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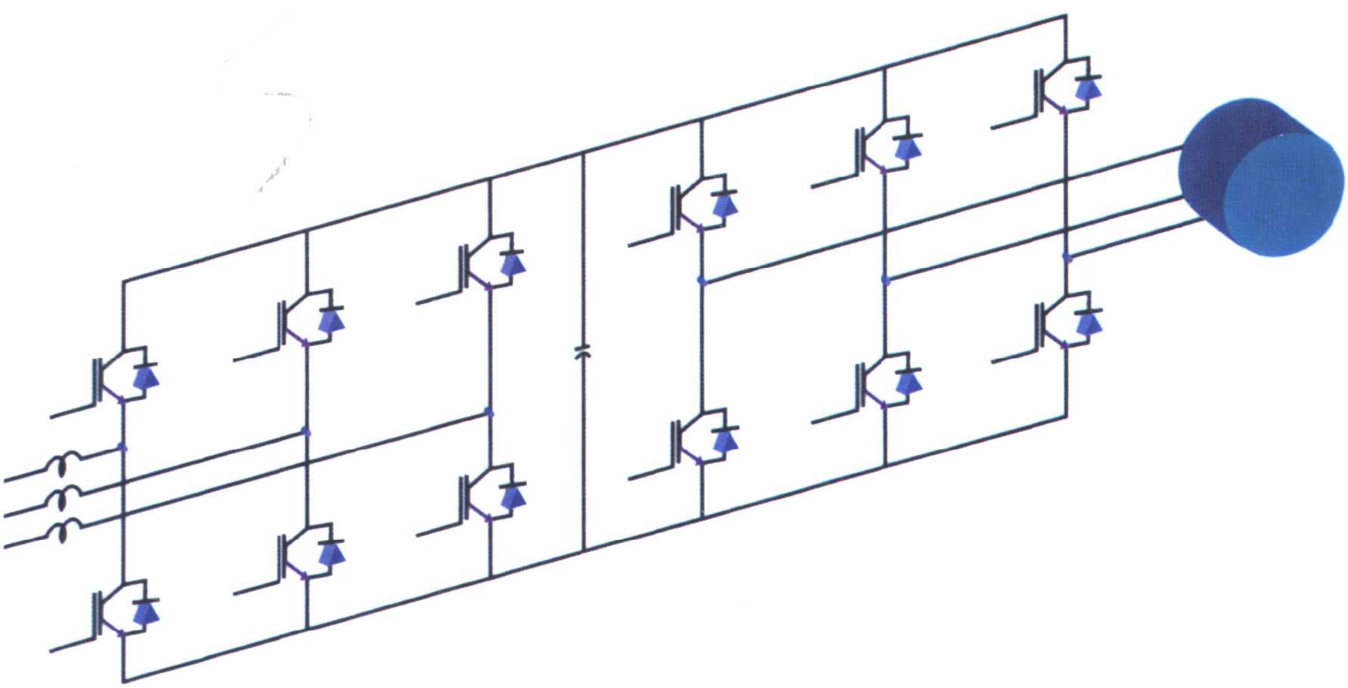
现代电力电子学与交流传动（英文版）

Modern Power Electronics and AC Drives



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（美）比马尔 K.博斯（Bimal K.Bose）著

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出版说明

随着我国加入WTO，国际间的竞争越来越激烈，而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才，加快我国教育改革的步伐，国家教育部近来出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机，机械工业出版社拟于近期推出一系列国外影印版教材，其内容涉及高等学校公共基础课，以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材，在有条件的学校推动开展英语授课或双语教学，自然也引进了先进的教学思想和教学方法，这对提高我国自编教材的水平，加强学生的英语实际应用能力，使我国的高等教育尽快与国际接轨，必将起到积极的推动作用。

为了做好教材的引进工作，机械工业出版社特别成立了由著名专家组成的国外高校优秀教材审定委员会。这些专家对实施双语教学做了深入细致的调查研究，对引进原版教材提出许多建设性意见，并慎重地对每一本将要引进的原版教材一审再审，精选再精选，确认教材本身的质量水平，以及权威性和先进性，以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中，审定委员会还结合我国高校教学课程体系的设置和要求，对原版教材的教学思想和方法的先进性、科学性严格把关，同时尽量考虑原版教材的系统性和经济性。

这套教材出版后，我们将根据各高校的双语教学计划，举办原版教材的教师培训，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

机械工业出版社

2002年3月

序

《Modern Power Electronics and AC Drives》一书，是2002年出版的电力电子技术领域的最新著作。作者Bimal K. Bose是IEEE终身会员、美国田纳西大学电力电子学科“康德拉杰出讲座”教授（这一职位只有少数成就突出的学者才能竞聘获得）。他从事电力电子技术领域的科学研究已有40多年，曾7次获得IEEE奖项，拥有20多项美国专利。他曾经担任IEEE工业电子学会的电力电子分会技术委员会主席、IEEE工业电子学报副主编、诺克斯韦尔电力电子中心首席科学家，在国际电力电子界享有很高的声誉。

Bose教授不仅在科研方面成果卓著，而且还为电力电子学与交流传动技术的教学与技术普及做出了很大贡献。1981年他编辑出版了论文集《Adjustable Seed AC Drive Systems》。由于该书集中反映了当时交流调速技术的最新成果，所以很快被北方交通大学肖幼萍教授等译为中文。这本书对我国20世纪80年代交流调速的科学研究与技术普及影响很大。1986年Bose教授出版了《Power Electronics and AC Drives》。该书是专门为大学高年级学生或研究生撰写的一本教材。1997年，他主编的专著《Power Electronics and Variable Frequency Drives——Technology and Applications》出版。这两本书也都很快出版了中译本。Bose教授曾自豪地提到自己的三部著作均被译为中文，对中国怀有深厚的感情。他曾多次访问中国，并在我国几所大学担任名誉教授或顾问。

1986年出版的《Power Electronics and AC Drives》是Bose教授多年在田纳西大学讲授电力电子学与交流传动的经验总结，已经被世界许多大学用作参考书，Bose教授本人也认为那是他最重要的著作。但是，十几年来，电力电子技术又有了新的重大发展，特别是第三代电力半导体器件IGBT以及IGCT等的应用，使电力电子装置与系统在电压等级、功率范畴与控制策略等方面都有了很大进步。因此，本书继承了1986年教材的风格与结构，并在其基础上做了大量更新与扩展。另外，作者还结合他本人最近的科研方向，新增加了“专家系统”、“模糊逻辑”和“神经网络在电力电子技术领域中的应用”三章内容，约占全书篇幅的五分之一。鉴于微机技术已经成为电类专业学生的必修课程，本书删去了1986年教材中的“微机原理”与“微机应用”两章内容。

本书详尽介绍了电力半导体器件、交流电动机、相控变流器、周波变换器、电压型逆变器、电流型逆变器、感应电动机转差功率回收控制、感应电动机传动

的控制与状态估计、同步电动机传动的控制与状态估计、专家系统原理与应用、模糊逻辑原理与应用和神经网络原理与应用等内容，涵盖了现代电力电子学与交流传动技术的整个体系。本书结构合理，内容深入浅出，语言通俗易懂，非常适合用作电气工程类专业本科生与研究生的教材，也可以作为电气工程师的参考书。相信本书能对我国电力电子技术的双语教学改革起到重要的作用。

范　瑜

北京交通大学电气工程学院

2002年10月

About the Author

Dr. Bimal K. Bose (*Life Fellow, IEEE*) currently holds the Condra Chair of Excellence in Power Electronics at the University of Tennessee, Knoxville since 1987. Prior to this, he was a research engineer in General Electric R & D Center in Schenectady, NY for 11 years (1976-87) and faculty member of Rensselaer Polytechnic Institute, Troy, NY for 5 years (1971-76). He has been in the power electronics area for more than 40 years and contributed widely that includes more than 150 papers, 21 U.S. Patents, 6 books (including this one) and invited presentations, tutorials and keynote addresses throughout the world. He is the recipient of a number of awards and honors that include IEEE Millennium Medal (2000), IEEE Continuing Education Award (1997), IEEE Lamme Gold Medal (1996), IEEE Industrial Electronics Society Eugene Mittelmann Award (for life-time achievement)(1994), IEEE Region 3 Outstanding Engineer Award (1994), IEEE Industry Applications Society Outstanding Achievement Award (1993), General Electric Silver Patent Medal(1986) and Publication Award (1987), and Calcutta University Mouat Gold Medal (1970).

Preface

It is with pride, excitement and a lot of expectations, I am presenting this book to the professional community of the world. As you know, power electronics and motor drives constitute a complex and interdisciplinary subject which have gone through spectacular evolution in the last three decades. Recently, artificial intelligence (AI) techniques are extending the frontier of this technology. It is without any doubt that the power electronics will play a dominant role in the 21st century in industrial, commercial, residential, aerospace, utility and military applications with the emphasis for energy saving and solving environmental pollution problems.

I have been in the power electronics area for more than forty years (since the technology was born) through my career pursuits in academia and industry, and have followed the technology evolution very aggressively. In the past, I contributed a number of books (authored and edited) in power electronics area of which Power Electronics and AC Drives (Prentice Hall-1986) is most important. It was taken as an advanced text in many universities in the world. This new book can be considered as significant updating and expansion of the previous book where I have tried to embed practically whatever knowledge I have in power electronics and ac drives. It contains the subject from A-to-Z, i.e., power semiconductor devices, electrical machines, different classes of converters, induction and synchronous motor drives with control and estimation, and AI techniques (expert system, fuzzy logic and neural networks). In essence, I have tried to incorporate practically all the aspects of state-of-the-art technology of power electronics and motor drives in the book. The content of the book is essentially based on my lecture notes of one senior course and three graduate courses, which I have developed and taught in the University of Tennessee during the last fourteen years. It will be my deep satisfaction if I can see that the book is being considered as a text in more universities than the previous one. The universities, which are already following my previous book, can now safely accept this new book.

The content of the book can be summarized as follows: Chapter 1 contains description of different types of power semiconductor devices including the recent IGCT, where IGBT device has been emphasized. Chapter 2 describes induction and synchronous machine theories in somewhat detail from the viewpoint of variable frequency drive applications, which include dynamic d-q machine models. Complex space vectors have been introduced but avoided in much of the text because, in the author's opinion, they tend to frighten most of the students. Switched reluctance machine has been included for completeness. Chapters 3 and 4 discuss the classical phase-controlled thyristor converters and cycloconverters, respectively. For completeness, high frequency link converters are included in Chapter 4. Chapter 5 covers voltage-fed converters and PWM techniques where space vector PWM has been emphasized. More recent topics, such as soft-switching, power factor compensation, multi-level converters, static VAR compensators and active filters are included. Chapter 6 deals with current-fed converters that include PWM converters. Chapter 6 describes slip power recovery drives with wound-rotor induction motors, and mainly consist of Kramer and Scherbius drives. Chapter 8 covers control and estimation of cage type induction motor drives which includes discussion on speed sensorless control and drive self-commissioning. Induction motor drive is a dominant theme in the book. Chapter 9 describes control and estimation of synchronous machine drives that includes sensorless control and a brief description of switched reluctance motor drive. Chapter 10 gives a brief description of expert system and its applications. In the author's opinion, ES has a lot of potentiality but has been practically ignored by the power electronics community. Chapter 11 deals with fuzzy logic and its applications, and finally, Chapter 12 gives description of neural network and its applications. In the author's opinion, the ANN technology will have a large impact on power electronics area in future. A set of questions has been formulated for different chapters which will be forwarded to readers on request [bbose@utk.edu].

This book could not be possible without the help of some of my professional colleagues and students. First, I am deeply grateful to Burak Ozpineci, my graduate student, for his enormous help in the manuscript preparation of the book. Next, my gratitude goes to the student Joao Pinto who helped me in revising the manuscript. The two demo programs in Chapters 11 and 12 were developed by him for the book. I would like to express my thanks to Dr. In-Dong Kim of Pukyong National University, Korea (who was formerly visiting professor in my laboratory) for supplying the Corel Flow software that helped us to draw most of the art work. I am very grateful to Prof. Paresh Sen of Queen's University, Canada for his constant encouragement. Also, I thank Prof. Marian Kazmierkowsky of Warsaw University of Technology, Poland; Prof. Marcelo Simoes of Colorado School of Mines, and Dr. Ned Mohan of University of Minnesota for their help.

Finally, I thank Wil Mara, Prentice Hall PTR's production editor, for doing this enormous job so efficiently. Also on the production end, I thank Aurelia Scharnhorst for her superb page composition, and Corinne Ovadia for her skillful creation of hundreds of new drawings.

I am deeply grateful to the brilliant scientists and engineers on whose scholarly contributions this book is based. Finally, I am very grateful to my wife Arati for her immense patience and sacrifice while preparing this book during the last three years.

Bimal K. Bose
University of Tennessee

List of Principal Symbols

Symbols are generally defined locally. The list of principal symbols used in the text is given below.

d^e - q^e	Synchronously rotating reference frame (or rotating frame) direct and quadrature axes
d^s - q^s	Stationary reference frame direct and quadrature axes (also known as α - β axes)
f	Frequency (Hz)
I_d	Dc current (Ampere)
I_f	Machine field current
I_L	Rms load current
I_m	Rms magnetizing current
I_P	Rms active current
I_Q	Rms reactive current
I_r	Rms rotor current (referred to stator)
I_s	Rms stator current
$i_{dr}{}^s$	d^s – axis rotor current
$i_{ds}{}^s$	d^s – axis stator current
i_{qr}	q^e – axis rotor current
i_{qs}	q^e – axis stator current
J	Moment of inertia (Kg-m^2)
X_r	Rotor reactance (Ohm)
X_s	Synchronous reactance

X_{ds}	d^e – axis synchronous reactance
X_{lr}	Rotor leakage reactance
X_{ls}	Stator leakage reactance
X_{qs}	q^e – axis synchronous reactance
α	Firing angle
β	Advance angle
γ	Turn-off angle
δ	Torque or power angle of synchronous machine
θ	Thermal impedance (Ohm) (also torque angle or angle)
θ_e	Angle of synchronously rotating frame $(\omega_e t)$
θ_r	Rotor angle
θ_{sl}	Slip angle
μ	Overlap angle
τ	Time constant (s)
L_c	Commutating inductance (Henry)
L_d	Dc link filter inductance
L_m	Magnetizing inductance
L_r	Rotor inductance
L_s	Stator inductance
L_{lr}	Rotor leakage inductance
L_{ls}	Stator leakage inductance
L_{dm}	d^e – axis magnetizing inductance
L_{qm}	q^e – axis magnetizing inductance
N	Turns ratio (primary to secondary)
N_e	Synchronous speed (rpm)
N_r	Rotor speed
P	Number of poles (also active power)
P_g	Airgap power (watts)
P_m	Mechanical output power
Q	Reactive power
R_r	Rotor resistance (Ohm)
R_s	Stator resistance
S	Slip (per unit)
T	Time period (s) (also temperature) (°C)
T_e	Developed torque (Nm)

T_L	Load torque
t_{off}	Turn-off time (s)
V_d	Dc voltage
V_I	Inverter dc voltage
V_f	Induced emf
V_m	Peak phase voltage (volt)
V_g	Rms airgap voltage
V_R	Rectifier dc voltage
v_s	Instantaneous supply voltage
v_d	Inst. Dc voltage
v_f	Inst. Field voltage
${v_{dr}}^s$	d^s – axis rotor voltage
${v_{ds}}^s$	d^s – axis stator voltage
v_{qr}	q^e – axis rotor voltage
v_{qs}	q^e – axis stator voltage
ϕ	Displacement power factor angle
ψ_a	Armature reaction flux linkage (Weber-turns)
ψ_f	Field flux linkage
ψ_m	Airgap flux linkage
ψ_r	Rotor flux linkage
ψ_s	Stator flux linkage
${\psi_{dr}}^s$	d^s – axis rotor flux linkage
${\psi_{ds}}^s$	d^s – axis stator flux linkage
ψ_{qr}	q^e – axis rotor flux linkage
ψ_{qs}	q^e – axis stator flux linkage
ω_e (or ω)	Stator or line frequency (r/s)
ω_m	Rotor mechanical speed
ω_r	Rotor electrical speed
ω_{sl}	Slip frequency
$\hat{X}$	Peak value of a sinusoidal phasor or sinusoidal space vector magnitude (also estimated parameter) (X is any arbitrary variable)
	Space vector (X is arbitrary variable)

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