ADVANCED DC/DC CONVERTERS

Fang Lin Luo
Hong Ye

CRC PRESS

Boca Raton London New York Washington, D.C.

POWER ELECTRONICS AND APPLICATIONS SERIES

Muhammad H. Rashid, Series Editor
University of West Florida

PUBLISHED TITLES

Complex Behavior of Switching Power Converters
Chi Kong Tse

DSP-Based Electromechanical Motion Control
Hamid A. Toliyat and Steven Campbell

Advanced DC/DC Converters
Fang Lin Luo and Hong Ye

FORTHCOMING TITLES

Renewable Energy Systems: Design and Analysis with Induction Generators
Marcelo Godoy Simoes and Felix Alberto Farret

ADVANCED DC/DC CONVERTERS

Fang Lin Luo
Hong Ye

CRC PRESS

Boca Raton London New York Washington, D.C.

Library of Congress Cataloging-in-Publication Data

Luo, Fang Lin.
Advanced DC/DC converters / Fang Lin Luo and Hong Ye.
p. cm. — (Power electronics and applications series)
Includes bibliographical references and index.
ISBN 0-8493-1956-0 (alk. paper)
1. DC-to-DC converters. I. Ye, Hong, 1973- II. Title. III. Series.

TK7887.6.L86 2003
621.31′32—dc21 2003051622

Visit the CRC Press Web site at www.crcpress.com

International Standard Book Number 0-8493-1956-0
Library of Congress Card Number 2003051622
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

Dedicated to
Our respected great lady Mme. Liao Jing
Ms. Luo Yuan Zhi and her family

Preface

The purpose of this book is to provide up-to-date information on advanced DC/DC converters that is both concise and useful for engineering students and practicing professionals. It is well organized in 748 pages with 320 diagrams to introduce more than 100 topologies of the advanced DC/DC converters originally developed by the authors. EMI/EMC reduction and various DC voltage sources are also illustrated in this book. All prototypes represent novel approaches and great contributions to modern power engineering.

Power engineering is the method used to supply electrical energy from a source to its users. It is of vital importance to industry. It is likely that the air we breathe and water we drink are taken for granted until they are not there. Energy conversion technique is the main focus of power engineering. The corresponding equipment can be divided into four groups:

- AC/AC transformers
- AC/DC rectifiers
- DC/DC converters
- DC/AC inverters

From recent reports, the production of DC/DC converters occupies the largest percentage of the total turnover of all conversion equipment production. DC/DC conversion technology is progressing rapidly. According to incomplete statistics, there are more than 500 topologies of DC/DC converters existing, with new topologies created every year. It is a lofty undertaking to treat the large number of DC/DC converters. The authors have sorted these converters into six generations since 2001. This systematical work is very helpful for DC/DC converter's evolution and development. The converters are listed below:

1. First generation (classical/traditional) converters
2. Second generation (multiple-quadrant) converters
3. Third generation (switched component) converters
4. Fourth generation (soft-switching) converters
5. Fifth generation (synchronous rectifier) converters
6. Sixth generation (multiple-element resonant power) converters

A review of the DC/DC conversion technique development reveals that the idea was induced from other equipment. Transformers successfully convert an AC source voltage to other AC output voltage(s) with very high efficiency. Rectifier devices such as diode, transistor, and thysistor effectively rectify an AC source voltage to DC output voltage. Nearly eight decades ago, people sought to invent equipment to convert a DC source voltage to another DC output voltage(s) with high efficiency. Unfortunately, no such simple apparatus such as a transformer and/or rectifier was found for DC/DC conversion purpose.

High frequency switch-on and -off semiconductor devices paved the way for chopper circuits. This invention inspired the idea for DC/DC conversion. Therefore, the fundamental DC/DC converters were derived from the corresponding choppers. At present, the fundamental converters — Buck converter, Boost converter, and Buck-Boost converter — are still the basic circuits for DC/DC conversion technique in research and development.

The voltage-lift technique is a popular method that is widely applied in electronic circuit design. Applying this technique effectively overcomes the effects of parasitic elements and greatly increases the output voltage. Therefore, these DC/DC converters can convert the source voltage into a higher output voltage with high power efficiency, high power density, and simple structure. It is applied in the periodical switching circuit. Usually, a capacitor is charged during switch-on by a certain voltage. This charged capacitor voltage can be arranged on top-up to output voltage during switch-off. Therefore, the output voltage can be lifted. A typical example is the sawtooth-wave generator with voltage-lift circuit.

The voltage-lift technique has been successfully employed in the design of DC/DC converters. However, its output voltage increases in arithmetic progression, stage by stage. The super-lift technique is a great achievement in DC/DC conversion technology. It is more powerful than the voltage-lift technique; the output voltage transfer gain of super-lift converters can be very high, which increases in geometric progression, stage by stage. It effectively enhances the voltage transfer gain in power series. Four series of super-lift converters created by the authors are introduced in this book. Some industrial applications verified their versatile and powerful characteristics.

Multiple-quadrant operation is often required in industrial applications. Most publications in the literature concentrate on the single-quadrant operation. This fact is reasonable since most novel approaches were derived from its simple structure. To compensate for these losses, the authors have spent much time and spirit to develop multiple-quadrant converters, positive-negative converters in various generations.

This book is organized in 18 chapters. The DC/DC conversion technique is introduced in Chapter 1 and the voltage list converters in Chapter 2. Chapters 3 to 6 introduce the four series super-lift converters. Chapter 7 introduces the second generation converters; and Chapter 8, the third generation converters. Chapters 9 and 10 introduce the two-series multiple-lift push-pull switched-capacitor converters. Chapter 11 introduces the fourth

generation converters and Chapter 12 the fifth generation converters. Chapters 13 to 16 introduce the sixth generation converters. Chapter 17 introduces various DC voltage sources; and Chapter 18 introduces the gating-signal generator, EMI/EMC, and some applications.

The authors are pioneers in DC/DC conversion technology. They have devoted many years to this research area and created a large number of outstanding converters, including world-renowned series DC/DC converters, namely, Luo-Converters, which cover all six generation converters. Super-lift converters are our favorite achievement in our 20-years' research fruits. Our biographies and information are provided on the following page.

Our acknowledgment goes to the executive editor for this book.

Dr. Fang Lin Luo and Dr. Hong Ye
Nanyang Technological University
Singapore

Authors

Dr. Fang Lin Luo is currently with the School of Electrical and Electronic Engineering, Nanyang Technological University (NTU), Singapore. He received his B.Sc. degree, first class with honors in Radio-Electronic Physics at the Sichuan University, Chengdu, Sichuan, China and his Ph.D. degree in Electrical Engineering and Computer Science at Cambridge University, England, in 1986.

Dr. Luo was with the Chinese Automation Research Institute of Metallurgy, Beijing, China as a Senior Engineer after his graduation from Sichuan University. He was with the Entreprises Saunier Duval, Paris, France as a project engineer from 1981 to 1982. He was with Hocking NDT Ltd, Allen-Bradley IAP Ltd., and Simplatroll Ltd. in England as a Senior Engineer after he received his Ph.D. degree from Cambridge University. He is a Senior Member of the IEEE. He has published two textbooks and 198 technical papers in *IEE Proceedings* and *IEEE Transactions*, and various international conferences. His present research interest is in power electronics and DC and AC motor drives with computerized artificial intelligent control and digital signal processing, and AC/DC and DC/DC converters and DC/AC inverters.

Dr. Luo is the Chief Editor of the international journal *Power Supply Technologies and Applications*. He is currently the Associate Editor of *IEEE Transactions on Power Electronics* in charge of the technical topic *Low Power Converters*.

Dr. Hong Ye is currently with the School of Electrical and Electronic Engineering, Nanyang Technological University (NTU), Singapore. She received her B.S. (with honors) in 1995 and the M.S. degree in Engineering from Xi'an Jiaotong University, China in 1999. She completed her Ph.D. degree in 2002 in Information Technology (IT) in the School of Electrical and Electronic Engineering, Nanyang Technological University (NTU), Singapore.

Dr. Ye was with the Research and Development Institute, Xi'an Instrument Group, XIYI

Company, Ltd., Xi'an, China as a Research Engineer from 1995 to 1997. Dr. Ye is an IEEE Member and has authored two textbooks and more than 38 technical papers in *IEEE Transactions*, *IEE Proceedings*, and other international journals and various international conferences. Her research interests are in the areas of DC/DC converters, signal processing, operations research, and structural biology.

Contents