# ELECTRIC MACHINERY FUNDAMENTALS

# ELECTRIC MACHINERY FUNDAMENTALS

FOURTH EDITION

**Stephen J. Chapman**

*BAE SYSTEMS Australia*


**Higher Education**

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York
San Francisco St. Louis Bangkok Bogotá Caracas Kuala Lumpur
Lisbon London Madrid Mexico City Milan Montreal New Delhi
Santiago Seoul Singapore Sydney Taipei Toronto

The McGraw-Hill Companies

Mc Graw Hill Higher Education

ELECTRIC MACHINERY FUNDAMENTALS, FOURTH EDITION



This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 DOC/DOC 0 9 8 7 6 5 4 3

ISBN 0–07–246523–9

Publisher: *Elizabeth A. Jones*
Senior sponsoring editor: *Carlise Paulson*
Managing developmental editor: *Emily J. Lupash*
Marketing manager: *Dawn R. Bercier*
Senior project manager: *Sheila M. Frank*
Senior production supervisor: *Laura Fuller*
Senior media project manager: *Tammy Juran*
Senior designer: *David W. Hash*
Lead photo research coordinator: *Carrie K. Burger*
Compositor: *GAC—Indianapolis*
Typeface: *10/12 Times Roman*
Printer: *R. R. Donnelley Crawfordsville, IN*

**Library of Congress Cataloging-in-Publication Data**

Chapman, Stephen J.
Electric machinery fundamentals / Stephen Chapman. — 4th ed.
p. cm.
Includes index.
ISBN 0–07–246523–9
1. Electric machinery. I. Title.

TK2000.C46 2005
621.31'042—dc22 2003065174
CIP

www.mhhe.com

THIS WORK IS DEDICATED WITH LOVE TO
MY MOTHER, LOUISE G. CHAPMAN,
ON THE OCCASION
OF HER EIGHTY-FIFTH BIRTHDAY.

# ABOUT THE AUTHOR

**Stephen J. Chapman** received a B.S. in Electrical Engineering from Louisiana State University (1975) and an M.S.E. in Electrical Engineering from the University of Central Florida (1979), and pursued further graduate studies at Rice University.

From 1975 to 1980, he served as an officer in the U.S. Navy, assigned to teach electrical engineering at the U.S. Naval Nuclear Power School in Orlando, Florida. From 1980 to 1982, he was affiliated with the University of Houston, where he ran the power systems program in the College of Technology.

From 1982 to 1988 and from 1991 to 1995, he served as a member of the technical staff of the Massachusetts Institute of Technology's Lincoln Laboratory, both at the main facility in Lexington, Massachusetts, and at the field site on Kwajalein Atoll in the Republic of the Marshall Islands. While there, he did research in radar signal processing systems. He ultimately became the leader of four large operational range instrumentation radars at the Kwajalein field site (TRADEX, ALTAIR, ALCOR, and MMW).

From 1988 to 1991, Mr. Chapman was a research engineer in Shell Development Company in Houston, Texas, where he did seismic signal processing research. He was also affiliated with the University of Houston, where he continued to teach on a part-time basis.

Mr. Chapman is currently manager of systems modeling and operational analysis for BAE SYSTEMS Australia, in Melbourne.

Mr. Chapman is a senior member of the Institute of Electrical and Electronic Engineers (and several of its component societies). He is also a member of the Association for Computing Machinery and the Institution of Engineers (Australia).

# BRIEF CONTENTS

# TABLE OF CONTENTS

# PREFACE

In the years since the first edition of *Electric Machinery Fundamentals* was published, there has been rapid advance in the development of larger and more sophisticated solid-state motor drive packages. The first edition of this book stated that dc motors were the method of choice for demanding variable-speed applications. That statement is no longer true today. Now, the system of choice for speed control applications is most often an ac induction motor with a solid-state motor drive. DC motors have been largely relegated to special-purpose applications where a dc power source is readily available, such as in automotive electrical systems.

The third edition of the book was extensively restructured to reflect these changes. The material on ac motors and generators is now covered in Chapters 4 through 7, before the material on dc machines. In addition, the dc machinery coverage was reduced compared to earlier editions. The fourth edition continues with this same basic structure.

Chapter 1 provides an introduction to basic machinery concepts, and concludes by applying those concepts to a linear dc machine, which is the simplest possible example of a machine. Chapter 2 covers transformers, and Chapter 3 is an introduction to solid-state power electronic circuits. The material in Chapter 3 is optional, but it supports ac and dc motor control discussions in Chapters 7, 9, and 10.

After Chapter 3, an instructor may choose to teach either dc or ac machinery first. Chapters 4 through 9 cover ac machinery, and Chapters 8 and 9 cover dc machinery. These chapter sequences have been made completely independent of each other, so that instructors can cover the material in the order that best suits their needs. For example, a one-semester course with a primary concentration in ac machinery might consist of parts of Chapters 1 to 7, with any remaining time devoted to dc machinery. A one-semester course with a primary concentration in dc machinery might consist of parts of Chapters 1, 3, 8, and 9, with any remaining time devoted to ac machinery. Chapter 10 is devoted to single-phase and special-purpose motors, such as universal motors, stepper motors, brushless dc motors, and shaded-pole motors.

The homework problems and the ends of chapters have been revised and corrected, and more than 70 percent of the problems are either new or modified since the last edition.

In recent years, there have been major changes in the methods used to teach machinery to electrical engineering and electrical technology students. Excellent analytical tools such as MATLAB have become widely available in university engineering curricula. These tools make very complex calculations simple to perform, and allow students to explore the behavior of problems interactively. This edition of *Electric Machinery Fundamentals* makes selected use of MATLAB to enhance a student's learning experience where appropriate. For example, students use MATLAB in Chapter 7 to calculate the torque–speed characteristics of induction motors and to explore the properties of double-cage induction motors.

This text does not teach MATLAB; it assumes that the student is familiar with it through previous work. Also, the book does *not* depend on a student having MATLAB. MATLAB provides an enhancement to the learning experience if it is available, but if it is not, the examples involving MATLAB can simply be skipped, and the remainder of the text still makes sense.

Supplemental materials supporting the book are available from the book's website, at www.mhhe.com/engcs/electrical/chapman. The materials available at that address include MATLAB source code, pointers to sites of interest to machinery students, a list of errata in the text, some supplemental topics that are not covered in the main text, and supplemental MATLAB tools.

This book would never have been possible without the help of dozens of people over the past 18 years. I am not able to acknowledge them all here, but I would especially like to thank Charles P. LeMone, Teruo Nakawaga, and Tadeo Mose of Toshiba International Corporation for their invaluable help with the solid-state machinery control material in Chapter 3. I would also like to thank Jeffrey Kostecki, Jim Wright, and others at Marathon Electric Company for supplying measured data from some of the real generators that the company builds. Their material has enhanced this revision.

Finally, I would like to thank my wife Rosa and our children Avi, David, Rachel, Aaron, Sarah, Naomi, Shira, and Devorah for their forbearance during the revision process. I couldn't imagine a better incentive to write!

***Stephen J. Chapman***
***Melbourne, Victoria, Australia***