Preface to the IEEE Reissued Edition

Many textbooks have been written to describe a power system operating under balanced or normal conditions. A few texts also deal, at least in an elementary manner, with the unbalanced system conditions. The primary object of this book is to provide a text to be used by graduate students and to challenge the student to draw upon a background of knowledge from earlier studies. Since this is intended for advanced studies, the student reader should be able to use circuit concepts at the advanced undergraduate or beginning graduate level and should have a working knowledge of matrix notation. Particular stress here is placed upon a clear, concise notation, since it is the author's belief that this facilitates learning.

Although the thrust of the book is toward the solution of advanced problems, a thorough background is laid in the early chapters by solving elementary configurations of unbalanced systems. This serves to establish the algebraic style and notation of the book as well as to provide the reader with a growing knowledge and facility with symmetrical components. It also introduces the elementary concepts for those not familiar with this discipline. In either case, this background information of the early chapters should be studied since it establishes certain conventions used throughout the book.

The text contains sufficient material for an entire year of study on the subject. The first three chapters are introductory and may be covered rapidly in a graduate level class where the students have already been introduced to symmetrical components. This material should be reviewed, at least in a quick reading, as the matrix notation used throughout the book is introduced in these chapters.

The middle portion of the book, Chapters 4 through 7, treats the subject of *power system parameters.* Here, the sequence impedances of transmission lines, machines, and transformers are developed in detail. This is important material and is often omitted in the education of power engineers. Methods are used here that permit exact solutions of very general physical problems, such as finding the impedance of untransposed or partially transposed lines. Matrix methods are used to clarify computations and adapt them to computer usage.

The final portion of the book presents the application of symmetrical components to a variety of problems and provides an introduction to computer solution methods for large networks. Here, one learns to appreciate the use of matrix algebra in the solution of complex problems. This section also reinforces the engineer's appreciation of symmetrical components as a problem-solving technique.

In preparing the manuscript of a book of this type, one stands on the shoulders of giants. Several excellent books introduced these concepts in the first half of the

twentieth century, in particular those by C. F. Wagner and R. D. Evans, G. O. Calabrese, and the books by Edith Clarke, are classics on symmetrical components and are still used by many of us. Their basic ideas are enlarged upon here, and the presentation simplified by the use of matrix methods, thereby aiding understanding and making computer solution much easier. The author's colleagues at Iowa State University played an important role in the development of the book. They used the book in its early stages, found many problems, and offered helpful suggestions for areas needing improvement. The electrical engineering department at Iowa State University was also helpful and understanding of the need for this effort and provided support in many ways.

This new printing of the book by IEEE Press provides software that was especially developed at Iowa State University for the solution of exactly the kind of problems introduced in this book. The program PWRMAT was developed by the author, fellow faculty members, and graduate students for the purpose of providing the engineer with a convenient method of solving the many problems associated with matrices of complex numbers. The program has been improved over the years by Iowa State University and has been used and enjoyed by many students for at least twenty years. Iowa State University has graciously agreed that the program could be distributed with this printing of the book to make problem solving easier. This is important, since the drudgery of solving these complex problems by calculator distracts the engineering student from the objective of learning the concepts. The software and text file versions of the user's manual are attached to the book on diskettes. The software is easy to master and to use. It permits the user to write small programs in a simple language that can read a user-created data file to solve the problem at hand and print the computed results in an orderly matrix notation. Operations such as matrix inversion or reduction are accomplished with ease. It is hoped that the addition of this software will help many new readers in their desire to become more proficient with the important subjects covered in this book.

P. M. Anderson
San Diego, California

Preface

Many textbooks have been written dealing with the power system that operates under balanced or normal conditions. A few, particularly the excellent recent text by W. D. Stevenson [9], deal in an elementary way with both normal and faulted systems. Most of the books treating unbalanced and faulted systems, however, have been in print for years and are inadequate for several reasons. Nevertheless, in spite of their date of copyright, the serious student should become familiar with the famous works of C. F. Wagner and R. D. Evans [10], the outstanding volumes by Edith Clarke [11] and the more recent work of Calabrese [24].

The goal here is to produce a text to be used by graduate students, one that can draw upon a background of knowledge from previous courses. Since this is an advanced text, the student should be able to employ circuit concepts not usually taught to undergraduates and should recognize the beauty and simplicity of matrix notation. Particular stress is placed upon a clear, concise notation since it is the author's belief that this facilitates learning.

Although the thrust of the book is toward the solution of advanced problems, a thorough background is laid by solving elementary configurations of unbalanced systems. This serves to establish the algebraic style and notation of the book. It also serves to introduce the elementary concepts to the uninitiated. Thus for some it will be an organized review and for others an introduction to the solution of faulted networks. In either case this background should be studied since it establishes certain conventions used later.

The text contains sufficient material for a two-semester or three-quarter treatment of the subject. The first three chapters are introductory and may be covered rapidly in a graduate class where the students have already been introduced to symmetrical components. This material should be reviewed, at least in a quick reading, as the matrix notation used throughout the book is introduced in these chapters.

The middle portion of the book, Chapters 4 through 7, treat the subject of *power system parameters*. Here the sequence impedances of lines, machines, and transformers are developed in detail. This is important material and is often omitted in the education of power engineers. Methods are used here which permit exact solutions of very general physical problems such as finding the impedance of untransposed or partially transposed lines. Matrix methods are used to clarify these computations and adapt them to computer usage.

The final portion of the book presents the application of symmetrical com-

ponents to a variety of problems and provides an introduction to computer solution of large networks. Here one learns to appreciate the use of matrix algebra in the solution of complex problems. This section also reinforces the engineer's appreciation of symmetrical components as a problem-solving technique.

At Iowa State University we have found it convenient to cover most of the first 10 chapters in a two-quarter sequence, leaving computer applications as a separate course. This means that some of the sections in Chapters 1-10 must be omitted, but the student is encouraged to pursue these on his own. In this two-quarter presentation Chapters 1-3 are skimmed quickly since the course carries an undergraduate prerequisite which introduces symmetrical components. Then the balance of the first quarter is spent on power system parameters, leaving the applications for the second quarter.

This book would not have been possible without the unique contribution of many individuals to whom the author is greatly indebted. Several Iowa State University colleagues, particularly W. B. Boast, J. W. Nilsson, and J. E. Lagerstrom (now of the University of Nebraska), are largely responsible for the author's interest in the subject. These three were also responsible for the organization and teaching of a short course in symmetrical components, taught in connection with the Iowa State University A-C Network Analyzer for 10 years or so. The author's interest in this course, first as a student and later as a teacher, helped him gain competence in the subject. Indeed, many ideas expressed here are taken directly or indirectly from the short course notes. The influence of the late W. L. Cassell must also be mentioned, for his insistence on a clear notation has contributed to the education and understanding of many students, the author included. The author is particularly indebted to David D. Robb who used much of the book in a graduate class and made countless valuable suggestions for improvements. Portions of the computer solutions presented are the work of J. R. Pavlat and G. N. Johnson, and these contributions are gratefully acknowledged.

Finally, I wish to express my thanks to the Electrical Engineering Department of Iowa State University and to W. B. Boast, head of the department, for giving me the opportunity to prepare this material. Special thanks are due to my wife, Ginny, who provided both moral support and expert proofreading, and to my editor, Nancy Bohlen, who is a marvel with both mathematical notation and eccentric authors.