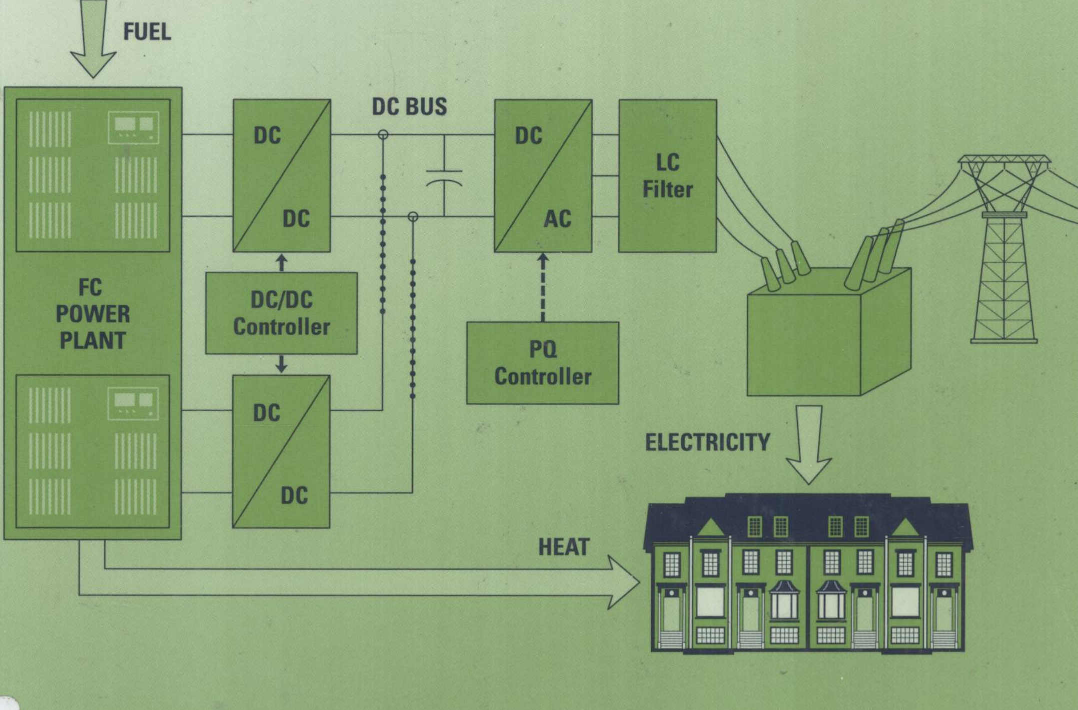
MODELING AND CONTROL OF FUEL CELLS

DISTRIBUTED GENERATION APPLICATIONS

M. Hashem Nehrir
Caisheng Wang



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Modeling and Control of Fuel Cells: Distributed Generation Applications
M. Hashem Nehrir and Caisheng Wang

PREFACE

Fuel cells (FCs) have caught intensive attention in the last decade. Following their successful development for the manned space program by the U.S. National Aeronautical and Space Administration (NASA) in the 1960s, significant advances have been achieved in the fuel cell technology and the applications of different types of fuel cells.

Environmental concerns and world-wide social and political pressure to reduce carbon dioxide emission, and the desire to seek higher energy conversion efficiencies in electrical power generation, have been the main drivers for fuel cell technological advances and their applications, including distributed power generation and fuel cell vehicle applications. Electrical power producers are seeking ways to gain competitive position in the deregulated power market by contributing to reduced environmental emissions. In addition, as a part of the requirement to pursue technologies to reduce carbon emissions, the automobile industry has started FC vehicle development with the ultimate goal of reaching zero-emission car.

The operation of fuel cells, being based on electrochemical principles, is normally better understood by scientists (i.e., chemists, physicists, and material scientists) and chemical engineers working in this area. Since the end product of fuel cells is electricity, their operation also needs to be understood by electrical engineers working in the area to be able to design interfacing electrical circuits and controllers to achieve their improved performance. For this reason accurate and user-friendly dynamic fuel cell models are needed to evaluate their steady-state and transient performance from electrical engineering. This book bridges the gap between the two groups, namely scientists/chemical engineers and electrical engineers. It explains the principle of operation of fuel cells in a simple language understood by electrical engineers. It also explains the development of physically-based dynamic models for PEM fuel cells (PEMFCs) and tubular solid-oxide fuel cells (SOFCs), which have great potential for distributed generation (DG) and mobile applications. The main focus of the book, however, is on modeling, control and applications of the above two types of fuel cells. PEMFCs are suitable for residential and backup power as well as DG and FC vehicle applications. SOFCs are high-temperature fuel cells suitable for DG and combined heat and power (CHP) operation to achieve high system energy efficiency.

This book is the result of over 10 years of research on PEMFC and SOFC. It combines the theory, modeling, interfacing, and control of FC systems in one place. The book is intended to be a resource for all engineers, in particular, electrical, chemical, and mechanical engineers, and for all those interested in designing controllers and interfacing circuits for FC energy systems and FC vehicles of the future. An overview of the chapters covered in the book is given below:

Chapter 1 gives a brief history of U.S. electric utility formation and background about the restructured utility that leads to increased interest in DG. Then, an overview of DG and its different types, DG applications of FCs, an introduction to hydrogen economy, and a need for a FC-powered society are covered.

Chapter 2 gives a brief coverage of electrical and thermal energy, fundamentals of thermodynamics, and electrochemical processes, which have lead to the operation of FCs. The principles of operation of major types of FCs and electrolyzer are also covered.

Chapters 3–5 cover the modeling of PEMFC, tubular SOFC, and electrolyzer, respectively. The development of a physically-based dynamic model and equivalent electrical circuit model for PEMFC and PEMFC model validation are given in Chapter 3. Chapter 4 covers the development of a physically-based dynamic model for tubular SOFC under different operating conditions. The process of water electrolysis and electrolyzer modeling are introduced in Chapter 5. The emphasis in these chapters is on the electrical terminal characteristics of PEMFC, tubular SOFC, and electrolyzer.

An introduction to and modeling of power electronic switching devices and circuits for FC energy systems is given in Chapter 6. Power electronic (power conditioning) devices are important and integral part of FC systems to obtain conditioned electricity output with desired power quality. The development of the models in the rotating (*dq*) reference frame, which is useful in controller design (covered in Chapters 7 and 8) is also presented.

Fuel cells face a variety of load and/or electrical disturbances. Proper controllers must be integral parts of FC systems to achieve their reliable and durable operation in delivering electricity of desired quality. Chapters 7 and 8 cover control methodologies and controller designs for stand-alone and grid-connected operation of FCDG systems, respectively.

Hybrid alternative energy power generation systems are expected to be an important part of the power generation paradigm of the future. Chapter 9 covers two distinct examples of applying the developed FC models and controller design methodologies for designing hybrid DG systems including FCs. The chapter covers the design and performance investigation of a hybrid wind/photovoltaic (PV)/FC-electrolyzer system using PEMFC and the operation and efficiency evaluation of SOFC in CHP (combined-cycle) mode.

Three major challenges to fuel cell commercialization (cost, fuel and fuel infrastructure, and materials and manufacturing) are outlined in Chapter 10. A summary of authors' opinions on current developmental status and future potential of fuel cells is also given in the chapter.

An important feature of this book is the electronic files of the computer models provided with it, available at ftp://ftp.wiley.com/sci_tech_med/fuel_cells. They are MATLAB/SIMULINK and PSpice-based files of PEMFC and MATLAB/SIMULINK-based files of SOFC dynamic models, and their FCDG applications. The models have been developed and simulation results obtained on MATLAB/SIMULINK version 7.0.4. Instruction for running the models is given in Appendix A at the end of the book. Basic knowledge of MATLAB/SIMULINK or PSPICE is required to run the models. We hope these models and their DG applications will be useful to educators, students, and researchers worldwide in developing new methodologies for modeling and control of FC energy systems of the future.

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Dr. Paul Gannon of the MSU Chemical & Biological Engineering (CBE) Department contributed in the writing of Chapter 10 (*Present Challenges and Future of Fuel Cells*). His knowledge on fuel processing, internal operation of fuel cells and the challenges involved in bringing fuel cells into widespread use helped us bring this book to completion.

Mr. Chris Colson, currently a Ph.D. candidate in the MSU ECE Department contributed to the hybrid operation and efficiency evaluation of SOFC in combined heat and power mode. His previous work in this area co-authored by the authors of this book, as well as Professor Emeritus Max Diebert of MSU CBE and Professor Ruhul Amin of MSU Mechanical & Industrial Engineering, is used as an example in Chapter 9. Mr. Colson also helped in editing a portion of the book, for which we are thankful.

During the course of our research, we made many presentations at technical conferences on the modeling and control of PEMFC and SOFC.

We are thankful to the many people who made constructive comments and suggestions to us after attending our presentations. Their comments helped us enrich the contents of this book.

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C. W.

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