Preface

In preparing the Sixth Edition of this book, I wanted to introduce several new topics that are having an important impact in the field of electric power. Consequently, in the next few paragraphs I wish to bring these five new topics to your attention.

1) In Chapter 13, Sections 13.33 to 13.36, I explain the properties and behavior of the doubly-fed induction machine. The speed is varied by applying a fixed frequency to the stator and a variable frequency to the rotor, hence the name "doubly-fed". Such machines have traditionally been used as variable-speed motors to drive large pumps. However, they have found a new application in the form of doubly-fed wind turbine generators to produce electricity. Owing to the importance of wind turbines, I thought it necessary to devote some space and time to this special machine.

2) In Chapter 21, Sections 21.45 to 21.51, I made some important modifications to the treatment of pulse-width modulation (PWM). New text and figures have been added to better illustrate this technology.

3) Chapter 23 covers several methods of electronically controlling the speed of electric motors. In Sections 23.31 to 23.40 I have added another important method, named Direct Torque Control (DTC). Instead of using constant frequency pulse-width modulation and vector control, DTC employs a special bang-bang (hysteresis) technique. Thus, DTC requires a new viewpoint regarding speed and torque control. The explanation is straightforward, based on induction motor principles.

4) In Chapter 24, Sections 24.28 to 24.35, I discuss wind power and the use of turbines to extract energy from the wind. Several methods of generating electric power are explained, each with its own particular merits.

5) Chapter 28, Sections 28.20 to 28.24 introduces the HVDC Light™ method of transmitting electric power. An important new way of carrying power to remote locations, it has been rendered possible on account of the ever-increasing power-handling capacity of IGBTs. Their high switching frequencies permit the use of PWM techniques using converters in the tens of megawatt range. As a result, the size of harmonic filters is greatly reduced and, more importantly, the converters can absorb or deliver reactive power as required.

As an added feature, the Instructor's Manual for this Sixth Edition has been completely transformed. Instead of the hand-written Solution to Problems, the entire manual is now typeset, making it much easier to read. Also, as an independent source of information, industrial problems (and solutions) are regularly displayed on the Theodore Wildi Web Site: http://www.wildi-theo.com.

The new material presented in this Sixth Edition amounts to about 50 pages. However, it is important to recognize that these extra pages rest upon hundreds of pages that are already in the book. For example, if a book were written about wind generators alone, it would require at least 200 pages to describe the principle of induction machines, power electronics, speed control, and so forth. The broad coverage of my book permits the introduction of such important new topics without having to re-explain the underlying principles. They are already there. Also, it offers the reader the special advantage of seeing how all these technical subjects hang together.

An overview of evolving technologies

The previous edition of my book was prompted in part by the great increase of computers in industrial controls and automation. Computer programs can simulate relays and relay contacts. These on/off computerized controls have eliminated the wiring and installation of hardware components in favor of virtual relays and contacts that can be programmed on a keyboard. With the help of internet communications, these Programmable Logic Controllers (PLCs) are often integrated with the overall manufacturing process, leading seamlessly to integration with management, sales, procurement, and consumer satisfaction.

Similar upheavals have occurred in power technology. It is simply amazing to witness the entrance of power electronics into every facet of industrial drives. Thus, it is no longer pertinent to discuss dc and ac machines in isolation because wherever they are being installed, an electronic control forms part of the package. Consequently, the term *drive* now involves not the motor alone but the entire unit that directs the torque and speed of the machine. This directly influences the way that courses on electric power are being taught.

How has this dramatic change come about? It is mainly due to the development of high-power solid state switching devices, such as insulated gate bipolar transistors (IGBTs), that can operate at frequencies of up to 20 kHz. The change has also been driven by thyristors and gate turn-off thyristors (GTOs) that can handle currents of several thousand amperes at voltages of up to 5 kV. Another key element is the computing power of microprocessors that can process signal data in real time with incredible speed.

The high switching frequencies of IGBTs permit the use of pulse-width-modulation techniques in power converters. This, in turn, enables torque and speed control of induction motors down to zero speed.

Most industrial drives are in the fractional horsepower to the 500 hp range. That is precisely the range now available for control by IGBTs. The result has been an explosion in the retrofitting of outmoded drives. Lower maintenance costs, higher efficiency, and greater productivity have made such changeovers economically attractive. Thus, dc drives are being replaced by induction motor drives which require less maintenance, while offering equal and often superior dynamic performance.

Every sector of industrial and commercial activity has therefore been affected by this revolutionary converter technology. Electric elevators; electric locomotives; electric transit vehicles; servomechanisms; heating, ventilating and air conditioning systems; fans; compressors; and innumerable industrial production lines are being modified to utilize this new technology.

The change is also affecting the transmission and distribution of electric power – an industry that has been relatively stable for over 50 years. Here, we are seeing large rotating machines, such as synchronous condensers and frequency changers, being replaced by solid-state converters that have no moving parts at all.

Important development work has also resulted in the creation of high-power static switches, thyristor-controlled series capacitors, and converters that can fill the role of phase-shift transformers. These new methods of power flow control, known by the acronym FACTS (Flexible AC Transmission Systems) will permit existing transmission and distribution lines to carry more power to meet the ever-increasing demand for electricity. On account of their extremely fast response, the converters can also stabilize a network that may suddenly be menaced by an unexpected disturbance.

It is a remarkable fact that these innovations all rest on a common base. In other words, the converter technology used in electric motor drives is similar to that employed to control the flow of power in electric utilities. As a result, everything falls neatly and coherently into place. The teaching and learning of electric machines, drives and power systems is thereby made much easier.

A brief look at some key chapters

The writing of circuit equations is included Chapter 2. Most students know how to solve such equations but many experience difficulty in *formulating* them. I disclose an ac/dc circuit-solving methodology that is particularly easy to follow. Readers will be glad to refer to this section as a convenient reminder of the circuit-solving procedure.

Chapter 11 on *Special Transformers* includes higher frequency transformers. The reader is guided through the reasoning behind the design of such transformers, and why they become smaller as the frequency is increased. High-frequency transformers are directly related to the higher frequencies encountered in switching converters.

Chapter 16 on *Synchronous Generators* shows why an increase in size inevitably leads to higher efficiencies and greater outputs per kilogram.This fundamental aspect of machine design will interest many readers.

Chapter 18 develops the equivalent circuit diagram of a single-phase induction motor. It presents a rigorous, yet simple approach, based on the 3-phase induction motor.

Chapter 21 on the *Fundamental Elements of Power Electronics* discusses switching converters and pulse width modulation (PWM) techniques. It illustrates the extraordinary versatility of IGBT converters and how they can be made to generate almost any waveshape and frequency.

Chapter 23 on *Electronic Control of Alternating Current Motors* covers the properties of induction motors operating at variable speeds. A special section explains the basics of PWM drives and flux vector control.

Chapter 29, titled *Transmission and Distribution Solid State Controllers* explains the technologies that are being developed to electronically control the flow of electric power. It also discusses the quality of electric power as regards sags, swells, harmonics, and brownouts. As deregulation of electric power becomes a reality, these electronic methods of controlling the quality of electricity will become increasingly important.

Chapter 30 on *Harmonics* reveals how they are generated and how they affect the behavior of capacitors, inductors, cables, transformers, and the quality of electric power. Harmonics are often viewed with awe and trepidation. This chapter explains in simple language where they come from and how they can be minimized and controlled.

To whom is this book addressed?

The subject matter covered in this book requires only a background in basic circuit theory, algebra, and some trigonometry.

Owing to its user-friendly treatment of even complex topics, this book will meet the needs of a broad range of readers. First, it is appropriate for students following a two-year electrical program in community colleges, technical institutes, and universities. Owing to its very broad coverage, the text can also be incorporated in a 4 - year technology program. Many universities have adopted the book for their electric power service courses.

Instructors responsible for *industrial training* will find that this book contains a wealth of practical information that can be directly applied to that greatest laboratory of all – the electrical industry itself.

Finally, at a time when much effort is being devoted to continuing education, this book, with its many worked-out problems, is particularly well adapted for self study.

The exercises at the end of each chapter are divided into three levels of learning – practical, intermediate and advanced. Furthermore, to encourage the reader to solve the problems, answers are given at the end of the book.

For further information, the reader is invited to consult the list of books, technical articles and Web sites in the References section toward the end of the book.

A quick glance through the book shows the importance given to photographs. All equipment and systems are illustrated by diagrams and pictures, showing them in various stages of construction, or in actual use. Some students may never have visited an industrial plant or seen up close the equipment used in the transmission and distribution of electrical energy. The photographs help convey the magnificent size of these devices and machines.

Throughout the 31 chapters, a conscious effort was made to establish coherence, so that the reader can see how the various concepts fit together. For example, the terminology and power equations for synchronous machines are similar to those found in transmission lines. Transmission lines, in turn, bring up the question of reactive power. And reactive power is an important aspect in electronic converters. Therefore, knowledge gained in one sector is strengthened and broadened by discovering that it can be used in another sector. As a result, the learning of electrical machines, drives, and power systems becomes a challenging, thought-provoking experience.

In order to convey the real-world aspects of machinery and power systems, particular attention has been paid to the inertia of revolving masses, the physical limitations of materials and the problems created by heat. It is felt that this approach falls in line with the multidisciplinary programs of many colleges and technical institutes.

In summary, this book employs a theoretical, practical, multidisciplinary approach to give a broad understanding of electric power technology. Clearly, it is no longer the staid subject it was considered to be some years ago. There is good reason to believe that this dynamic, expanding field will open career opportunities for many people.

I would like to make a final remark concerning the use of my book. As mentioned previously, power technology has made a quantum jump in the past ten years, mainly on account of the availability of fast-acting semiconductors. In the field of electrical machines, drives, and power systems, there will now ensue a long period of consolidation during which existing machines and devices will be replaced by newer models. But the basic technology covered in my book will not change significantly in the foreseeable future. Consequently, the reader will find that this Sixth Edition textbook can also be used as a valuable long-term reference book.

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