bel, and Claudio Cañizares</i>                         |      |
| <br>  |      |
| <b>Chapter 10</b> Angle, Voltage, and Frequency Stability .....                           | 401  |
| <i>Claudio Cañizares, Luis Rouco, and Göran Andersson</i>                                 |      |

|                   |  |     |
|-------------------|--|-----|
| <b>Chapter 11</b> | Three-Phase Power Flow and Harmonic Analysis .....     | 461 |
|                   | <i>Wilsun Xu and Julio García-Mayordomo</i>            |     |
| <b>Chapter 12</b> | Electromagnetic Transients Analysis .....              | 509 |
|                   | <i>Juan A. Martínez-Velasco and José R. Martí</i>      |     |
| <b>Appendix A</b> | Solution of Linear Equation Systems .....              | 583 |
|                   | <i>Fernando L. Alvarado and Antonio Gómez-Expósito</i> |     |
| <b>Appendix B</b> | Mathematical Programming .....                         | 601 |
|                   | <i>Antonio J. Conejo</i>                               |     |
| <b>Appendix C</b> | Dynamic Models of Electric Machines .....              | 627 |
|                   | <i>Luis Rouco</i>                                      |     |
| Index             | .....  | 643 |



As demonstrated by recent major blackouts, power grids and their associated markets play a vital role in the operation of our society. Understanding how electric generation, transmission, and delivery systems interact and operate is paramount to guaranteeing reliable sources of electricity.

**Electric Energy Systems** offers highly comprehensive and detailed coverage of power systems operations, uniquely integrating technical and economic analyses. The book fully develops classical subjects such as load flow, short-circuit analysis, and economic dispatch within the context of the new deregulated, competitive electricity markets. With contributions from 24 internationally recognized specialists in power engineering, the text also presents a wide range of advanced topics, including harmonic load flow, state estimation, and voltage and frequency control as well as electromagnetic transients, fault analysis, and angle stability.

A much-needed and updated extension on classical power systems analysis books, **Electric Energy Systems** provides an in-depth analysis of the most relevant issues affecting the bloodline of our society, the generation and transmission systems for electric energy.

Cover image: 34-MW Wind Farm at Arlanzón (Burgos province, in Spain). Courtesy of Neo Energía.



**CRC Press**

Taylor & Francis Group  
an **informa** business

[www.crcpress.com](http://www.crcpress.com)

6000 Broken Sound Parkway, NW  
Suite 300, Boca Raton, FL 33487

270 Madison Avenue  
New York, NY 10016

2 Park Square, Milton Park  
Abingdon, Oxon OX14 4RN, UK

7365

ISBN: 978-0-8493-7365-7

90000



9 780849 373657