PREFACE

Engineering for sustainability is an emerging theme for the twenty-first century, and the need for more environmentally benign electric power systems is a critical part of this new thrust. Renewable energy systems that take advantage of energy sources that won't diminish over time and are independent of fluctuations in price and availability are playing an ever-increasing role in modern power systems. Wind farms in the United States and Europe have become the fastest growing source of electric power; solar-powered photovoltaic systems are entering the marketplace; fuel cells that will generate electricity without pollution are on the horizon. Moreover, the newest fossil-fueled power plants approach twice the efficiency of the old coal burners that they are replacing while emitting only a tiny fraction of the pollution.

There are compelling reasons to believe that the traditional system of large, central power stations connected to their customers by hundreds or thousands of miles of transmission lines will likely be supplemented and eventually replaced with cleaner, smaller plants located closer to their loads. Not only do such distributed generation systems reduce transmission line losses and costs, but the potential to capture and utilize waste heat on site greatly increases their overall efficiency and economic advantages. Moreover, distributed generation systems offer increased reliability and reduced threat of massive and widespread power failures of the sort that blacked out much of the northeastern United States in the summer of 2003.

It is an exciting time in the electric power industry, worldwide. New technologies on both sides of the meter leading to structural changes in the way that power is provided and used, an emerging demand for electricity in the developing countries where some two billion people now live without any access to power, and increased attention being paid to the environmental impacts of power production are all leading to the need for new books, new courses, and a new generation of engineers who will find satisfying, productive careers in this newly transformed industry.

This book has been written primarily as a textbook for new courses on renewable and efficient electric power systems. It has been designed to encourage self-teaching by providing numerous completely worked examples throughout. Virtually every topic that lends itself to quantitative analysis is illustrated with such examples. Each chapter ends with a set of problems that provide added practice for the student and that should facilitate the preparation of homework assignments by the instructor.

While the book has been written with upper division engineering students in mind, it could easily be moved up or down in the curriculum as necessary. Since courses covering this subject are initially likely to have to stand more or less on their own, the book has been written to be quite self-sufficient. That is, it includes some historical, regulatory, and utility industry context as well as most of the electricity, thermodynamics, and engineering economy background needed to understand these new power technologies.

Engineering students want to use their quantitative skills, and they want to design things. This text goes well beyond just introducing how energy technologies work; it also provides enough technical background to be able to do first-order calculations on how well such systems will actually perform. That is, for example, given certain windspeed characteristics, how can we estimate the energy delivered from a wind turbine? How can we predict solar insolation and from that estimate the size of a photovoltaic system needed to deliver the energy needed by a water pump, a house, or an isolated communication relay station? How would we size a fuel cell to provide both electricity and heat for a building, and at what rate would hydrogen have to be supplied to be able to do so? How would we evaluate whether investments in these systems are rational economic decisions? That is, the book is quantitative and applications oriented with an emphasis on resource estimation, system sizing, and economic evaluation.

Since some students may not have had any electrical engineering background, the first chapter introduces the basic concepts of electricity and magnetism needed to understand electric circuits. And, since most students, including many who have had a good first course in electrical engineering, have not been exposed to anything related to electric power, a practical orientation to such topics as power factor, transmission lines, three-phase power, power supplies, and power quality is given in the second chapter.

Chapter 3 gives an overview of the development of today's electric power industry, including the regulatory and historical evolution of the industry as well as the technical side of power generation. Included is enough thermodynamics to understand basic heat engines and how that all relates to modern steam-cycle, gas-turbine, combined-cycle, and cogeneration power plants. A first-cut at evaluating the most cost-effective combination of these various types of power plants in an electric utility system is also presented.

The transition from large, central power stations to smaller distributed generation systems is described in Chapter 4. The chapter emphasizes combined heat and power systems and introduces an array of small, efficient technologies, including reciprocating internal combustion engines, microturbines, Stirling engines, concentrating solar power dish and trough systems, micro-hydropower, and biomass systems for electricity generation. Special attention is given to understanding the physics of fuel cells and their potential to become major power conversion systems for the future.

The concept of distributed resources, on both sides of the electric meter, is introduced in Chapter 5 with a special emphasis on techniques for evaluating the economic attributes of the technologies that can most efficiently utilize these resources. Energy conservation supply curves on the demand side, along with the economics of cogeneration on the supply side, are presented. Careful attention is given to assessing the economic and environmental benefits of utilizing waste heat and the technologies for converting it to useful energy services such as air conditioning.

Chapter 6 is entirely on wind power. Wind turbines have become the most cost-effective renewable energy systems available today and are now completely competitive with essentially all conventional generation systems. The chapter develops techniques for evaluating the power available in the wind and how efficiently it can be captured and converted to electricity in modern wind turbines. Combining wind statistics with turbine characteristics makes it possible to estimate the energy and economics of systems ranging from a single, home-size wind turbine to large wind farms of the sort that are being rapidly built across the United States, Europe, and Asia.

Given the importance of the sun as a source of renewable energy, Chapter 7 develops a rather complete set of equations that can be used to estimate the solar resource available on a clear day at any location and time on earth. Data for actual solar energy at sites across the United States are also presented, and techniques for utilizing that data for preliminary solar systems design are presented.

Chapters 8 and 9 provide a large block of material on the conversion of solar energy into electricity using photovoltaics (PVs). Chapter 8 describes the basic physics of PVs and develops equivalent circuit models that are useful for understanding their electrical behavior. Chapter 9 is a very heavily design-oriented approach to PV systems, with an emphasis on grid-connected, rooftop designs, off-grid stand-alone systems, and PV water-pumping systems.

I think it is reasonable to say this book has been in the making for over three and one-half decades, beginning with the impact that Denis Hayes and Earth Day 1970 had in shifting my career from semiconductors and computer logic to environmental engineering. Then it was Amory Lovins' groundbreaking paper "The Soft Energy Path: The Road Not Taken?" (Foreign Affairs, 1976) that focused my attention on the relationship between energy and environment and the important roles that renewables and efficiency must play in meeting the coming challenges. The penetrating analyses of Art Rosenfeld at the University of California, Berkeley, and the astute political perspectives of Ralph Cavanagh at the Natural Resources Defense Council have been constant sources of guidance and inspiration. These and other trailblazers have illuminated the path, but it has been the challenging, committed, enthusiastic students in my Stanford classes who have kept me invigorated, excited and energized over the years, and I am deeply indebted to them for their stimulation and friendship.

I specifically want to thank Joel Swisher at the Rocky Mountain Institute for help with the material on distributed generation, Jon Koomey at Lawrence Berkeley National Laboratory for reviewing the sections on combined heat and power and Eric Youngren of Rainshadow Solar for his demonstrations of microhydro power and photovoltaic systems in the field. I especially want to thank Bryan Palmintier for his careful reading of the manuscript and the many suggestions he made to improve its readability and accuracy. Finally, I raise my glass, as we do each evening, to my wife, Mary, who helps the sun rise every day of my life.

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