Preface

This book is intended to provide the engineer with technical information on subsynchronous resonance (SSR), and to show how the computation of eigenvalues for the study of SSR in an interconnected power system can be accomplished. It is primarily a book on mathematical modeling. It describes and explains the differential equations of the power system that are required for the study of SSR. However, the objective of modeling is analysis. The analysis of SSR may be performed in several different ways, depending on the magnitude of the disturbance and the purpose of the study. The goal here is to examine the *small disturbance* behavior of a system in which SSR oscillations may exist. Therefore, we present the equations to compute the *eigenvalues* of the power system so that the interaction between the network and the turbine-generator units can be studied. Eigenvalue analysis requires that the system be linear. Since turbine-generator equations are nonlinear, the linearization of these equations is also explained in detail. The equations are also normalized to ease the problem of providing data for existing systems and for estimating data for future systems that are under study.

There are many references that describe SSR phenomena, some general or introductory in nature, and others very technical and detailed. The authors have been motivated to provide a book that is tutorial on the subject of SSR, and to provide more detail in the explanations than one generally finds in the technical literature. It is assumed that the user of this book is acquainted with power systems and the general way in which power systems are modeled for analysis. Normalization of the power system equations is performed here, but without detailed explanation. This implies that background study may be required by some readers, and this study is certainly recommended. In some cases, the background reading may be very important. Numerous references are cited to point the way and certain references are mentioned in the text that are believed to be helpful.

The authors wish to acknowledge the support of the Los Angeles Department of Water and Power (DWP) and the Arizona Public Service Company (APS) for sponsoring the work that led to the writing of this book. In particular, the advice and assistance of Eli Katz and Richard Lee of DWP and of Richard Farmer of APS are acknowledged. Mr. Katz was the prime mover in having this work undertaken, and he did so in anticipation of his retirement, at which time he realized that he was about the only person in his company with experience in solving SSR problems. He and Mr. Lee felt

that a tutorial reference book would be helpful to their younger colleagues, since there are no textbooks on the subject, and requested that a tutorial report be submitted on the subject. They also felt that their company needed the eigenvalue computation capability to reinforce other methods then in use by their company for SSR studies.

Mr. Farmer of APS also became involved in the project and assisted greatly in its success, drawing on his personal knowledge of the subject. He provided valuable insight and was responsible for focusing our work at the microcomputer level. This had not been previously considered, partly because eigenvalue computation is computer intensive and had "always been done" on large computers. In retrospect, this was a great idea, and we all became quite enthusiastic about it.

This project led to a collaboration among the three authors, and indeed led to the writing of this book. Jim Van Ness was our expert on eigenvalue and eigenvector computation. We used the program PALS that he had written earlier for the Bonneville Power Administration as the backbone code for the eigenvalue/eigenvector calculations. Jim was also responsible for the coding of our additions to that backbone program and for testing our equations on his computer to make sure we were getting the right answers.

Baj Agrawal was our expert on many topics, but particularly the specification of data for making SSR studies. His extensive experience in performing system tests to determine these data provided us with valuable insights. We hope that his documentation of this information will be helpful to the reader, especially those who have the responsibility of system testing. Much of this information has never before appeared in a tutorial book before, and is taken from fairly recent research documents.

Paul Anderson provided the material on modeling of the system, its transformation, and normalization. He worked on much of the descriptive material for the book and served as a managing editor to see that it all came together in the same language, if not in the same style.

It was a good collaboration for the three of us and we learned to appreciate the expertise of our colleagues as we worked together. We sincerely hope that this comes through for the reader and that the book might be as interesting for the engineer to read as it was for us to prepare.

The authors would like to thank several individuals who provided valuable assistance in the preparation and checking of the manuscript. Most of the

figures were prepared on the computer by Garrett Rusch, a student at the University of California at San Diego, whose skill in computer graphics drafting is acknowledged. We are also indebted to Jai-Soo Jang, a graduate student at Northwestern University, who studied the entire manuscript and found many typographical errors that we were glad to have corrected. We also thank Mahmood Mirheydar for his work in preparing data in a convenient form for plotting. Finally, we extend a special thanks Dr. Christopher Pottle of Cornell University, who helped us to understand the proper methods for modeling the network for eigenvalue calculations and provided us with a computer program for this evaluation.

For those who might be interested in the details of producing a book of this kind, a few facts concerning its production may be of interest. This book was written entirely on a Macintosh®[1] computer using the program Word® 4.0[2]. All the line drawings were produced using MacDraw® and MacDraw®II[3], and the plots were produced using the Igor©[4] program. All equations were written using the program Mathtype®[5] . The pages were printed using a Linotronic®[6] 300 printer, at a resolution of 1270 dots per inch. The typeface is New Century Schoolbook, and was chosen for its clarity and style, and because it lends itself well to mathematical expressions. The personal computer process permitted the authors to deliver camera ready copy directly to IEEE. Since the text did not have to be reset by a professional typographer, the usual process of page proofs and galleys was thereby eliminated. This saved a great deal of time and prevented the introduction of errors in the retyping of the entire book and, especially, the equations. This is the first book published by IEEE using this process, but will surely not be the last.

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