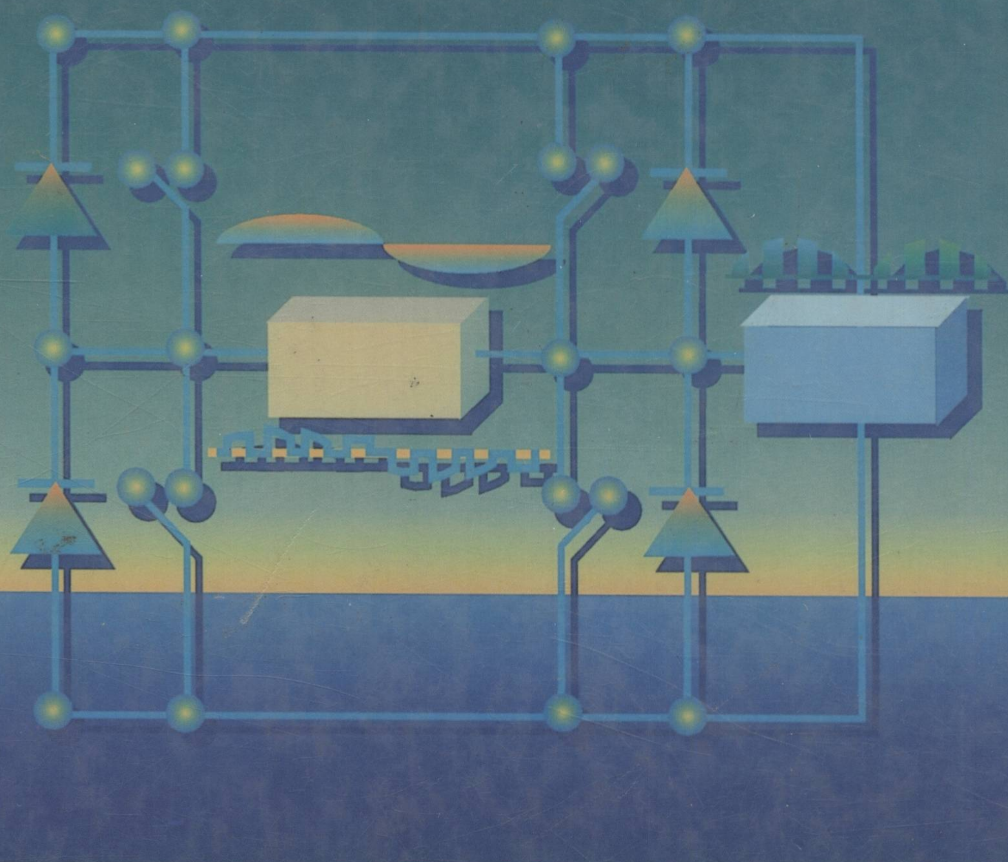
# POWER ELECTRONICS

## CIRCUITS, DEVICES, AND APPLICATIONS

SECOND EDITION



MUHAMMAD H. RASHID

# Power Electronics

## *Circuits, Devices, and Applications*

**Second edition**



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## COMMONLY USED FUNCTIONS

| | $-A$ | $90 \pm A$ | $180 \pm A$ | $270 \pm A$ | $360k \pm A$ |
|---|---|---|---|---|---|
| sin | $-\sin A$ | $\cos A$ | $\mp \sin A$ | $-\cos A$ | $\pm \sin A$ |
| cos | $\cos A$ | $\mp \sin A$ | $-\cos A$ | $\pm \sin A$ | $\cos A$ |

$$\sin (A \pm B) = \sin A \cos B \pm \cos A \sin B$$

$$\cos (A \pm B) = \cos A \cos B \mp \sin A \sin B$$

$$\sin 2A = 2 \sin A \cos A$$

$$\cos 2A = 1 - 2 \sin^2 A = 2 \cos^2 A - 1$$

$$\sin A + \sin B = 2 \sin \frac{A + B}{2} \cos \frac{A - B}{2}$$

$$\sin A - \sin B = 2 \cos \frac{A + B}{2} \sin \frac{A - B}{2}$$

$$\cos A + \cos B = 2 \cos \frac{A + B}{2} \cos \frac{A - B}{2}$$

$$\cos A - \cos B = 2 \sin \frac{A + B}{2} \sin \frac{B - A}{2}$$

$$\sin A \sin B = \frac{1}{2} [\cos (A - B) - \cos (A + B)]$$

$$\cos A \cos B = \frac{1}{2} [\cos (A - B) + \cos (A + B)]$$

$$\sin A \cos B = \frac{1}{2} [\sin (A - B) + \sin (A + B)]$$

$$\int \sin nx \, dx = -\frac{\cos nx}{n}$$

$$\int \sin^2 nx \, dx = \frac{x}{2} - \frac{\sin 2nx}{4n}$$

## COMMONLY USED FUNCTIONS

$$\int \sin mx \sin nx\, dx = \frac{\sin (m-n)x}{2(m-n)} - \frac{\sin (m+n)x}{2(m+n)} \quad \text{for } m = n$$

$$\int \cos nx\, dx = \frac{\sin nx}{n}$$

$$\int \cos^2 nx\, dx = \frac{x}{2} + \frac{\sin 2nx}{4n}$$

$$\int \cos mx \cos nx\, dx = \frac{\sin (m-n)x}{2(m-n)} + \frac{\sin (m+n)x}{2(m+n)} \quad \text{for } m = n$$

$$\int \sin nx \cos nx\, dx = \frac{\sin^2 nx}{2n}$$

$$\int \sin mx \cos nx\, dx = -\frac{\cos (m-n)x}{2(m-n)} - \frac{\cos (m+n)x}{2(m+n)} \quad \text{for } m = n$$

## SOME UNITS AND CONSTANTS

| Quantity | Units | Equivalent |
|---|---|---|
| Length | 1 meter (m) | 3.281 feet (ft) |
| | | 39.36 inches (in) |
| Mass | 1 kilogram (kg) | 2.205 pounds (lb) |
| | | 35.27 ounces (oz) |
| Force | 1 newton (N) | 0.2248 force pounds (lbf) |
| Torque | 1 newton-meter (N.m.) | 0.738 pound-feet (lbf.ft) |
| Moment of inertia | 1 kilogram-meter² ($kg.m^2$) | 23.7 pound-feet² ($lb.ft^2$) |
| Power | 1 watt (W) | 0.7376 foot-pounds/second |
| | | $1.341 \times 10^{-3}$ horsepower (hp) |
| Energy | 1 joules (J) | 1 watt-second |
| | | 0.7376 foot-pounds |
| | | $2.778 \times 10^{-7}$ kilowatt-hours (kWh) |
| Horsepower | 1 hp | 746 watts |
| Magnetic flux | 1 weber (Wb) | $10^8$ maxwells or lines |
| Magnetic flux density | 1 tesla (T) | 1 weber/meter² ($Wb/m^2$) |
| | | $10^4$ gauss |
| Magnetic field intensity | 1 ampere-turn/meter (At/m) | $1.257 \times 10^2$ oersted |
| Permeability of free space | $\mu_0 = 4\pi \times 10^7$ H/m | |

*To my parents, my wife Fatema*
*and*
*my children, Faeza, Farzana, and Hasan*

# Preface

*Power Electronics* is intended as a textbook for a course on "power electronics/ static power converters" for junior or senior undergraduate students in electrical and electronic engineering. It could also be used as a textbook for graduate students and could be a reference book for practicing engineers involved in the design and applications of power electronics. The prerequisites would be courses on basic electronics and basic electrical circuits. The content of *Power Electronics* is beyond the scope of a one-semester course. For an undergraduate course, Chapters 1 to 11 should be adequate to provide a strong background on power electronics. Chapters 12 to 16 could be left for other courses or included in a graduate course.

The time allocated to a course on power electronics in a typical undergraduate curriculum is normally only one semester. Power electronics has already advanced to the point where it is difficult to cover the entire subject in a one-semester course. The fundamentals of power electronics are well established and they do not change rapidly. However, the device characteristics are continuously being improved and new devices are added. *Power Electronics*, which employs the bottom-down approach, covers device characteristics conversion techniques first, and then applications. It emphasizes the fundamental principles of power conversions. This edition of power electronics is a complete revision of its first edition, and (i) features bottom-down approach, rather than top-down approach, (ii) introduces the state-of-the-art advanced Modulation Techniques, (iii) presents a new chapter on "Resonant-Pulse Inverters" and covers the state-of-the-art techniques, (iv) integrates the industry standard software, SPICE, and design examples that are verified by SPICE simulation, (v) examines converters with RL-loads, and (vi) has corrected typos, and expanded sections and/or paragraphs to add explanations. The book is divided into five parts:

1. Introduction—Chapter 1
2. Commutation techniques of SCRs and power conversion techniques—Chapters 3, 5, 6, 7, 9, 10, and 11
3. Devices—Chapters 2, 4, and 8
4. Applications—Chapters 12, 13, 14, and 15
5. Protections—Chapter 6

Topics like three-phase circuits, magnetic circuits, switching functions of converters, dc transient analysis, and Fourier analysis are reviewed in the Appendixes.

Power electronics deals with the applications of solid-state electronics for the control and conversion of electric power. Conversion techniques require the switching on and off of power semiconductor devices. Low-level electronics circuits, which normally consist of integrated circuits and discrete components, generate the required gating signals for the power devices. Integrated circuits and discrete components are being replaced by microprocessors.

An ideal power device should have no switching-on and -off limitations in terms of turn-on time, turn-off time, current, and voltage handling capabilities. Power semiconductor technology is rapidly developing fast switching power devices with increasing voltage and current limits. Power switching devices such as power BJTs, power MOSFETs, SITs, IGBTs, MCTs, SITHs, SCRs, TRIACs, GTOs, and other semiconductor devices are finding increasing applications in a wide range of products. With the availability of faster switching devices, the applications of modern microprocessors in synthesizing the control strategy for gating power devices to meet the conversion specifications are widening the scope of power electronics. The power electronics revolution has gained the momentum, since late 80s and early 90s. Within the next 30 years, power electronics will shape and condition the electricity somewhere between its generation and all its users. The potential applications of power electronics is yet to be fully explored. The potential applications of power electronics is yet to be fully explored but we've made every effort to cover as many applications as possible in this book.

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Fort Wayne, Indiana

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