LOW PRICE EDITION

PEARSON Education

Electric Machines

Theory, Operation, Applications, Adjustment, and Control

Second Edition

Charles I. Hubert

ELECTRIC MACHINES
Theory, Operation, Applications, Adjustment, and Control

Second Edition

es I. Hubert

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ates Merchant Marine Academy

Shahnaz

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PEARSON
Education

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Dedicated to my lovely wife Josephine for her understanding and encouragement.

Preface

This second edition retains the easy-to-understand student-oriented approach that was the hallmark of the first edition. Additional steps were added to some derivations, and some example problems were expanded for even greater clarity and ease of understanding. New example problems and new homework problems were also added to further enhance student learning. Also added is a section on the high-efficiency NEMA design E AC motors.

The text is designed to be used for a one- or two-semester course in electrical machinery. The minimum prerequisite for effective use of the text is a circuits course and a working knowledge of complex algebra and phasor diagrams. A review of current, voltage, and power relationships in the three-phase system, including applications of complex power, is provided in Appendix A for students who need extra help.

The text is unique in that it responds to the needs of faculty in many colleges who have expressed the desire that more attention be given to current industrial requirements. The most frequent request was for a text that allows faculty to devote more time to motors than to generators, and more time to machine characteristics than to different types of armature windings. To accomplish this, motors are presented before generators, and just enough material on armature windings is provided to acquaint the students with basic armature construction and associated technical terms. NEMA standards and tables are introduced in the solution of application-type problems similar to those found on professional engineering license examinations.

To make more efficient use of student time, transformers and AC machines are presented before DC machines; this sequence was developed and used at the United States Merchant Marine Academy for more than 30 years, where a one-quarter course in AC machines was followed by a one-quarter course in DC machines. Teaching transformers and AC machines when knowledge of AC circuits is still fresh is simple and straightforward. The application of phasor diagrams and complex algebra to equivalent series and equivalent series–parallel circuits of AC machines and transformers provides immediate reinforcement of AC circuit theory.

Alternating current machines and transformers are the building blocks of most present-day power and industrial systems and, as such, require greater emphasis than do DC machines. Furthermore, because conventional DC machines are in effect AC machines whose commutators provide the necessary AC/DC and DC/AC conversion, some additional efficiency may be obtained by presenting AC machines before DC machines.

Presenting motors before generators in both AC and DC machines and presenting DC machines as a stand-alone block of three chapters provide significant freedom in course development. Some easy choices include a one-semester course in only AC machines; a one-semester course in both AC and DC machines (de-emphasizing generators); and a two-semester course that includes all topics on motors and generators for both AC and DC machines. Suggested course outlines are included in the Instructor's Manual.

ORGANIZATION OF THE TEXT

The first chapter provides the basic background common to all machines and transformers. It includes such topics as the development of mechanical force by the interaction of magnetic fields, electromagnetically induced voltages, space angles, electrical degrees, magnetic circuits, and magnetization curves.

The substance of the machinery course begins with transformers in Chapters 2 and 3. Transformers are relatively easy to visualize, and tie in nicely with the ideal transformer covered in a prerequisite circuits course.

The study of induction machines in Chapters 4 and 5 follows naturally from transformers, where the stator is the primary and the rotor is the secondary. Furthermore, introducing induction machines immediately after transformers permits the newly developed equivalent-circuit model and associated phasor diagrams of the transformer to be easily applied to induction-motor theory, illustrating the common relationship they share. Where feasible, approximations are made that allow simplified and practical calculations.

Single-phase induction motors, discussed in Chapter 6, are a natural continuation of three-phase induction motors. Included are capacitor motors, and resistance split-phase motors. Special-purpose motors, such as shaded-pole motors, reluctance motors, hysteresis motors, stepper motors, universal motors, and linear-induction motors are covered in Chapter 7.

Synchronous motors are developed in Chapter 8, and tie in nicely with the rotating field theory of induction motors. The transition from synchronous motor action to synchronous generator operation is presented in Chapter 9. Changes in power angle, as the shaft load is gradually removed and a driving torque applied, are shown on a common phasor diagram. Also included is the parallel operation of synchronous machines, division of load, and power factor correction.

The material on DC machines is designed as a stand-alone block of three chapters (Chapters 10, 11, and 12), so that if desirable it may be taught effectively prior to AC machines and transformers. Thus, courses with special objectives, curriculum requirements, or laboratory constraints that require the early introduction of DC machines may be easily accommodated. Faculty teaching one-quarter or one-semester courses that emphasize AC machines, but still include a very brief introduction to DC machines, will find Chapter 10 (Principles of Direct-Current Machines) more than adequate for the purpose.

Chapter 13 provides a brief introduction to electronic and magnetic control of motors. Typical examples of reversing, speed control, braking, and ladder-type circuits are included. Programmable logic controllers (PLCs) are touched on briefly to provide an insight into this expanding field.

Common Core: The text provides a common core of minimum essentials, supplemented with optional material selected (by the instructor) from a wide range of topics in supplemental chapters. The common core, outlined in the Instructor's Manual, assures a basic understanding of electrical machines, while preparing the student for this millennium. This is accomplished by devoting more time to AC and special-purpose machines than to DC machines, devoting more time to motors than to generators, devoting more time to machine characteristics than to armature windings, and making extensive use of NEMA standards and tables in discussions, examples, and problems.

The common core requires approximately 27 periods and is recommended for all electrical machinery courses regardless of length (one quarter, one semester, two quarters, or two semesters). The limited time available in one-quarter machines courses (approximately 30 periods) will, in most cases, limit course content to the common core. However, if magnetic circuits and transformers are covered in previous courses, these common-core topics should be replaced with optional topics selected to meet regional industrial requirements.

One-semester, two-semester, and two-quarter courses provide ample opportunity for more extensive use of optional topics, enabling the instructor to tailor the course to meet specific objectives. A listing of optional topics available in supplemental chapters is given in the Instructor's Manual, along with a universal one-semester outline that is easily adaptable to different course requirements.

Boldface Letters in Equations: Boldface letters in equations and circuit diagrams are used throughout the text to designate the following as *complex numbers:* current phasors **I**, voltage phasors **V** and **E**, admittance **Y**, impedance **Z**, and phasor power (complex power) **S**. The corresponding magnitudes are printed as |**I**|, |**V**|, |**E**|, |**Y**|, |**Z**|, |**S**|, or *I, V, E, Y, Z, S.*

Boldface Numbers in Rectangular Brackets: Boldface numbers in rectangular brackets, e.g., **[5]**, direct the student to specific end-of-chapter references. This encourages further investigation; students will not have to search a collection of general references for additional information on a specific topic.

Significant Figures: If the answer to one part of a problem is required data for the solution of another part, the unrounded answer is used to minimize continuing errors. Thus, where appropriate, the answers to multipart problems are given in both unrounded form and rounded form. For example, if the answer to part (a) of a problem calls for three significant figures, the text may show it as 127.1648 ⇒ <u>127</u>. Although <u>127</u> is the answer, 127.1648 is substituted in parts (b), (c), etc., as appropriate.

Summary of Equations: A summary of equations at the end of each chapter helps guide the students in solving chapter problems, and is a handy reference for the electrical power portions of professional engineering exams. Furthermore, since the equations are keyed to the text, it is easy for the reader to find the associated application and derivation.

Problem Numbers: Problem numbers are keyed to chapter sections by a triple-number system. For example, Problem 5–9/12 indicates that Chapter 5, Problem 9, requires Section 5–12. This makes it easier for faculty to assign homework problems, and easier for a student to pick additional problems for review. Problems recommended for computer solution (using commercially available software) are indicated with an asterisk.

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Charles I. Hubert

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