

POWER ELECTRONICS HANDBOOK

DEVICES, CIRCUITS, AND APPLICATIONS

Third Edition

Edited by

Muhammad H. Rashid, Ph.D.,

Fellow IET (UK), Fellow IEEE (USA)

Professor

Electrical and Computer Engineering

University of West Florida

11000 University Parkway

Pensacola, FL 32514-5754, U.S.A.

Phone: 850-474-2976

e-mail: mrashid@uwf.edu


ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON • NEW YORK • OXFORD
PARIS • SAN DIEGO • SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Butterworth-Heinemann is an imprint of Elsevier




Table of Contents

Chapter 1	Introduction	1
	<i>Philip T. Krein</i> <i>Department of Electrical and Computer Engineering</i> <i>University of Illinois</i> <i>Urbana, Illinois, USA</i>	
Section I: Power Electronics Devices		
Chapter 2	The Power Diode	17
	<i>Ali I. Maswood</i> <i>School ofEEE</i> <i>Nanyang Technological University</i> <i>Nanyang Avenue, Singapore</i>	
Chapter 3	Power Bipolar Transistors	29
	<i>Marcelo Godoy Simoes</i> <i>Engineering Division</i> <i>Colorado School of Mines</i> <i>Golden, Colorado, USA</i>	
Chapter 4	The Power MOSFET	43
	<i>Issa Batarseh</i> <i>School of Electrical Engineering and Computer Science</i> <i>University of Central Florida</i> <i>4000 Central Florida Blvd.</i> <i>Orlando, Florida, USA</i>	
Chapter 5	Insulated Gate Bipolar Transistor	73
	<i>S. Abedinpour and K. Shenai</i> <i>Department of Electrical Engineering and Computer Science</i> <i>University of Illinois at Chicago</i> <i>851, South Morgan Street (MIC 154)</i> <i>Chicago, Illinois, USA</i>	

Chapter 6 Thyristors

Angus Bryant
Department of Engineering
University of Warwick
Coventry CV4 7AL, UK

Enrico Santi
Department of Electrical Engineering
University of South Carolina
Columbia, South Carolina, USA

Jerry Hudgins
Department of Electrical Engineering
University of Nebraska
Lincoln, Nebraska, USA

Patrick Palmer
Department of Engineering
University of Cambridge
Trumpington Street
Cambridge CB2 1PZ, UK

Chapter 7 Gate Turn-off Thyristors

Muhammad H. Rashid
Electrical and Computer Engineering
University of West Florida
11000 University Parkway
Pensacola, Florida 32514-5754, USA

Chapter 8 MOS Controlled Thyristors (MCTs)

S. Yuvarajan
Department of Electrical Engineering
North Dakota State University
P.O. Box 5285
Fargo, North Dakota, USA

Chapter 9 Static Induction Devices

Bogdan M. Wilamowski
Alabama Microelectronics Science and Technology Center
Auburn University
Alabama, USA

Section II: Power Conversion

Chapter 10 Diode Rectifiers

Yim-Shu Lee and Martin H. L. Chow
Department of Electronic and Information Engineering
The Hong Kong Polytechnic
University Hung Horn
Hong Kong

Table of Contents

- Chapter 11 Single-phase Controlled Rectifiers
*Jose Rodriguez, Pablo Lezana,
Samir Kouro, and Alejandro Weinstein
Department of Electronics
Universidad Tecnica Federico
Santa Maria, Valparaiso, Chile*
- Chapter 12 Three-phase Controlled Rectifiers
*Juan W. Dixon
Department of Electrical Engineering
Pontificia Universidad Catolica de Chile
Vicuna Mackenna 4860, Santiago, Chile*
- Chapter 13 DC-DC Converters
*Dariusz Czarkowski
Department of Electrical and Computer Engineering
Polytechnic University
Brooklyn, New York, USA*
- Chapter 14 DC/DC Conversion Technique and Twelve Series Luo-converters
*Fang Lin Luo
School ofEEE, Block SI
Nanyang Technological University
Nanyang Avenue, Singapore*
*Hong Ye
School of Biological Sciences, Block SBS
Nanyang Technological University
Nanyang Avenue, Singapore*
- Chapter 15 Inverters
*Jose R. Espinoza
Departamento de Ingenieria Electrica, of 220
Universidad de Concepcion Casilla 160-C, Correo 3
Concepcion, Chile*
- Chapter 16 Resonant and Soft-switching Converters
*S. Y. (Ron) Hui and Henry S. H. Chung
Department of Electronic Engineering
City University of Hong Kong
Tat Chee Avenue, Kowloon
Hong Kong*
- Chapter 17 Multilevel Power Converters
*Surin Khomfoi
King Mongkut's Institute of Technology Ladkrabang
Thailand*
*Leon M. Tolbert
The University of Tennessee
Department of Electrical Engineering and Computer Science
Knoxville, Tennessee, USA*

- Chapter 18 AC-AC Converters
A. K. Chattopadhyay
Department of Electrical Engineering
Bengal Engineering & Science University
Shibpur, Howrah, India
- Chapter 19 Power Factor Correction Circuits
Issa Batarseh and Huai Wei
School of Electrical Engineering and Computer Science
University of Central Florida
4000 Central Florida Blvd.
Orlando, Florida, USA
- Chapter 20 Gate Drive Circuitry for Power Converters
Irshad Khan
University of Cape Town
Department of Electrical Engineering
Cape Town, South Africa

Section III: General Applications

- Chapter 21 Power Electronics in Capacitor Charging Applications
William C. Dillard
Archangel Systems, Incorporated
1635 Pumphrey Avenue Auburn
Alabama, USA
- Chapter 22 Electronic Ballasts
J. Marcos Alonso
Electrical Engineering Department
University of Oviedo
Campus de Viesques s/n
Edificio de Electronica
33204 Gijon, Asturias, Spain
- Chapter 23 Power Supplies
Y. M. Lai
Department of Electronic and Information Engineering
The Hong Kong Polytechnic University
Hong Kong
- Chapter 24 Uninterruptible Power Supplies
Adel Nasiri
Power Electronics and Motor Drives Laboratory
University of Wisconsin-Milwaukee
3200 North Cramer Street
Milwaukee, Wisconsin, USA

Table of Contents

Chapter 25 Automotive Applications of Power Electronics

David J. Perreault

*Massachusetts Institute of Technology
Laboratory for Electromagnetic and Electronic Systems
77 Massachusetts Avenue, 10-039
Cambridge, Massachusetts, USA*

Khurram Afridi

*Techlogix, 800 West Cummings Park
1925, Woburn, Massachusetts, USA*

Iftikhar A. Khan

*Delphi Automotive Systems
2705 South Goyer Road
MS D35 Kokomo
Indiana, USA*

Chapter 26 Solid State Pulsed Power Electronics

Luis Redondo

*Instituto Superior de Engenharia de Lisboa
DEEA, and Nuclear Physics Center from Lisbon University
Av. Prof. Gama Pinto 2, 1649-003 Lisboa, Portugal*

J. Fernando Silva

*TULisbon, Instituto Superior Tecnico, DEEC, A.C. Energia,
Center for Innovation on Electrical and Energy Engineering
Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*

Section IV: Power Generation and Distribution

Chapter 27 Photovoltaic System Conversion

Dr. Lana El Chaar, Ph. D.

*Electrical Engineering Department
The Petroleum Institute
P.O. Box 2533, Abu Dhabi, UAE*

Chapter-28 Power Electronics for Renewable Energy Sources

C. V. Nayar, S. M. Islam

*H. Dehbonei, and K. Tan
Department of Electrical and Computer Engineering
Curtin University of Technology
GPO Box U1987, Perth
Western Australia 6845, Australia*

H. Sharma

*Research Institute for Sustainable Energy
Murdoch University
Perth, Western Australia, Australia*

- Chapter 29 High-Frequency Inverters: From Photovoltaic, Wind, and Fuel-Cell-Based Renewable- and Alternative-Energy DER/DG Systems to Energy-Storage Applications

S. K. Mazumder
Department of Electrical and Computer Engineering
Director, Laboratory for Energy and
Switching-Electronics Systems (LESES)
University of Illinois
Chicago, USA

- Chapter 30 Wind Turbine Applications

Juan M. Carrasco, Eduardo Galvn, and
Ramn Portillo
Department of Electronic Engineering
Engineering School, Seville University, Spain

- Chapter 31 HVDC Transmission

Vijay K. Sood
Hydro-Quebec (IREQ), 1800 Lionel Boulet
Varenes, Quebec, Canada

- Chapter 32 Flexible AC Transmission Systems

E. H. Watanabe
Electrical Engineering Department
COPPE/Federal University of Rio de Janeiro
Brazil, South America

M. Aredes
Electrical Engineering Department
Polytechnic School and COPPE/
Federal University of Rio de Janeiro
Brazil, South America

P. G. Barbosa
Electrical Engineering Department
Federal University of Juiz de Fora
Brazil, South America

F. K. de Araujo Lima
Electrical Engineering Department
Federal University of Cear
Brazil, South America

R. F. da Silva Dias
Pos-doctoral Fellow at Toronto
University supported by Capes Foundation
Ministry of Education
Brazil, South America

G. Santos
Eneltec- Energia Eletrica e Tecnologia
Brazil, South America

Section V: Motor Drives

Chapter 33 Drives Types and Specifications

Yahya Shakweh
Technical Director
FKI Industrial Drives & Controls, England, UK

Chapter 34 Motor Drives

M. F. Rahman
School of Electrical Engineering and Telecommunications
The University of New South Wales, Sydney
New South Wales 2052, Australia

D. Patterson
Northern Territory Centre for Energy Research
Faculty of Technology
Northern Territory University
Darwin, Northern Territory 0909, Australia

A. Cheok
Department of Electrical and Computer Engineering
National University of Singapore
10 Kent Ridge Crescent
Singapore

R. Betz
Department of Electrical and Computer Engineering
University of Newcastle, Callaghan
New South Wales, Australia

Chapter 35 Novel AI-Based Soft Computing Applications in Motor Drives

Adel M. Sharaf and Adel A. A. El-Gammal
Centre for Engineering Studies,
Energy Research, University of
Trinidad and Tobago UTT
Point Lisas Campus, Esperanza Road
Brechin Castle, Couva. P.O. Box 957

Section VI: Control

Chapter 36 Advanced Control of Switching Power Converters

J. Fernando Silva and
Sdnia Ferreira Pinto
TU Lisbon, Instituto Superior Tecnico, DEEC
A.C. Energia, Center for Innovation on Electrical and Energy Engineering
AV. Rorisco Pais 1
1049-001 Lisboa, Portugal

Chapter 37	Fuzzy Logic Applications in Electrical Drives and Power Electronics	1115
	<p><i>Ahmed Rubaai</i> <i>Electrical and Computer Engineering Department</i> <i>Howard University, Washington</i> <i>DC 20059, USA</i></p> <p><i>Paul Young</i> <i>RadiantBlue Technologies, 4501</i> <i>Singer Ct, Ste 220, Chantilly, VA 2015</i></p> <p><i>Abdu Ofoli</i> <i>Electrical Engineering Department</i> <i>The University of Tennessee at Chattanooga</i> <i>Chattanooga, TN 37403, USA</i></p> <p><i>Marcel J. Castro-Sitiriche</i> <i>Electrical and Computer Engineering Department</i> <i>University of Puerto Rico at Mayagüez</i> <i>Mayaguez, Puerto Rico, 00681</i></p>	
Chapter 38	Artificial Neural Network Applications in Power Electronics and Electrical Drives	1139
	<p><i>B. Karanayil and M. F. Rahman</i> <i>School of Electrical Engineering and Telecommunications</i> <i>The University of New South Wales</i> <i>Sydney, New South Wales 2052, Australia</i></p>	
Chapter 39	DSP-based Control of Variable Speed Drives	1155
	<p><i>Hamida A. Toliyat</i> <i>Electrical and Computer Engineering Department</i> <i>Texas A&M University, 3128 Tamus</i> <i>216g Zachry Engineering Center</i> <i>College Station, Texas, USA</i></p> <p><i>Mehdi Abohassani</i> <i>Black & Decker (US) Inc.</i> <i>701 E Joppa Rd., TW100</i> <i>Towson, Maryland, USA</i></p> <p><i>Peyman Niazi</i> <i>Maxtor Co.</i> <i>333 South St., Shrewsbury</i> <i>Massachusetts, USA</i></p> <p><i>Lei Hao</i> <i>Wavecrest Laboratories</i> <i>1613 Star Batt Drive</i> <i>Rochester Hills, Michigan, USA</i></p>	
Section VII: Power Quality and EMI Issues		
Chapter 40	Power Quality	1179
	<p><i>S. Mark Halpin and Angela Card</i> <i>Department of Electrical and Computer Engineering</i> <i>Auburn University</i> <i>Alabama, USA</i></p>	

Table of Contents

Chapter 41 Active Filters

Luis Moran

*Electrical Engineering Dept.
Universidad de Concepcion
Concepcion, Chile*

Juan Dixon

*Electrical Engineering Dept.
Universidad Catdlica de Chile
Santiago, Chile*

Chapter 42 , EMI Effects of Power Converters

Andrzej M. Trzynadlowski

*Electrical Engineering Department
University of Nevada
260 Reno, Nevada, USA*

Section VIII: Simulation and Packaging

Chapter 43 Computer Simulation of Power Electronics and Motor Drives

Michael Giesselmann, P. E.

*Center for Pulsed Power and Power Electronics
Department of Electrical and Computer Engineering
Texas Tech University, Lubbock
Texas, USA*

Chapter 44 Packaging and Smart Power Systems

Douglas C. Hopkins

*Dir.—Electronic Power and Energy Research Laboratory
University at Buffalo
332 Bonner Hall
Buffalo, New York, USA*

Section IX: Energy Sources, Storage and Transmission

Chapter 45 Energy Sources

*Dr. Alireza Khaligh and Dr. Omer C. Onai**

*Energy Harvesting an Renewable Energies Laboratory (EHREL)
Electric Power and Power Electronics Center (EPPEC)
Electrical and Computer Engineering Department
Illinois Institute of Technology
Chicago, IL*

**Oak Ridge National Laboratory
Oak Ridge, TN*

Chapter 46	Energy Storage	1331
	<i>Sheldon S. Williamson and Pablo A. Cassani</i> <i>Power Electronics and Energy</i> <i>Research (PEER) Group, P. D.</i> <i>Ziogas Power Electronics Laboratory</i> <i>Department of Electrical and Computer Engineering</i> <i>Concordia University, Montreal</i> <i>Quebec, Canada</i>	
	<i>Srdjan Lukic</i> <i>Department of Electrical and</i> <i>Computer Engineering, North</i> <i>Carolina State University</i> <i>Raleigh, North Carolina, USA</i>	
	<i>Benjamin Blunier</i> <i>Universite de Technologie de</i> <i>Belfort-Montbeliard, Belfort</i> <i>Cedex, France</i>	
Chapter 47	Electric Power Transmission	1357
	<i>Ir. Zahrul Faizi bin Hussien,</i> <i>Azlan Abdul Rahim, and</i> <i>Noradlina Abdullah</i> <i>Transmission and Distribution</i> <i>TNB Research, Malaysia</i>	
Index		1375