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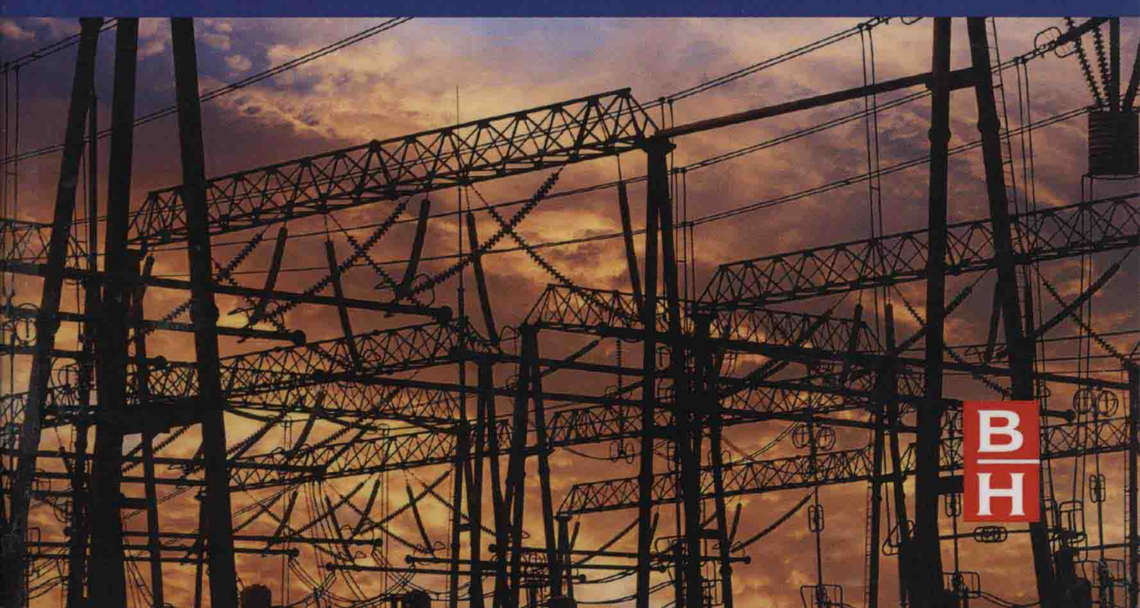

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Université de Technologie de Compiègne, France

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BIOGRAPHY OF MANUELA SECHILARIU

Manuela Sechilariu received the Dipl.Ing. degree in electrical engineering in 1986 from the Institute Polytechnic Iasi, Romania, and the PhD degree in electrical engineering and automatic in 1993 from the Université d'Angers, France. In 2013 she obtained the HDR degree in electrical engineering from the Université de Technologie de Compiègne, France, the highest French academic title, and then the qualification required for full professor. The obtaining of HDR, accreditation to supervise research, confers official recognition of the high scientific level and capability to optimally manage a research strategy in a sufficiently wide scientific field (smart grid and microgrids). In 1989 she became an assistant professor with the Institute Polytechnic Iasi, Romania, and in 1994 she became an associate professor with the Université d'Angers, France. In 2002 she joined the Université de Technologie de Compiègne, France.

Manuela Sechilariu has more than 20 years of research experience. Her first research topic focused on the modeling and simulation of static converters by Petri Net, which quickly led to the study of hybrid dynamic systems. Contributions were made to the definition, classification, and optimal control of these systems. Since 2006 she has directed research in the study of decentralized renewable electricity production, urban microgrids, and energy management systems. She has delivered several invited lectures and has published more than 60 refereed scientific and technical papers in international journals and conferences, with more than 350 citations (SCOPUS), on topics such as renewable energy systems, including microgrids, photovoltaic-powered systems, economic dispatch optimization, supervisory control, and Petri Net and Stateflow modeling.

Her research has been funded by agencies and sponsors including the CNRS (National Center for Scientific Research), ADEME (The French Environment and Energy Management Agency), FEDER (European Fund for Regional Economic Development), and CRP (Picardie Regional Council). She has managed several national research projects and industrial research contracts.

She is a member of several professional bodies and academic boards, including the IEEE (Institute of Electrical and Electronics Engineers), the

French Research Group GDR SEEDS (Electric Power Systems in their Corporate Social Dimension), and the 63rd section of the French National Council of Universities. Manuela Sechilariu has reviewed projects of various scientific national research organizations (French and Czech) and articles for many international journals (active reviewer for several IEEE Transactions and Elsevier journals) and conferences. She has directed and co-supervised many dozens of MsEng. and PhD theses and dissertations. She has participated in many academic councils and committees either as a member or as a deputy member of the selection committee for candidates for associate professor position. For the last 10 academic years she has served as director of the Dipl.Ing. degree major "Systems and Networks for Built Environment" and then as a member of the PhD School Board.

Manuela Sechilariu's broad research interests focus on power and energy systems, the smart grid, microgrids, distributed generation, photovoltaic-powered systems, energy management, optimization, intelligent control, and Petri Net modeling.

Affiliations and Expertise

Professor and researcher on modeling, simulation, and power management applied to renewable energy in microgrids with AVENUES Laboratory, Université de Technologie de Compiègne, France.

BIOGRAPHY OF FABRICE LOCMENT

Fabrice Locment received the Dipl.Ing. degree in electrical engineering from Polytech Lille, Ecole Polytechnique Universitaire de Lille, France, in 2003, and MS and PhD degrees in electrical engineering from the Université des Sciences et Technologies de Lille, France, in 2003 and 2006, respectively. Since 2008 he has been an associate professor with the Université de Technologie de Compiègne, France. In December 2015 he obtained the HDR degree in electrical engineering from the Université de Technologie de Compiègne, France, the highest French academic title. The obtaining of HDR, accreditation to supervise research, confers official recognition of the high scientific level and capability to optimally manage a research strategy in a sufficiently wide scientific field.

His current research interests include designing, modeling, and control of electrical systems, particularly photovoltaic and wind turbine systems. He published more than 50 refereed scientific and technical papers in international journals and conferences, with over 450 citations (SCOPUS) on topics such as renewable energy systems, including microgrids, photovoltaic and wind powered systems, maximum power point tracking, and energetic macroscopic representation modeling.

Fabrice Locment was involved in several national research projects funded by agencies and sponsors including the CNRS (National Center for Scientific Research), ADEME (The French Environment and Energy Management Agency), FEDER (European Fund for Regional Economic Development), and CRP (Picardie Regional Council).

Fabrice Locment has reviewed projects of various scientific French national research organizations and articles for many international journals and conferences. He has directed and co-supervised many dozens of MsEng and PhD theses and dissertations. He has participated in many academic councils and department committees. During recent academic years he served as director of the Dipl.Ing. degree major "Integrated Technical Systems."

Affiliations and Expertise

Professor and researcher on designing, modeling, and control of electrical systems with AVENUES Laboratory, Université de Technologie de Compiègne, France.

FOREWORD

At a period when mankind is implementing an energy transition, Manuela Sechilariu and Fabrice Locment's book very aptly provides us with useful insights into electrical smart microgrids (for buildings, villages, districts, or cities) and into the exploitation of renewable resources on such a geographic scale.

Only renewable energy resources will be up to the task of reconciling the needs of a world population of 10 billion with the constraints of sustainable development. In such a context, electricity is to play a major role as is already demonstrated by its growing share in the global energy mix. Because it is now easily and economically converted from renewable resources, electric power is an undeniable vector of progress, but it is essential to continue improving the efficiency of its distribution and its uses. In this respect this book contributes to offering, with great scientific rigor, solutions to this wide-ranging issue.

In 2014 approximately 22% of global electricity was from renewable sources, and its share has been progressing at an average annual growth rate of almost 6% over the past decade. That same year the share of nonrenewable sources was in decline because it had dropped to a growth rate of 2.8% per year over the same period. Photovoltaic and wind sources have the greatest potential and play a major part in the growth of renewable electricity. To optimize performance these conversion chains now systematically use electronic power converters and, naturally, deliver direct current (DC). For the same reasons electricity storage systems are also well suited to DC. Likewise, all of the modern uses of electricity are much better suited to DC use. Under these conditions the use of alternating current (AC; 50 or 60 Hz), which is still widely dominant, contributes to the complexity of power architectures. AC also leads to an increase of losses in unnecessary conversion stages and to a waste of raw materials and embodied energy.

All of us have heard of the wars of the currents that happened in the late 19th century, particularly in Europe and America. Most famous among the advocates of DC were Marcel Deprez in Europe and Thomas Edison in America, whereas among the defenders of AC there were engineers from Siemens and Nikola Tesla (Westinghouse). AC finally took over because there were, at the time, very good technological reasons to justify its supremacy. However, since the late 20th century a revolutionary technology has gradually come to the forefront—power electronics (solid-state conversion with power semiconductors). This technology is now almost everywhere and will now allow DC to regain ground over AC power. Of course the inertia of standards is a major obstacle, and it may be long before DC surpasses AC, but I am sure this will eventually happen!

DC power distribution, especially in buildings and urban areas, is to play a key role in an efficient use of renewable resources as well as in the securing of greater resilience from electrical systems. DC will produce better performing smart grids, which will be more reliable and more efficient all along their life cycle while saving energy resources and raw materials.

This book, which is based on scientific and technological research performed by the team of Manuela Sechilariu and Fabrice Locment, presents a very relevant synthesis of DC electrical architectures and power management methods. Technological aspects are thoroughly examined and give greater credibility to the book. The authors provide numerous energy models as well as management strategies and control laws at the different stages of power conversion. They focus on the conversion of solar renewable resources (photovoltaic conversion); energy storage systems; backup generators; and, of course, smart microgrids, which combine all of these aspects. Moreover, the numerous experimental results and associated simulations strongly contribute to the high quality of this book.

I hope this book will have many readers who, whether they are scientists or students, will no doubt appreciate the excellent quality of the work performed by the authors. Finally, I hope that this book will contribute to accelerating the sustainable energy transition that mankind so urgently needs.

Rennes, December 7, 2015
Bernard Multon
Professor at Ecole Normale Supérieure de Rennes
SATIE CNRS Laboratory

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We are heartily thankful to Professor Bernard Multon, French forward-thinking leader in renewable energy, whose leading-edge research in electrical engineering is making huge contributions to renewable energies field development. We are very grateful for his permanent encouragement and especially for his eloquent foreword, which introduces this book and highlights our expertise field, despite his very busy schedule. Thank you, Professor Multon, for inspiring all of us.

We would like to express our gratitude to several PhD students at Avenues Laboratory, Microgrid Research Team, for their scientific and technical contributions as well as some experimental results. Many of our scientific and technical papers in international journals and at conferences on the field of microgrids were coauthored with these PhD students whose theses were supervised by us.

We would like to thank and acknowledge the valuable support of CNRS (National Center for Scientific Research), ADEME (The French Environment and Energy Management Agency), FEDER (European Fund for Regional Economic Development), and CRP (Picardie Regional Council) that funded some of the research included in this book.

Our thanks are extended to the Université de Technologie de Compiègne for creating and maintaining an excellent academic environment that promotes innovation and technology; this had a positive impact on this research. Thanks also to our colleagues of the Urban Systems Engineering Department, Avenues Laboratory, and the LEC laboratory for a friendly and interesting working environment. We would like to extend special acknowledgement to our academic staff.

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Lastly, we are thankful to all of those who provided support, read, wrote, and offered comments and review on this research work; we offer our regards to all of those who played a part and who supported them in any respect during the completion of this book project.

ABBREVIATIONS

AC	Alternating current
ACR	Automatic current regulator
AGM	Absorbent glass mat
AVR	Automatic voltage regulator
CEC	Californian Energy Commission
DC	Direct current
EDF	Electricité de France
FL	Fuzzy logic
HMI	Human-machine interface
HVDC	High-voltage direct current
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated gate bipolar transistor
ImP&O	Improved perturb and observe
InC	Incremental conductance
IoT	Internet of Things
IP	Integral proportional
LED	Light-emitting diodes
Li-ion	Lithium ion
LUT	Look-up table
M2M	Machine to Machine
MPP	Maximum power point
MPPT	Maximum power point tracking
NiCd	Nickel cadmium
NiMH	Nickel metal hydride
NOCT	Nominal operating cell temperature
P&O	Perturb and observe
PCC	Point of common coupling
PEL	Programmable electronic load
PI	Proportional integral
PLL	Phase-locked loop
PN	Petri Net
PV	Photovoltaic
PVA	Photovoltaic array
PWM	Pulse width modulation
SD	Science Direct
STC	Standard test condition
V2G	Vehicle-to-Grid
V2L	Vehicle-to-Load

GENERAL INTRODUCTION

1. CONTEXT AND MOTIVATION

Currently, the global environmental issue, in part because of the use of fossil/fissile fuels for electricity production, is a key concern in the various strata of society in many countries. To avoid an ecological crisis that will no doubt be more severe than the economic one, reduction of the environmental footprint, greenhouse gas emissions, and consumption of fossil/fissile fuels in favor of alternative energy is a mandatory crossing point. This is the global energy transition that means the passage of the current energy system using nonrenewable resources to an energy mix based mainly on renewable resources. This means developing alternatives to fossil and fissile fuels, which are finite and nonrenewable resources at the human scale. The energy transition provides for their gradual replacement by renewable energy sources for almost all human activities (transport, industry, lighting, heating, etc.).

The international community is becoming aware of the major environmental problems caused by human activity. The World Energy Council is an international organization supporting accessible and sustainable energy development across the planet. It highlights that to provide sustainable energy policies it is important to take into account the three following dimensions:

- *Energy security*: The effective management of the primary energy supply from domestic and external sources, the reliability of the energy infrastructure, and the ability of energy providers to meet current and future demand.
- *Energy equity*: Accessibility and affordability of the energy supply across the population.
- *Environmental sustainability*: The achievement of supply- and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.

Thus the energy transition also induces a behavioral and sociotechnical transition, involving a radical change in energy policy as moving from demand-oriented policy to a policy determined by supply along the possibilities of distributed production. This is also to avoid overproduction and unnecessary consumption to save more energy and benefit from better energy efficiency.

The public power grid that operates today is confronting the demands to improve reliability, reduce costs, increase efficiency, comply with policies and regulations concerning the environment, integrate renewable energy sources and electric vehicles to the power grid, etc. The promising smart grid can meet these priorities. This network is designed primarily for information exchange concerning the requirements and availability of the power grid and for help balancing power by avoiding an undesirable injection and performing smoothing of loads during peak hours. The smart grid is defined as the power grid that uses innovative monitoring, controls the transmission of information, and uses self-healing technologies to provide better services to electricity producers and distributors, flexible choice for end users, good reliability, and security of supply. This very complex smart grid, with bidirectional power flow and communication, requires much work to implement it in reality.

On the other hand, the electricity production seeks to produce more and more energy from renewable sources (wind, solar, biomass, and geothermal sources), but integrating power from renewable resources into the utility power grid (ie, public grid) can be a huge challenge. The intermittent and random production of renewable sources is always a problem for their large-scale integration into the power grid. There is not yet a worldwide standard for smart grid topology, but regarding better integration of renewable sources of low and middle power, microgrids seem to have an important place. A microgrid consists of renewable and traditional sources, energy storage systems, and controllable loads that can be adjusted. A microgrid allows the connection with the public grid and ensures ancillary services (control of the voltage and frequency fluctuations), energy flow, load sharing, and load shedding during islanding, and it takes into account the constraints of the public grid transmitted by the smart grid through the smart grid communication bus. Thus around the world researchers and engineers are deploying increasing efforts to design and implement intelligent microgrids to achieve the energy goals of the 21st century, such as improved reliability based on diversification of sources of electricity production. Nevertheless, ensuring reliable distribution of electricity based on a microgrid and realizing its integration into the centralized larger production of the power grid are not easy to achieve.

Regarding environmental sustainability, one of the most energy-intensive sectors is the construction sector, representing in the near future almost a half of total energy consumption and a quarter of greenhouse gas