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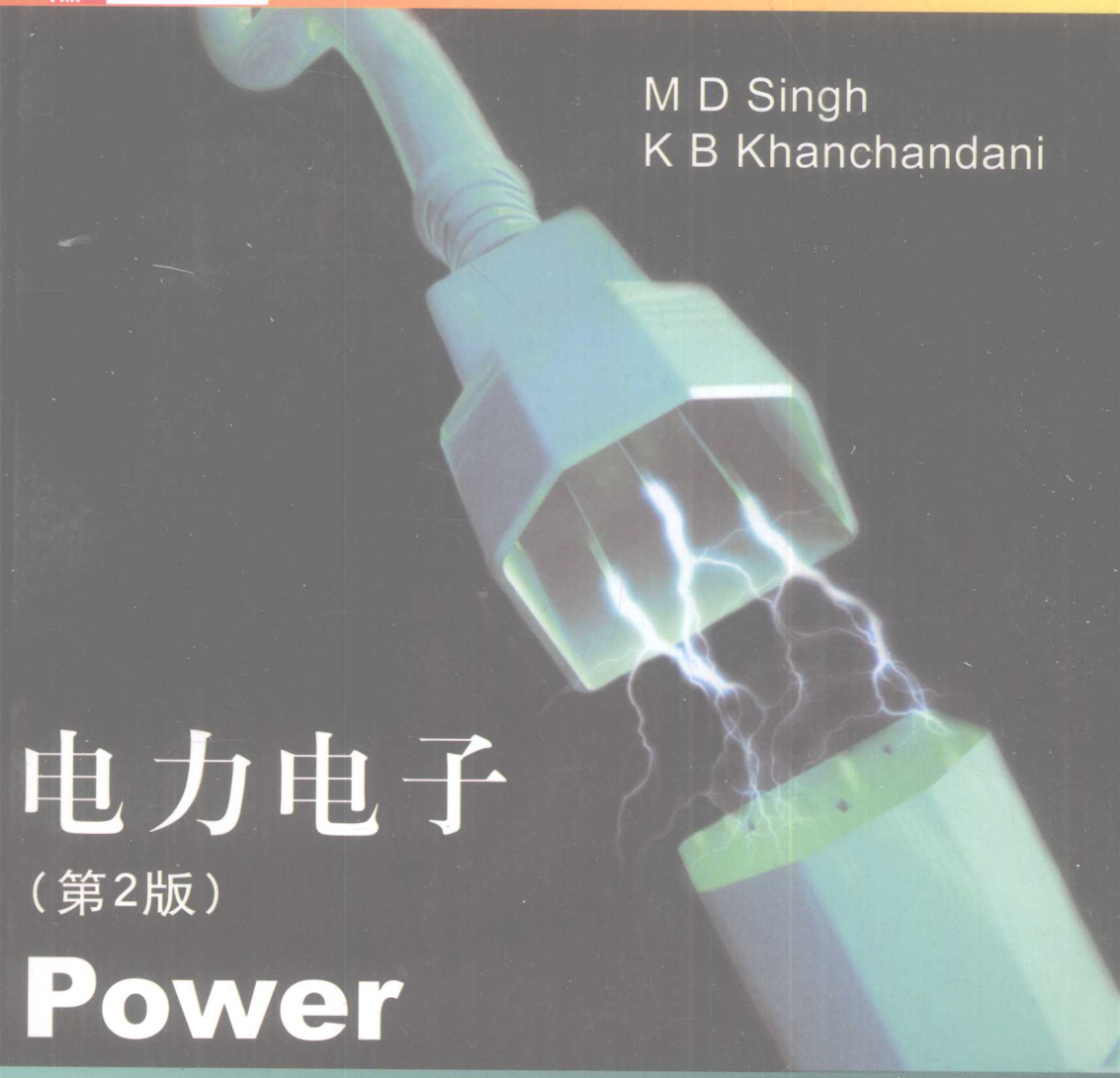

电力电子

（第2版）

Power Electronics

(Second Edition)

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序

电力电子技术是一门融合了电力、功率半导体和控制学科领域的综合性技术。随着电力电子技术的不断发展，它在工业生产、电力牵引、新能源发电、家用电器和国防工业等许多国民经济领域中得到越来越广泛的应用，成为国民经济发展中的关键支撑技术，并为电气工程学科的技术创新提供了源源不断的动力。因此，对于正在学习或者正在应用电力电子技术的学者或者工程技术人员，有必要对电力电子学科的发展及技术现状有一个系统而深入的认识，特推荐该书作为学习电力电子技术基础的重要参考书。

该书的作者 M D Singh 博士和 K B Khanchandani 博士都在电力电子技术领域有多年的科研和教学经验，他们在本书中系统、全面、细致地讲述了经典电力电子技术及现代电力电子技术基础。从电力电子技术系统的总体认识、晶闸管的基本原理和特性、晶闸管的门极触发和晶闸管的串并联使用，到相控变换器、双向变换器、斩波器、逆变器、交交变流器、交流调节器和谐振变换器，进而到器件的保护和冷却、直流传动控制和交流传动控制，直至电力电子技术的各种应用，都进行了详细的介绍和分析。该书以经典电力电子技术内容为主，也包括了一些现代电力电子技术的内容，比如关于自关断器件 IGBT、MOSFET、IGCT 等及其相关换流电路的介绍。该书作为一本电力电子技术基础教材，具有以下一些突出特点：

（1）概念清晰，描述细致。

（2）插图精致，信息量大。

（3）计算推导严格，实例数据详尽。

（4）每章后面的思考题和计算题丰富。

由此可见，该书是一本关于经典电力电子技术系统介绍和现代电力电子技术快速入门难得的专门教材和参考书，对于那些想深入系统地了解经典电力电子技术，同时又想对现代电力电子技术有所了解的电气工程、自动控制、电子技术等专业的本科生、研究生或者业内工程技术人员，该书是一本很好的参考书。

赵争鸣

2011 年 3 月于清华园

About the Authors

Dr M D Singh, former Principal at Laxmi Narayan College of Technology, Bhopal, worked as Assistant Director and Scientist at CEERI, Pilani, and has been Vice-President of the Indian Physics Association, BITS, Pilani. A former member of IEEE (USA) and a life member of IETE (India), Dr. Singh has contributed several research papers in many reputed national and international journals and has three patents to his credit. He obtained his B.E. from Jabalpur University and M.E. and Ph.D. from BITS, Pilani. He has widely travelled abroad and worked at several European institutions. Dr. Singh has been involved in research and teaching in power electronics, TV systems and satellite communication for over 40 years.

Dr K B Khanchandani is Professor, Department of Electronics and Telecommunication Engineering, SSGM College of Engineering, Shegaon. He has over 18 years of teaching and research experience in Power Electronics. He has published a number of research papers in journals, both national and international. He obtained his B.E. and M.E. from Amravati University and Ph.D. from National Institute of Technology, Bhopal. He has been involved in teaching and research in areas of power electronics, signal processing, analog and digital system design and VLSI design. He has worked on several research/development and laboratory modernization projects.

In
Loving Memory of Our
Late Parents

Preface to the Second Edition

The field of electrical engineering is generally segmented into three major areas—electronics, power and control. Power electronics is a combination of these three areas. In broad terms, the function of power electronics is to process and control the electrical energy by supplying voltage and current in a form that is optimally suited to the load. The advent of power semiconductor devices, *thyristors,* in 1957, has been an exciting breakthrough in the art of electric power conversion and its control. Power electronics has undergone intense technological evolution during the last three decades. Starting with the conventional thyristor-type devices in early days, the recent availability of high-frequency, high-power, MOS-gated self-controlled devices are opening new frontiers in the field.

In modern power electronics equipment, there are essentially two types of semiconductor elements: the power semiconductors that can be considered as the muscles of the equipment, and the microelectronics control chips that provide power to the brain. Both the elements are digital in nature, except that one manipulates power upto gigawatts and the other handles only miliwatts. The close coordination of this end of the spectrum of electronics offers reduced size, cost advantages and high-level of performance.

The market demands on industry for productivity and quality are increasing. This has resulted in an increasing demand for automation in production processes and hence in the use of variable speed drives.

The use of electric cars, electric trams and electric subway trains can substantially reduce urban pollution problems. Power electronics permits generation of electric power from environmentally clean photovoltaic, fuel cells and wind energy sources. Widespread application of power electronics, with an eye for energy conservation and generation of power from environmentally clean sources, can help in solving problems like acid rains and greenhouse effects.

This textbook presents the basic tools for the analysis and design of power electronic circuits and provides methods and procedures suitable for a variety of power electronic applications. This text is suitable for undergraduate-level courses in power electronics and/or electrical machines and drives. It is also intended for

practicing engineers who wish to gain knowledge of the recent developments in this rapidly expanding field.

In response to the comment and suggestions from students and teachers, several changes in the presentation of topics have been made and new topics have been included in this revised edition of the book.

The second edition offers several improvements over the first edition. Many sections have been rewritten to further simplify the presentation. Several chapters have been revised by adding new updated material. New problems have been formulated for many chapters.

The book consists of 16 chapters. Two chapters (Chapters 1 and 12) are newly added and the sequence of chapters has been modified for better flow of the content. The following is a brief description of the topics that are covered in each chapter with an emphasis on the revisions that have been made in the second edition.

Chapter 1 contains an overview of power electronics and its applications to make the reader aware of the meaning of power electronics and its importance.

Chapter 2 deals with the physical principle of thyristors, their structural details and switching characteristics. The section on turn-on switching characteristics has been completely revised.

Chapter 3 gives a brief description of gate triggering circuits. A new section on *microprocessor interfacing to power thyristors* has been added.

Chapter 4 contains series and parallel operations of thyristor.

Chapter 5 covers the various power semiconductor devices such as power MOSFETs, GTOs, IGBTs, SITs, SITHs, IGCTs, MCTs, MTOs and ETOs. Device structures and physical operations are described and typical terminal characteristics are shown. Many sections are completely revised. The section on power transistors along with solved examples has been moved over to the online learning centre (OLC) of the book. New sections and subsections on IGBTs and ETOs have been added.

Chapter 6 presents various phase-controlled rectifier circuits with their mathematical analysis and performance factors. A new section on power-factor improvement has been added. Many sections have been revised for better understanding. Sections on Firing Circuits for Line Commutated Converters and Triggering Circuits for Single-phase Fully Controlled Converters have been removed from the book. However, these are available on the OLC of the book.

Chapter 7 gives a detailed account of dual converters and their characteristics.

Chapter 8 is devoted to the discussion of the principles of choppers in D.C-to -D.C. conversion. A new section on *flyback converters* has been added. The section on chopper firing circuit has been removed and is available on the website.

Chapter 9 gives a comprehensive treatment of dc–ac inverters in which the various voltage-fed and current-fed inverter circuits are discussed and some

typical forced-commutating circuits are investigated. A number of design examples are presented. Sections on three-phase bridge inverters with input circuit commutation and three-phase current source inverters are now available on the website.

Chapter 10 introduces the phase-controlled cycloconverters. The section on ring-connected cycloconverter circuits has been relegated to the website.

Chapter 11 presents a.c. regulators.

Chapter 12 deals with *resonant converters* where LC resonant circuits are utilized to improve the performance of converters. This chapter is newly added and covers the basic technology of resonant and soft-switching converters. Various forms of soft-switching techniques such as ZVS and ZCS are addressed.

Chapter 13 introduces the protection, cooling and mounting of power semiconductor devices.

Chapter 14 discusses various schemes for D.C. motor speed control. The section on closed loop control of D.C. drives has been shifted to the website.

Chapter 15 introduces variable speed A.C. drives and briefly describes their benefits. It examines their classifications from different perspectives. The section on microprocessor controlled A.C. drive has been removed from the book and is available on the website.

Chapter 16 considers power electronics application circuits. Many sections in this chapter have been completely revised. Also, many new sections have been added.

Web Supplements

The Online Learning Centre of the book at (*http://www.mhhe.com/singh/pe2e*) has separate sections for students and instructors. Students' resource consists of PSPICE simulation examples and multiple-choice questions with answers. For instructors, the website offers the solutions manual wherein all the exercise problems in the book have been solved. It also has chapterwise PowerPoint slides which will help the teachers in preparing lectures and presentations.

M D Singh
K B Khanchandani

Preface to the First Edition

The field of electrical engineering is generally segmented into three major areas—electronics, power and control. Power electronics involves a combination of these three areas. In broad terms, the function of power electronics is to process and control the electrical energy by supplying voltage and current in a form that is optimally suited to the load. The advent of the power semiconductor device, *thyristor* in 1957, has been an exciting breakthrough in the art of electric power conversion and its control. Power electronics has undergone intense technological evolution during the last three decades. Starting with the conventional thyristor-type devices in the early days, the recent availability of high frequency, high power, MOS-gated self-controlled devices is opening new frontiers in power electronics.

In a modern power electronic equipment, there are essentially two types of semiconductor elements: the power semiconductors that can be considered as the muscle of the equipment, and the microelectronic control chips that provide the power to the brain. Both elements are digital in nature, except that one manipulates power up to gigawatts and the other handles only milliwatts. The close coordination of these end-of-the-spectrum electronics offers reduced size, cost advantages and high level of performance.

The market demands on industry for productivity and quality are increasing. This results in the increasing demand for automation in production processes and hence for the use of variable speed drives. Today, power electronics is an indispensable tool in any advanced country's industrial economy. Saving energy is an important aspect of power electronics applications.

The use of electric cars, electric trams and electric subway trains can substantially reduce urban pollution problems. Power electronics permits generation of electric power from environmentally clean photovoltaic, fuel cell and wind energy sources. Widespread application of power electronics, with an eye for energy conservation and generation of power from environmentally clean sources, can help in solving problems like acid rain and greenhouse effects.

This textbook is intended as an introduction to the basic theory and practice of modern power electronics, in particular it deals with the applications of power

electronic techniques for d.c. and a.c. motor control. The text is suitable for degree-level and postgraduate courses in power electronics and/or electrical machines and drives. It is also intended for practicing engineers who wish to acquaint themselves with the recent developments in this rapidly expanding field.

The book consists of 14 chapters.

Chapter 1 deals with the physical principles of thyristors, their structural details and their switching characteristics. Chapter 2 gives a brief description of thyristor-firing circuits. Series and parallel operations of thyristors are discussed in Chapter 3.

Chapter 4 discusses all types of line-commutated phase-controlled converters with their mathematical analysis as well as performance factors and triggering circuits for these converters.

Chapter 5 is a comprehensive treatment of d.c.-a.c. inverters in which the various voltage-fed and current-fed inverter circuits are discussed, and some typical thyristor forced-commutating circuits are investigated.

Chapter 6 is devoted to the discussion of the principles of choppers in d.c. to d.c. conversion. Chapter 7 introduces the phase controlled cycloconverters. Chapter 8 gives a detailed account of dual converters and their characteristics. Chapter 9 deals with a.c. voltage controllers.

Chapter 10 discusses the various modern power semiconductor devices such as power transistors, power MOSFETs, GTOs, IGBTs, SITs and SITHs. Device structures and physical operations are described and typical terminal characteristics are shown.

Protection, cooling and mounting of SCRs is discussed in Chapter 11. Power electronics control of d.c. and a.c. motors is treated in Chapters 12 and 13 respectively. Chapter 14 considers power electronic application circuits.

Most importantly, it was the help and advice of Tata McGraw-Hill Publishing staff that made this whole project a reality. In particular, we wish to thank Ms Vibha Mahajan, Assistant Sponsoring Editor, Mini Narayanan, Copy Editor, and Anjali Razdan, Proofreader, of Tata McGraw-Hill. We are grateful to the authorities of SSGM College of Engineering, Shegaon, for providing all the facilities necessary for writing the book.

We would like to express our thanks for the many useful comments and suggestions provided by colleagues who reviewed this book during the course of its development, especially to Prof. J K Chatterjee of IIT Delhi and Dr Murugesh Mudaliar of BMS College of Engineering, Bangalore.

Finally, we would like to thank our family members for their love, patience and understanding during the preparation of the book.

M D Singh
K B Khanchandani

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We are fortunate to have received many useful comments and suggestions from students, which have helped in improving the technical content and clarity of the book. We are grateful to all of them.

We are indebted to many readers in the academia and industry worldwide for their invaluable feedback and for taking the trouble to draw our attention to the improvements required and the errors in the first edition.

Our special thanks goes to the reviewers of the first edition who have helped tremendously in shaping the revised edition.

Prof Ms. Prerna Gaur (NSIT, Delhi) and Dr. Yaduvir Singh (TIET, Patiala) we very much hope that the above reviewers and others will keep the feedback coming.

Most importantly, it was the help and the advice of McGraw-Hill Education (India) staff that made this whole project a reality. In particular, we wish to thank Vibha Mahajan, Shalini Jha, Mini Narayanan and Anjali Razdan for their support, encouragement and hard work in bringing out this book. We are grateful to the authorities of SSGM College of Engineering, Shegaon, for providing all the facilities for writing this book.

Finally, the authors are grateful to their families for their love, tolerance, patience and support throughout this very time-consuming project. Readers of the book are welcome to send their comments and feedback.

M D Singh
K B Khanchandani

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