时代教育·国外高校优秀教材精选

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英文改编版·原书第4版）

电力系统分析与设计

Power System Analysis and Design

（美） J．邓肯．格洛佛 (J. Duncan Glover)
穆卢库特拉 S．萨尔马 (Mulukutla S. Sarma)
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附赠光盘

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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，机械工业出版社陆续推出了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了许多建设性意见，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

序

很高兴能再次为《电力系统分析与设计（英文改编版·原书第 4 版）》一书作序。本书第 3 版于 2002 年出版，于 2004 年在中国影印发行，受到了国内外电力系统分析设计领域工程技术人员和高校师生的广泛关注。这次在中国出版的第 4 版比第 3 版做了部分改动，使本书更加实用。本书主要介绍电力系统分析和设计的方法，并借助先进的电网可视化分析软件，帮助学生深入理解电力系统的基本理论和分析方法。

本书的主要特点如下：

1. 对于电气工程专业的大学生来说，本书内容十分全面，这是美国教材不同于我国教材之处，对于本书的内容，国内一般是分成几本教材来讲述的。类似的教材，如《电力系统分析》、《电力系统》、《电能系统基础》等，所涵盖的知识点都没有本书全面。

2. 编写内容新。本书是 2008 年出版的最新版，内容反映了电力系统领域内的最新问题和研究成果，包括电力市场环境下电力系统的一些问题。

3. 在本书的最后有 10 篇精选的论文，介绍了电力系统的简要历史、当前情况及发展新方向。例如，《*Visualizing the Electric Grid*（可视化电网）》介绍了可视化电网和潮流研究计算的简要历史。可视化电网是最新的研究成果，也是今后电力系统潮流计算、研究的方向。其中关于潮流管理、网络控制、电力市场环境下的输电阻塞、三维网络图、市场力等问题都是崭新的。《*Causes of the 14 August Blackout*（“8.14”大停电的起因）》讲述了美国的大停电事件，使学生在学习基础理论的同时，了解电力系统的实际情况以及发展新方向，激发学生的学习兴趣。

4. 本书附有一张 CD 光盘，内容是最新版“电力世界仿真器”（*PowerWorld Simulator Version 12*，PWS）。PWS 是一个优秀的电力系统计算可视化软件包，能够处理任何规模的电力系统，在高等学校、电力系统分析人员中被广泛应用。本书的 CD 在该软件平台上集成了计算例题、问题和课程设计，对学生学习及理解概念和方法很有帮助。值得一提的是，PWS 例子在用 PWS 实例求解的同时都给出了详细的手工求解，这使学生既能看到一个问题如何求解的细节，又能同时看到计算机求解的执行过程。PWS 的

另外一个优势是它易于扩展实例，学生可以快捷地改变实例参数并且立刻观察这些改变对求解结果的影响。

5. 每章都有丰富的习题和问题，有助于学生理解课程内容和基本概念。第 4 版中更新了 2～9 章的习题，使读者通过对习题的解答对内容有更为深入的理解。特别是书中还设计了 6 个课程设计（*Design Project*），如“系统规划”、“潮流计算/短路计算”等，学生可借助 *PWS* 来完成这些设计。而在国内教学中，这一项基本被取消了。实际上，对于工科大学生来说，这是很重要的。本书中的设计（*Design*）内容，很值得国内教学借鉴。

本书前两位作者都来自美国东北大学。该校在电力方面的教学和科学研究是比较优秀的。作者编写本书时，同时也吸收了其他院校的一些教学成果。第 4 版还增加了一位作者托马斯·詹姆斯·奥弗比（*Thomas J. Overbye*）教授，他来自于伊利诺伊大学，是最早进行电力系统可视化技术研究的学者之一。在第 4 版中，他更新了本书原版的第 6 章（潮流），第 11 章（电力系统控制）和第 13 章（暂态稳定性），还提供了 *PWS* 分析的例题、习题和 3 个课程设计。

本书适合作为大学本科电力系统或者电气工程专业，以及机电类专业“电气工程”相关课程的双语教学教材，也可作为相关专业研究生或电气工程师的参考书。

清华大学电机工程与应用电子技术系

周双喜

2009 年 1 月

前　言

《电力系统分析与设计（第 4 版）》由于知识点全面、系统，理论与工程实际联系紧密，实用性强，在国内外读者中广受赞誉，而成为电力系统分析设计领域的重要参考资料。

原书是基于美国国情而编写的高等学校教学用书，为了使该书的内容更为适用于广大的中国读者，应机械工业出版社之邀，编者在承担本书中文版翻译工作的同时，在综合考虑知识内容的适用性、连贯性和行文简洁的基础上，对原书内容、结构做了一些调整，形成了本英文改编版。

改编版相对原书作了如下调整：原书每章均包括“案例分析”和正文（包含“习题”和“课程设计”）两个部分。改编版为保证全书的完整性，保持原书正文内容不变，但从中国读者的应用角度出发，去掉了原书各章的“案例分析”部分。同时，从删除的“案例分析”中精选了 *10* 篇对国内读者较具代表性和借鉴意义的论文，组织在一起新增了第 *14* 章（*Extended*），为开阔读者视野提供一个窗口，以使广大读者了解电力系统发展现状及未来新方向。内容涉及分布式发电、可视化电网、广域安稳控制系统、动态安全评估等电力系统前沿领域。

改编版的出版，是将外文教材引入、消化，使之适合中国读者的一次有益的尝试。原书内容经过调整后将更好地体现“实用性强、应用性强”的特点。期望本书能够成为国内电力系统专业教师、学生的优秀参考教材。

广西电力工业勘察设计研究院数字电网研究中心的王庆红主持了本书的改编工作，覃晖、骆玲、黄丽娟参与了改编版的稿件整理工作。

本书改编者负责翻译的《电力系统分析与设计（中文版·原书第 4 版）》也即将出版。

王庆红

2009 年 1 月

TO ANNA ELIZABETH, OWEN JOSEPH, AND THOSE TO FOLLOW

i thank You God for most this amazing
day: for the leaping greenly spirits of trees
and a blue true dream of sky; and for everything
which is natural which is infinite which is yes

(i who have died am alive again today,
and this is the sun's birthday; this is the birth
day of life and of love and wings: and of the gay
great happening illimitably earth)

how should tasting touching hearing seeing
breathing any—lifted from the no
of all nothing—human merely being
doubt unimaginable You?

(now the ears of my ears awake and
now the eyes of my eyes are opened)

E. E. Cummings

PREFACE

The objective of this book is to present methods of power system analysis and design, particularly with the aid of a personal computer, in sufficient depth to give the student the basic theory at the undergraduate level. The approach is designed to develop students' thinking process, enabling them to reach a sound understanding of a broad range of topics related to power system engineering, while motivating their interest in the electrical power industry. Because we believe that fundamental physical concepts underlie creative engineering and form the most valuable and permanent part of an engineering education, we highlight physical concepts while giving due attention to mathematical techniques. Both theory and modeling are developed from simple beginnings so that they can be readily extended to new and complex situations.

Thomas J. Overbye, *University of Illinois at Urbana-Champaign*, is welcomed as a new co-author of this edition of the text. He is one of the creators of PowerWorld Simulator, a user-friendly extremely visual power system analysis and simulation software package that is integrated into this text. Professor Overbye's expertise in power system operations, control, stability, computational algorithms, and education help to insure the text remains up to date and student oriented.

This edition of the text also features the following: try; (1) an updated PowerWorld Simulator package; and (2) updated problems at the end of Chapters 2–9.

One of the most challenging aspects of engineering education is giving students an intuitive feel for the systems they are studying. Engineering systems are, for the most part, complex. While paper-and-pencil exercises can be quite useful for highlighting the fundamentals, they often fall short in imparting the desired intuitive insight. To help provide this insight, a CD enclosed with the book contains PowerWorld Simulator, which is used to integrate computer-based examples, problems, and design projects throughout the text.

PowerWorld Simulator was originally developed at the University of Illinois at Urbana–Champaign to teach the basics of power systems to nontechnical people involved in the electricity industry, with version 1.0 introduced in June 1994. The program's interactive and graphical design made it an immediate hit as an educational tool, but a funny thing happened—its

interactive and graphical design also appealed to engineers doing analysis of real power systems. To meet the needs of a growing group of users, PowerWorld Simulator was commercialized in 1996 by the formation of PowerWorld Corporation. Thus while retaining its appeal for education, over the years PowerWorld Simulator has evolved into a top-notch analysis package, able to handle power systems of any size. PowerWorld Simulator is now used throughout the power industry, with a range of users encompassing universities, utilities of all sizes, government regulators, power marketers, and consulting firms.

In integrating PowerWorld Simulator with the text, our design philosophy has been to use the software to extend, rather than replace, the fully worked examples provided in previous editions. Therefore, except when the problem size makes it impractical, each PowerWorld Simulator example includes a fully worked hand solution of the problem along with a PowerWorld Simulator case. This format allows students to simultaneously see the details of how a problem is solved and a computer implementation of the solution. The added benefit from PowerWorld Simulator is its ability to easily extend the example. Through its interactive design, students can quickly vary example parameters and immediately see the impact such changes have on the solution. By reworking the examples with the new parameters, students get immediate feedback on whether they understand the solution process. The interactive and visual design of PowerWorld Simulator also makes it an excellent tool for instructors to use for in-class demonstrations. With the many examples and problem cases contained on the CD, instructors can easily demonstrate many of the text topics. Additional PowerWorld Simulator functionality is introduced in the text examples, problems, and design projects.

The text is intended to be fully covered in a two-semester or three-quarter course offered to seniors and first-year graduate students. The organization of chapters and individual sections is flexible enough to give the instructor sufficient latitude in choosing topics to cover, especially in a one-semester course. The text is supported by an ample number of worked examples covering most of the theoretical points raised. The many problems to be worked with a calculator as well as problems to be worked using a personal computer have been expanded in this edition.

As background for this course, it is assumed that students have had courses in electric network theory (including transient analysis) and ordinary differential equations and have been exposed to linear systems, matrix algebra, and computer programming. In addition, it would be helpful, but not necessary, to have had an electric machines course.

After an introduction to the history of electric power systems along with present and future trends, Chapter 2 on fundamentals orients the students to the terminology and serves as a brief review. The chapter reviews phasor concepts, power, and single-phase as well as three-phase circuits.

Chapters 3 through 6 examine power transformers, transmission-line parameters, steady-state operation of transmission lines, and power flows including the Newton–Raphson method. These chapters provide a basic under-

standing of power systems under balanced three-phase, steady-state, normal operating conditions.

Chapters 7 through 10, which cover symmetrical faults, symmetrical components, unsymmetrical faults, and system protection, come under the general heading of power system short-circuit protection. Chapter 11 is a self-contained chapter on power system controls, including turbine-generator controls, load-frequency control, economic dispatch, and optimal power flow.

The last two chapters examine transient operation of transmission lines, including surge protection; and transient stability, which includes the swing equation, the equal-area criterion, and multimachine stability. These self-contained chapters come under the general heading of power system transients.

ACKNOWLEDGMENTS

The material in this text was gradually developed to meet the needs of classes taught at universities in the United States and abroad over the past 30 years. The 13 chapters were written by the first author, J. Duncan Glover, *Failure Electrical LLC*, who is indebted to many people who helped during the planning and writing of this book. The profound influence of earlier texts written on power systems, particularly by W. D. Stevenson, Jr., and the developments made by various outstanding engineers are gratefully acknowledged. Details of sources can only be made through references at the end of each chapter, as they are otherwise too numerous to mention.

Co-author Thomas Overbye updated Chapter 6 (*Power Flows*), Chapter 11 (*Power System Controls*), and Chapter 13 (*Transient Stability*) of this edition of the text. He also provided the examples and problems using PowerWorld Simulator as well as three design projects. Co-author Mulukutla Sarma, *Northeastern University*, contributed to end-of-chapter problems.

We commend Christopher Carson and Hilda Gowans of Thomson Engineering and Rose Kernan of RPK Editorial Services Inc., for their broad knowledge, skills, and ingenuity in publishing this edition. The reviewers of the fourth edition are as follows: Robert C. Degeneff, *Rensselaer Polytechnic Institute*; Venkata Dinavahi, *University of Alberta*; Richard G. Farmer, *Arizona State University*; Steven M. Hietpas, *South Dakota State University*; M. Hashem Nehrir, *Montana State University*; Anil Pahwa, *Kansas State University*; and Ghadir Radman; *Tennessee Technical University*.

The following reviewers made substantial contributions to the third edition: Sohrab Asgarpoor, *University of Nebraska–Lincoln*; Mariesa L. Crow, *University of Missouri–Rolla*; Ilya Y. Grinberg, *State University of New York, College at Buffalo*; Iqbal Husain, *The University of Akron*; W. H. Kersting, *New Mexico State University*; John A. Palmer, *Colorado School of Mines*; Satish J. Ranada, *New Mexico State University*; and Shyama C. Tandon, *California Polytechnic State University*.

The following reviewers made substantial contributions to the second

edition: Max D. Anderson, *University of Missouri–Rolla*; Sohrab Asgarpoor, *University of Nebraska–Lincoln*; Kaveh Ashenayi, *University of Tulsa*; Richard D. Christie, Jr., *University of Washington*; Mariesa L. Crow, *University of Missouri–Rolla*; Richard G. Farmer, *Arizona State University*; Saul Goldberg, *California Polytechnic University*; Clifford H. Grigg, *Rose-Hulman Institute of Technology*; Howard B. Hamilton, *University of Pittsburgh*; Leo Holzenthal, Jr., *University of New Orleans*; Walid Hubbi, *New Jersey Institute of Technology*; Charles W. Isherwood, *University of Massachusetts–Dartmouth*; W. H. Kersting, *New Mexico State University*; Wayne E. Knabach, *South Dakota State University*; Pierre-Jean Lagace, *IREQ Institut de Reserche d'Hydro–Quebec*; James T. Lancaster, *Alfred University*; Kwang Y. Lee, *Pennsylvania State University*; Mohsen Lotfalian, *University of Evansville*; Rene B. Marxheimer, *San Francisco State University*, Lamine Mili, *Virginia Polytechnic Institute and State University*; Osama A. Mohammed, *Florida International University*; Clifford C. Mosher, *Washington State University*, Anil Pahwa, *Kansas State University*; M. A. Pai, *University of Illinois at Urbana–Champaign*; R. Ramakumar, *Oklahoma State University*; Teodoro C. Robles, *Milwaukee School of Engineering*, Ronald G. Schultz, *Cleveland State University*; Stephen A. Sebo, *Ohio State University*; Raymond Shoults, *University of Texas at Arlington*, Richard D. Shultz, *University of Wisconsin at Platteville*; Charles Slivinsky, *University of Missouri–Columbia*; John P. Stahl, *Ohio Northern University*; E. K. Stanek, *University of Missouri–Rolla*; Robert D. Strattan, *University of Tulsa*; Tian-Shen Tang, *Texas A&M University–Kingsville*; S. S. Venkata, *University of Washington*; Francis M. Wells, *Vanderbilt University*; Bill Wieserman, *University of Pennsylvania–Johnstown*; Stephen Williams, *U.S. Naval Postgraduate School*; and Salah M. Yousif, *California State University–Sacramento*.

In addition, the following reviewers made many contributions to the first edition: Frederick C. Brockhurst, *Rose-Hulman Institute of Technology*; Bell A. Cogbill. *Northeastern University*; Saul Goldberg, *California Polytechnic State University*; Mack Grady, *University of Texas at Austin*; Leonard F. Grigsby, *Auburn University*; Howard Hamilton, *University of Pittsburgh*; William F. Horton, *California Polytechnic State University*; W. H. Kersting, *New Mexico State University*; John Pavlat, *Iowa State University*; R. Ramakumar, *Oklahoma State University*; B. Don Russell, *Texas A&M*; Sheppard Salon, *Rensselaer Polytechnic Institute*; Stephen A. Sebo, *Ohio State University*; and Dennis O. Wiitanen, *Michigan Technological University*.

In conclusion, the objective in writing this text and the accompanying software package will have been fulfilled if the book is considered to be student-oriented, comprehensive, and up to date, with consistent notation and necessary detailed explanation at the level for which it is intended.

LIST OF SYMBOLS, UNITS, AND NOTATION

Symbol	Description
a	operator $1/120°$
a_t	transformer turns ratio
A	area
A	transmission line parameter
$\boldsymbol{A}$	symmetrical components transformation matrix
B	loss coefficient
B	frequency bias constant
B	phasor magnetic flux density
B	transmission line parameter
C	capacitance
C	transmission line parameter
D	distance
D	transmission line parameter
E	phasor source voltage
E	phasor electric field strength
f	frequency
G	conductance
G	conductance matrix
H	normalized inertia constant
H	phasor magnetic field intensity
$i(t)$	instantaneous current
I	current magnitude (rms unless otherwise indicated)
I	phasor current
$\boldsymbol{I}$	vector of phasor currents
j	operator $1/90°$
J	moment of inertia
l	length
l	length
L	inductance
L	inductance matrix
N	number (of buses, lines, turns, etc.)
p.f.	power factor
$p(t)$	instantaneous power
P	real power
q	charge
Q	reactive power
r	radius
R	resistance
R	turbine-governor regulation constant
R	resistance matrix
s	Laplace operator
S	apparent power
S	complex power
t	time
T	period
T	temperature
T	torque
$v(t)$	instantaneous voltage
V	voltage magnitude (rms unless otherwise indicated)
V	phasor voltage
$\boldsymbol{V}$	vector of phasor voltages
X	reactance
X	reactance matrix
Y	phasor admittance
$\boldsymbol{Y}$	admittance matrix
Z	phasor impedance
$\boldsymbol{Z}$	impedance matrix
α	angular acceleration
α	transformer phase shift angle
β	current angle
β	area frequency response characteristic
δ	voltage angle
δ	torque angle
ε	permittivity
Γ	reflection or refraction coefficient

Symbol	Description	Symbol	Description
λ	magnetic flux linkage	θ	impedance angle
λ	penalty factor	θ	angular position
Φ	magnetic flux	μ	permeability
ρ	resistivity	v	velocity of propagation
τ	time in cycles	ω	radian frequency
τ	transmission line transit time		

SI Units

A	ampere
C	coulomb
F	farad
H	henry
Hz	hertz
J	joule
kg	kilogram
m	meter
N	newton
rad	radian
s	second
S	siemen
VA	voltampere
var	voltampere reactive
W	watt
Wb	weber
Ω	ohm

English Units

BTU	British thermal unit
cmil	circular mil
ft	foot
hp	horsepower
in	inch
mi	mile

Notation

Lowercase letters such as v(t) and i(t) indicate instantaneous values.
Uppercase letters such as V and I indicate rms values.
Uppercase letters in italic such as V and I indicate rms phasors.
Matrices and vectors with real components such as **R** and **I** are indicated by boldface type.
Matrices and vectors with complex components such as $\boldsymbol{Z}$ and $\boldsymbol{I}$ are indicated by boldface italic type.
Superscript T denotes vector or matrix transpose.
Asterisk (*) denotes complex conjugate.
■ indicates the end of an example and continuation of text.
PW highlights problems that utilize PowerWorld Simulator.

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