ELECTRICAL ENERGY EFFICIENCY

ELECTRICAL ENERGY EFFICIENCY

TECHNOLOGIES AND APPLICATIONS

Andreas Sumper
BarcelonaTech (UPC), Institute for Energy Research (IREC), Spain

Angelo Baggini
University of Bergamo, Italy

WILEY
A John Wiley & Sons, Ltd., Publication

This edition first published 2012

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

Library of Congress Cataloging-in-Publication Data

Electrical energy efficiency : technologies and applications / Andreas Sumper and Angelo Baggini.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-97551-0 (hardback)
1. Electric power–Conservation–Standards. 2. Energy conservation–Standards. 3. Energy dissipation.
4. Electric power transmission–Reliability. I. Baggini, Angelo B. II. Sumper, Andreas.
TJ163.3.E39 2012
621.31–dc23

2012000609

A catalogue record for this book is available from the British Library.

Print ISBN: 9780470975510

Typeset in 10/12pt Times by Aptara Inc., New Delhi, India

Contents

List of Contributors

Angelo Baggini
Industrial Engineering Department
University of Bergamo
Via Marconi 5 24044 Dalmine BG, Italy

Joan Bergas-Jané
Centre d'Innovació Tecnològica en
Convertidors Estàtics i Accionaments
(CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escuela Técnica Superior de Ingeniería
Industrial de Barcelona
Av. Diagonal, 647. Planta 2 08028
Barcelona, Spain

Franco Bua
ECD Engineering Consulting and Design
Vai Maffi 21
27100 Pavia, Italy

Mircea Chindris
Electrical Power Systems Dept.
Technical University of Cluj-Napoca
15, C.Daicoviciu st.
400020 Cluj-Napoca, Romania

Andrei Czicker
Electrical Power Systems Dept.
Technical University of Cluj-Napoca
15, C.Daicoviciu st.
400020 Cluj-Napoca, Romania

Wim Deprez
Dept. Electrical Engineering ESAT
K.U. Leuven, Research group ELECTA
Kasteelpark Arenberg 10
3001 Heverlee, Belgium

Stefan Fassbinder
Berantung elektrotechnische Anwendungen
Deutsches Kupferinstitut
Am Bonneshof 5
D-40474 Dusseldorf, Germany

Zbigniew Hanzelka
University of Science and Technology –
AGH
30-059 Cracow, Al. Mickiewicza 30
Poland

Joris Lemmens
Dept. Electrical Engineering ESAT
K.U. Leuven, Research group ELECTA
Kasteelpark Arenberg 10
3001 Heverlee, Belgium

Annalisa Marra
ECD Engineering Consulting and Design
Vai Maffi 21
27100 Pavia, Italy

Daniel Montesinos-Miracle
Centre d'Innovació Tecnològica en
Convertidors Estàtics i Accionaments
(CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escuela Técnica Superior de Ingeniería
Industrial de Barcelona

Av. Diagonal, 647. Planta 2 08028
Barcelona, Spain

Paola Pezzini
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escuela Técnica Superior de Ingeniería Industrial de Barcelona
Av. Diagonal, 647. Planta 2 08028
Barcelona, Spain

Krzysztof Piątek
University of Science and Technology – AGH
30-059 Cracow, Al. Mickiewicza 30,
Poland

Edris Pouresmaeil
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escuela Técnica Superior de Ingeniería Industrial de Barcelona
Av. Diagonal, 647. Planta 2 08028
Barcelona, Spain

Jaume Salom
Institut de Recerca en Energia de Catalunya (IREC)
Jardins de les Dones de Negre 1, 2^{a} pl.
08930 Sant Adrià de Besòs, Spain

Antoni Sudrià-Andreu
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escuela Técnica Superior de Ingeniería Industrial de Barcelona
Av. Diagonal, 647. Planta 2 08028
Barcelona, Spain

Andreas Sumper
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escola Universitària d'Enginyeria Tècnica Industrial de Barcelona
Carrer Comte d'Urgell, 187 - 08036
Barcelona, Spain

and

Institut de Recerca en Energia de Catalunya (IREC)
Jardins de les Dones de Negre 1, 2^{a} pl.
08930 Sant Adrià de Besòs, Spain

Waldemar Szpyra
University of Science and Technology – AGH
30-059 Cracow, Al. Mickiewicza 30,
Poland

Roman Targosz
Polish Copper Promotional Centre
Plac Jana Pawla II 1-2
50-136 Wrocalw, Poland

Roberto Villafáfila-Robles
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA)
Universitat Politècnica de Catalunya (UPC)
Escola Universitària d'Enginyeria Tècnica Industrial de Barcelona
Carrer Comte d'Urgell, 187 - 08036
Barcelona, Spain

Irena Wasiak
Politechnika Łódzka
Wydział Elektrotechniki, Elektroniki, Automatyki i Informatyki
Instytut Elektroenergetyki
ul. Stefanowskiego 18/22
90-924 Łódź, Poland

Preface

Energy efficiency technologies are common technologies from different engineering fields used to reduce the energy required to provide products and services. As electricity is the most flexible energy form known to humans and one of the most important energy forms used in industry and commercial applications, a specific focus on electrical energy efficiency is required. So, electrical energy efficiency is a set of engineering technologies that are dedicated to increasing the electrical energy efficiency of applications. These engineering technologies are very widespread and can vary from power quality engineering to the thermal engineering of electrical applications, including economic aspects.

Together with electrical safety, in the coming years electrical energy efficiency should become one of the mandatory design criteria in every process, installation or building.

The difficulty of electrical energy efficiency engineering is to obtain a holistic view of an application; in most cases a specific knowledge of the technology is needed, but a deep understanding of the industrial process and the problem to be solved is necessary in order to achieve the overall efficiency goal. Often, optimal solutions for partial problems provide a moderate contribution to the overall energy efficiency of the process. Engineers should have multidisciplinary knowledge, for instance knowledge about electrical applications, power quality, control techniques and heat transfer. Also, an important aspect to consider is the ability to analyse the industrial process and to determine what efficiency actions need to be taken.

The increase in electrical energy efficiency is closely related to the evaluation of the efficiency measures to be taken, mainly by investment analysis. Efficient solutions often need higher investments and these usually need management approval. The manager also has to understand how energy efficient solutions can improve the process efficiency and therefore a higher productivity can be achieved.

In 2000 a group of academics and industrialists launched a life-long learning programme co-funded by the European Commission dedicated to Power Quality problems called Leonardo Power Quality Initiative (LPQI). This project created a network of experts in energy that created several follow-on projects such as LPQIves and Leonardo Energy. Most of the information on these programmes is available at the Leonardo Energy webpage (http://www.leonardo-energy.org). Inspired by this project, part of this working group contributed to the *Handbook of Power Quality*, edited by Angelo Baggini in 2008.

In one of the project meetings in Brussels in 2008 the idea of a comprehensive book on electrical energy efficiency was born and the content of the book was worked out during the following years.

The novel approach in this book is to give the reader a straightforward introduction to the technologies and their applications used to increase electrical energy efficiency. The reader will find efficiency aspects emphasized in this comprehensive book and an expert view given on the most important industrial and commercial fields of electrical engineering. Each chapter covers a different technology in order to achieve an efficiency goal in a wide range of application fields.

Before you begin to study this book, we would like to mention the important contributions of all the authors of the chapters from all around the world. Without their expert views, this work would not be possible. We hope that you find this book interesting reading.

Andreas Sumper, Barcelona, Spain
Angelo Baggini, Pavia, Italy

Foreword

There are no doubts that energy security and climate change are two of the most frequent topics discussed by policy makers. The oil price is now at around US$100 per barrel and, because of the increasing demand and the continuing depletion of the reserves, this price level will stay or may even increase. The human impact on climate change is not disputed anymore in the scientific community, as well as the worrying news that the irreversible impact has already started and only a drastic change in the level of CO_2 emissions will mitigate the large and very costly impact on the society.

Energy efficiency and energy conservation are gaining importance as key components in many national and international strategies to mitigate the impact of climate change, to improve security of energy supply and increase competitiveness, to preserve natural resources (energy, material and water, amongst others) and also to reduce other energy-related environmental pollution. However, investment in energy efficiency technologies from R&D to implementation, in buildings, equipment and industrial systems, is still far too less than the economics and the energy and climate change situation would suggest.

Energy efficiency policies, programmes and support schemes are still very much needed to overcome market, institutional, financial and legal barriers, and to create a favourable market for energy efficiency investments at the level that a rational economic behaviour would justify. In particular, support schemes for energy efficient technologies are very much debated as many consider that the future energy cost savings should be enough to motivate end users.

The other major issue is the awareness that what matters in climate change is to reduce the absolute energy demand if we want to mitigate the inevitable full climate change impact. Reduction in energy demand can be achieved by improving the energy efficiency of the service provided (technological aspect) and/or by realising energy savings without necessarily making technological improvements (behavioural aspect, for instance less overheating or overcooling, less driving). Energy efficiency is an important component to achieve energy savings, as it allows having the same services (e.g. lighting, cooling, heating) with less use of energy. However, improved energy efficiency – i.e. replacing a technology with a more energy efficient one – does not per se assure energy savings, and there are numerous examples where as a result of introducing a more efficient technology the actual consumption indeed increases, because of the rebound effect or because of installing larger and more numerous appliances and equipment (larger volume of appliances, more frequent usage).

There is an increased interest in energy efficiency and energy savings amongst policy makers, economists and academics (from the technology, economy, policy and human behaviour side). There is the need to further explore energy efficiency technologies (such as control systems,

solid state lighting, variable speed drives and vacuum insulation) and gather new evidence on policies and socio-economic issues related to energy use, consumption and behaviour. At the same time, with increased policy activities in the energy efficiency and energy saving field, there is a new need to evaluate the past and present policies in different countries, to show the clear contribution of energy efficiency to energy security and climate change mitigation.

Paolo Bertoldi
European Commission
Joint Research Centre
Ispra Italy