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Book Review

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Power Electronics Textbook Is Mostly Magnetics

Power Electronics: Principles of Analysis and Design Emphasizing Magnetics, volumes 1 and 2, Thomas G. Wilson, Harry A Owen, Jr., Thomas G. Wilson, Jr., 752 pages (1 - 523, and index from 747 - 752 in Vol. 1, 524 - 752 in Vol. 2), glossy soft cover, ISBN-13: 978-1543140613; ISBN-10: 1543140610.

Reviewed by Dennis Feucht, Innovatia Laboratories, Cayo, Belize

This two-volume book on power electronics is a multigenerational effort, beginning with Thomas Wilson and put into published form by his son, Thomas Jr. The senior Wilson and Harry Owen recognized a great debt to their students over 35 years for their contribution to many of the concepts in this book, known to the students as "The Book" at Duke University in Durham, North Carolina. Perhaps this explains why the book does not have a publication date though it has indication of a copyright.

In giving an overview of the field in the introductory chapter (on p. 4), the authors remark, "Power electronics has a history that is much older than many practicing in the field today are likely to realize. The growth and development of this field has not been smooth and orderly, but rather significant technology advances in both components and circuits have brought about dramatic changes in the field that were largely unanticipated."

The authors view power electronics as "a challenging and exciting field with many new applications" and propose that the field began in 1912, when E.F.W. Alexanderson of General Electric patented the magnetic amplifier. This places power electronics near the beginning of electronics itself, with the invention of the Lee de Forest audion (triode), invented six years earlier.

The authors recognize that in most areas of electronics the importance of magnetics is minimal, but power electronics is an exception, having as a central role in power conversion, storage of energy in a magnetic field as a transfer medium. Unlike digital electronics, where large amounts of information can be stored in a relatively small volume, "Achieving similar advances in the density of electromagnetic energy storage will require the discovery or invention of new materials with superior energy-storage properties." (p. 9)

In typical textbook development of theory, the authors announce that power switches will be regarded as ideal, with zero switching time, zero on-resistance and infinite off-resistance, that power transfer is lossless (100% efficiency), and that the output storage capacitor of converters is large enough to make ripple voltage negligible. In other words, the output capacitor can be regarded as a voltage source.

The proliferation of consumer electronics, with small switching converters powering each unit, brings them onto center stage as examples of converters in chapters 12 to 18. Also, piecewise-linear modeling is introduced, hinting at the problem of modeling the nonlinearity of active devices functioning as power switches.

Chapter 2, "Concepts of Nonlinear Circuit Analysis," covers basic theory about circuit elements R, L, and C, voltage and current sources, and then three-terminal active devices. The piecewise-linear diode model is followed by more involved examples of piecewise-linear diode circuits, with hints about magnetic saturation. Chapter 3 also covers the topic of how to analyze switched circuits. Computer involvement appears as SIMPLIS simulator outputs of nonlinear responses. Continuing the nonlinearity thread, power-on and power-off transient circuit response is also demonstrated with simulated examples.

Chapter 4 continues laying the conceptual foundation for power electronics with basic magnetics concepts. A useful table gives magnetic units and conversion factors but continues the widespread conflation of reference indicators as "units" such as "turns" which is not a unit. This ongoing confusion is easily corrected by introducing reference frames of circuit and field, as shown in the following table (from *Power Electronics Design Optimization*, p. 27) and distinguishing between circuit inductance and field inductance or between circuit or field current or flux.

Table. Frames of reference for electrical circuits and magnetic fields.

Reference-Frame	Current	Inductance	Flux	Voltage
Electrical circuit (terminal quantities)	Circuit current, i	Circuit inductance, L	Circuit flux, $\lambda = N \cdot \phi$	Circuit voltage, v
Magnetic field	Field current (MMF), $Ni = N \cdot i$	Field inductance (per-turn-squared inductance), L	Field flux, ϕ	Field voltage, v/N

Following this is a conceptually insightful table of magnetic and electric analogs. The authors retain the historic symbols for magnetic and electric quantities. The SI (and not cgs) units are used. Basic equations for magnetic energy storage in cores are followed by residual induction and "coercive force" (coercivity) which is not force but is magnetic field intensity—another linguistic *faux pas* of historical origin. Illustrations are drawn well, clear in meaning, and captioned.

Chapter 5 continues with *fundaments* of inductors (and not as in the chapter title, "Fundamentals," as one of the leading analog circuit designers, Barrie Gilbert from Britain, once pointed out to me in correction of my American conflation of an adjective for a noun). These concepts are needed for core design, including parallel magnetic paths, path gaps, and other usual topics of the trade.

Chapter 6 continues this with transformers. The authors walk the fence on reference-frame language; the established word in transforming the circuit of one winding to the field, then to that of another winding is winding *referral*, though the infiltrating slang is "reflected". Thus, section 6.2.1 has the title, "Reflecting or Referring Currents, Voltages, and Impedance Elements"—an important topic to understand regardless of the language. Happily, the authors use the standard expression, "referred to" instead of the mirror metaphor, "reflected".

Sometimes it is useful to apply a vision metaphor from the standpoint of someone examining how a circuit works by inverting "referred to" to "viewed from," though this is informal. For instance, "The secondary winding circuit impedance is referred to the primary winding as …" is equivalent to "The secondary winding impedance, as viewed from the primary winding, is …" In the first case, we are on the secondary side, transforming its impedance over to the primary circuit while in the second case, we are on the primary side, looking across to the secondary-side impedance.

The familiar transformer T model is presented but also an equivalent Π model and its relationship to the T model. Besides basic transformer circuit concepts, this chapter covers core shapes, wire, and winding fill factor and polarity.

Chapter 7, "Magnetic Measurements," begins with waveform calculation that includes $B(H)$ characteristics. Some core physics, such as domain walls, is discussed. Then the substantive topic of eddy currents appears. Finally, section 7.8, "Dynamic Loops Measured with Step Change of DC Voltage," adds the measurement topic to the chapter, though the preceding coverage applies to measurement of $B(H)$ loops.

Chapter 8, "Magnetic Materials," goes through the various materials of which cores are made, both powder and sintered ferrite, and how to calculate magnetic core parameters. $B(H)$ and core loss curves abound in the figures. Chapter 9 on "transformer responses" reminds me more of electrical engineering, covering inrush current calculation, secondary load switching, and saturation effects.

With Chapter 10, we leave the fundaments and enter the realm of "Transformer Design". The first paragraph (p. 349) truly states that a multiplicity of design methods or procedures exist, and that the authors attempt to lay out "in a careful fashion the fundamental considerations that must underlie any design procedure and to present a procedure that leads to what might be considered a good design in most circumstances. No attempts at optimization are made." (See my *How2Power Today* articles[1] and book *PMDO*[2] for that.)

Step one is in the right direction—to start with the most basic physical constraints for a transformer, such as maximum temperature and allowable parasitic circuit elements. The design scheme chosen by the authors is the well-known *area-product* method. Subsequent subsections cover various aspects of design though they are not ordered in the logical steps I would choose in putting magnetic (core) design first followed by electrical (winding) design. These two aspects of design have their own optimizing criteria and to mix them can lead away from logical design sequencing.

A detailed design example is given, and like any such procedure, is iterative. (However, iteration can be minimized with an optimal procedure.) This chapter is perhaps a starting point for students, though I find that it is actually simpler to apply a more logical ordering to design sequencing that includes showing why the area-product method is both highly easy to use and highly suboptimal. Much better design schemes take more effort, but not much more.

Chapter 11 is about leakage inductance. The book is now turning attention to a topic of more concern in circuit design. Field-based approximations to leakage inductance are developed and how winding geometry affects the values. The first volume then proceeds to Appendix A, offering a tutorial summary of magnetic fundaments more basic than those in the first few chapters.

Appendix B is on $B(H)$ loops, C on circuit duality, and D on the transformer T equivalent circuit and how to measure model elements with open- and short-circuit measurements. The next appendix, Appendix K, is about FEA models and simulation of fringing flux in air gaps, L is about its estimation, and finally there is a six-page, two-column index. Now on to the second volume.

I could find no explanation as to why this work consists of two volumes, when the second volume would have fit more cohesively into the first. It might have to do with how thick a paperback book can be made without binding failure. Or perhaps volume 2 is an add-on to volume 1—additional development of the topic without the added work of a major new edition. The most likely reason might be that this volume moves to an extent away from magnetics to converter circuit design.

The first chapter—chapter 12—presents what are the three configurations of the PWM-switch, the basic contrived element of most resistance (dc to dc) converters, as developed by Richard Tymerski as a PhD student at VPI under his mentor, Vatché Vorpérian in the late 1980s. This was a conceptual breakthrough that simplified and unified the understanding of converter schemes.

Although the PWM-switch and (like the BJT or FET) its common-terminal two-port configurations are not described as such, the three configurations are brought in. Just as quickly, the topic of converter control appears, with “three basic control laws” (p. 538) with one of three waveform parameters held constant: frequency, on-time, or off-time. This chapter offers a first appearance of basic converter ideas while not developing them. It is a starting point, but the conceptually cleaner PWM-switch model is absent.

Chapter 13 develops converter design by deriving design formulas for the three PWM-switch configurations, and with an emphasis on magnetic field quantities instead of magnetic circuit quantities which I found to be a conflation of the magnetic part of magnetics design with circuit design. The transfer ratios are derived as formulas along with relevant waveform design parameters.

Chapter 14 reverts to magnetic design in pursuing (p. 590) the “Maximum Capacity of a core to store energy”. This is a basic question of magnetic design optimization, that of how the core transfer-energy density can be maximized for a given size of core (or what the smallest core is that can have a given density). However, the two basic limitations on energy storage density, ΔB (relating to maximum core loss and temperature) and average or operating-point H (relating to maximum saturation) I could not find.

Chapters 15 and 16 are about optimizing magnetic parameters such as the highly important number of turns N and permeability (air gap width) with storage capacitor or circuit losses—a jumble of circuit and core magnetics design.

Chapter 17 is titled “Effects of Parameter Variation on Energy-Storage Reactor Design and DC-To-DC Converter Performance”. This chapter is about how variation in the *field-referred inductance*—the per-turn-squared inductance—affects the circuit design. Chapter 18 continues similarly and mentions in one section power-factor correction. The chapters end followed by more appendices.

Appendix I derives equations for operation of converter configurations in CCM and DCM. Appendix J is about converter loss models, considering each component in turn. Finally, the volume 2 index is a repeat of the volume 1 index, as is the table of contents, the symbols and tables lists, and the preface.

I found the beneficial aspects of this book to be largely in the physics-oriented magnetic descriptions. Power electronics theory encompasses many different quantities and readers are benefited by the symbols listing in a glossary, which is found along with a list of tables in the front of this book before the preface.

The first chapters are oriented toward students, though for the book as a whole, the material is not as conceptually refined, simplified, and clarified as could be. I found it confusing and obfuscating of the key insights and questions for both power magnetics and circuits. The other two major concerns of power electronics design besides magnetics and circuit topology are control and parasitic behavior. Both of these are touched upon, but for the sweeping title of the book, *Power Electronics*, too much is left out.

The format of this book separates the illustrations from the text of each chapter and places them at the end of the chapter instead of with the text so that the reader could more readily refer to them. This was probably done because the book is published by the remaining author and not a book publisher with greater page layout resources. One feature of bunching the illustrations together is that more knowledgeable readers can more easily go through the pictures and refer to the text only when necessary.

If you have additional shelf space or want to have a more-complete power-electronics library, I recommend getting a copy of this book. It offers another viewpoint on the subject. Keep in mind that what this book presents is a certain set of topics oriented around magnetics that drives all else in the book.

References

1. See the How2Power Design Guide, and do keyword or author search on “Feucht”.
2. *Power Magnetics Design Optimization* by D. L. Feucht, Innovatia, innovatia.com.

About The Author

Dennis Feucht has been involved in power electronics for 40 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been working on projects in theoretical magnetics and power converter research.

To read Dennis’ reviews of other texts on power supply design, magnetics design and related topics, see How2Power’s Power Electronics Book Reviews.