"PEM Fuel Cells with Bio-Ethanol Processor Systems: A Multidisciplinary Study of Modelling, Simulation, Fault Diagnosis and Advanced Control"

Edited by M. S. Basualdo (CAPEG-CIFASIS-(CONICET-UNR-UPCAM) and UTN-FRRo, Argentina), D. Feroldi (CAPEG-CIFASIS-(CONICET-UNR-UPCAM) and DCC-FCEIA-UNR, Argentina) and R. Outbib (LSIS-Domaine Universitaire de Saint-Jérôme, Marseille, France), Green Energy and Technology, Springer-Verlag, London, UK, 2012, 461 pages, ISBN: 978-1-84996-183-7, £117.00, €139.05, US$179.00

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Reviewed by Laura Calvillo

School of Chemistry, University of Southampton, Highfield, Southampton SO17 1BJ, UK

Email: l.calvillo@soton.ac.uk

Introduction

"PEM Fuel Cells with Bio-Ethanol Processor Systems", edited by Marta S. Basualdo and Diego Feroldi (French-Argentine International Center of Information and Systems Sciences, Argentina) and Rachid Outbib (LSIS-Domaine Universitaire de Saint-Jérôme, Marseille, France), who are experts in simulation, control and fault detection of large systems, is part of the series Green Energy and Technology. This book presents some typical problems encountered in proton exchange membrane fuel cell (PEMFC) systems and proposes alternative ways of operation using conventional and advanced control techniques.

The book is divided into two main parts. The first part consists of eight chapters and is dedicated to fuel cell systems in terms of modelling, simulation, advanced control and diagnosis; the second part consists of six chapters and deals with fuel processor systems for the production of hydrogen from bio-ethanol. The writing style is clear and the authors give a detailed description of the systems and processes at the beginning of each chapter, which allows even the non-specialist reader to easily follow the concepts under discussion. However, in some of the chapters, prior knowledge of the specific software packages used is needed.

Part I: PEM Fuel Cells: Modeling, Simulation, Advanced Control and Diagnosis

Fuel Cell Systems: Concepts and Description

The book opens with two chapters in which the authors introduce the fuel cell systems and the main concepts discussed in the book. Chapter 1 by Diego Feroldi *et al.* starts by describing a fuel cell and its main applications, and includes the main characteristics of the different types of fuel cell technologies, covering important terms such as efficiency, operation and working temperature. Subsequently, the concept of control and diagnosis of PEMFC systems is introduced and the main challenges related to this control are described. Later, the authors deal with fuel cell hybrid systems (FCHSs), showing their advantages and methods for energy management. Finally, the problems related to hydrogen production and storage are commented on and different methods for producing hydrogen are described, focusing on processor systems for bio-ethanol, which are the subject of the second part of the book.

Chapter 2 by Diego Feroldi and Marta Basualdo, however, is focused on PEMFC systems, whose main components are the feeding channels, diffusion layer, and catalytic layer in both the anode and cathode, and the membrane. The unit formed by the catalytic layer and the membrane is called the membrane electrode assembly (MEA) and is the heart of the system. The electrocatalyst materials used in these systems are based on platinum nanoparticles dispersed on carbon materials.

The advantages and disadvantages of this kind of system are provided. The high efficiency and low operation temperature of PEMFC are some of their advantages, whereas their cost and the production cost of hydrogen are the main disadvantages. Then different modelling approaches described in the literature are presented, focusing on dynamic models. Particularly, the model that is used in the rest of the book to represent the system is described in detail. This model is also used to study the optimal operation conditions of a PEMFC system.

Simulation and Control Strategies

The following two chapters cover different control strategies for two of the main challenges in fuel cell operation: oxygen flow in the cathode and thermal behaviour. Chapter 3 by Diego Feroldi *et al.* is dedicated to oxygen flow, which is one of the most important factors in terms of system performance, since compressor consumption is a major parasitic power drain. For this purpose, two different advanced control strategies were tested. First, a methodology based on dynamic matrix control (DMC) was applied, both in the stationary and the transient state, and it was shown that the efficiency of the system can be improved by manipulating the valve that closes the cathode air flow and by changing the stack voltage. The simulation showed a good dynamic response. The second methodology was based on adaptive predictive control with robust filter (APCWRF). This methodology successfully managed the requirements of a PEM in different scenarios and working zones.

In Chapter 4, a new modelling approach for describing and controlling the thermal behaviour of a PEMFC, developed by Abdelkrim Salah *et al.* (LSIS, Aix-Marseille University, France), is described. The approach is based on parallel computing. The performance of three different systems: unified parallel C (UPC), parallel virtual machine (PVM) and message passing interface (MPI), are analysed by considering the computation times and the speedup of computation for each implementation. The proposed nodal network simulation model allows the cell temperature evolution to be observed with greater precision and the heat sensitive regions to be rapidly identified. The MPI and UPC systems with this nodal network gave the best performances, significantly improving the execution time.

In the second part of the chapter, it is first shown that the thermal aspect of PEMFC performance can be described by a bilinear model. Then a strategy based on feedback stabilisation is proposed to control the thermal behaviour, proving that the system can be made asymptotically stable for a desired temperature.

Fault Diagnosis

Chapter 5 by Andres Hernandez *et al.* (Escuela Colombiana de Ingeniería Julio Garavito, Colombia) is dedicated to the problem of fault diagnosis for PEMFC, presenting two strategies, the first based on electrical equivalence and the second on a statistical approach. Flooding failure is a particular focus of this chapter. The first strategy is based on the electrical equivalent model and is shown to be efficient in a dynamic system. In addition, it has the advantage that existing software for electrical network analysis can be easily adapted. The results obtained by this model are very promising for fuel cell fault diagnosis. The second strategy is not based on any model but on information from fuel cell conditions and cell operation modes. This strategy was experimentally tested for different operation modes, showing that they can be characterised by cell voltage distributions specific to each mode. It is then possible to identify the cause of a fault by establishing a relationship between the surface geometry of the voltage distribution and the phenomena which produced the fault.

In Chapter 6, written by Diego Feroldi, a new model-based fault diagnosis methodology for PEMFC systems is presented and tested. This new diagnosis methodology can correctly diagnose simulated faults, giving better results than other well known methodologies which use a binary signature matrix of analytical residuals. The new methodology has the advantage that it does not require knowledge of the magnitude of the fault to provide a diagnostic. In the second part of the chapter, this fault-tolerance methodology is included in the model predictive control (MPC) strategy, complementing Chapter 3. This has never been addressed in the literature for fuel cell systems before and constitutes one of the most important contributions of this book.

Fuel Cell Hybrid Systems

The next two chapters of the book are dedicated to FCHS. They constitute a continuation of Chapters 3 and 6, coupling the fuel cell system (FCS) with an energy storage system. First, Chapter 7 by Diego Feroldi deals with the design and analysis of FCHS oriented to automotive applications, comparing the use of batteries and supercapacitors as energy storage devices (**Figure 1**) and concluding that supercapacitors seem to be the best alternative. The main contributions of this chapter come from the three different methodologies proposed to design and analyse FCHS.

Then, in Chapter 8, energy management strategies for this type of system are addressed by Diego Feroldi. Three new strategies are proposed, two of them based on the FCS efficiency map: operating firstly in a zone where the efficiency is high and secondly at its point of maximum efficiency. The third strategy is based on using constrained

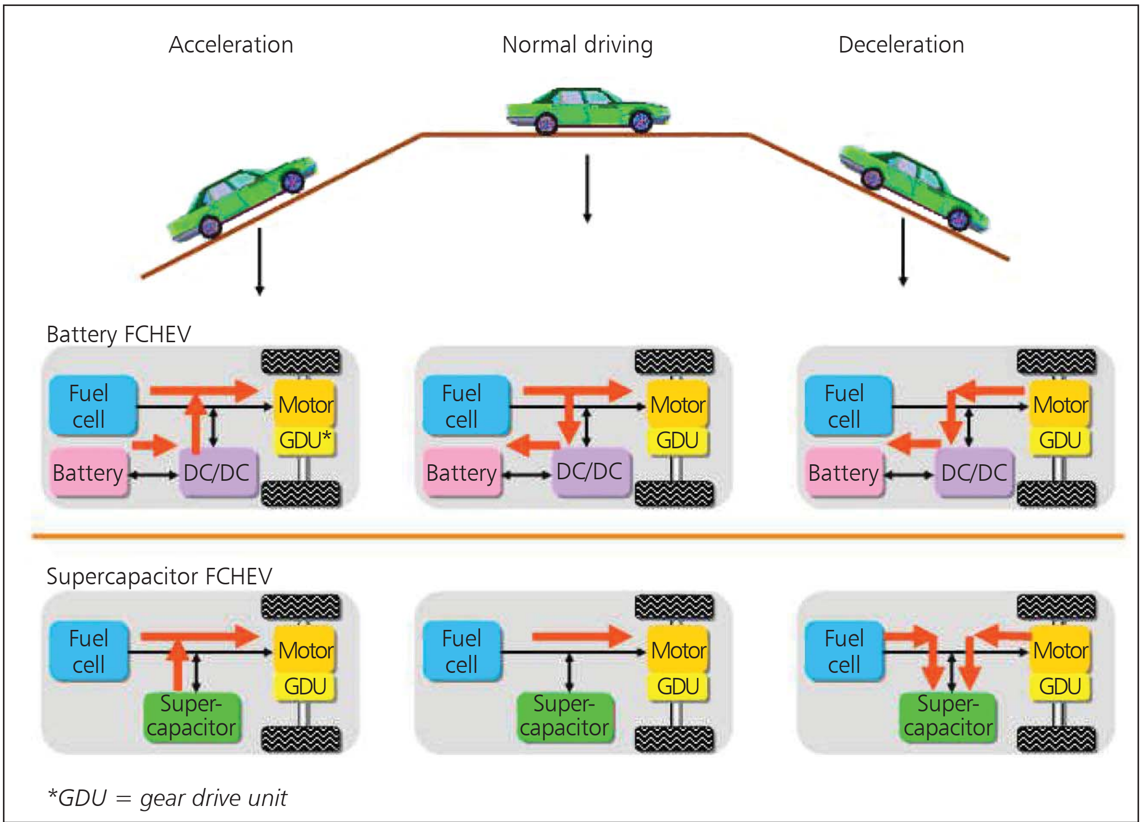


Fig. 1. Operating modes of battery and supercapacitor fuel cell hybrid electric vehicles (FCHEVs) (Image courtesy of Tae Won Lim, Fuel Cell Vehicle Group, Hyundai Motor Company and Kia Motors Corporation, Korea)

nonlinear programming to minimise hydrogen consumption. The author does a very good job of testing the different strategies, first in a simulation environment and then in an experimental setup, showing that it is possible to achieve a good reduction in hydrogen consumption.

Part II: PEM Fuel Cells in the Context of the Fuel Processor System with Bio-Ethanol

Design and Control of the Bio-Ethanol Processor with PEMFC

The second part of the book opens with four chapters (Chapters 9–12) dedicated to the design and control of bio-ethanol processors. Though the book does not mention pgm-based catalysts for this process, some work has been done on platinum, palladium or rhodium catalysts, among others (1–4). An extensive review of the bio-ethanol processor system (BPS) with PEMFC is given by Lucas Nieto Degliuomini *et al.* (CAPEG-CIFASIS-(CONICET-UNR-UPCAM), Argentina) in Chapter 9. A plant-wide heuristic control procedure was applied, whose good results were the basis for further investigations using a control-oriented dynamic model, described in Chapter 10 by Lucas Nieto Degliuomini *et al.* This model was used to obtain good efficiencies and to maximise heat recovery, but it also allows other possible kinetics, sizing of the system, etc. to be analysed.

Chapter 11 by Lucas Nieto Degliuomini *et al.* constitutes a detailed guide for developing a computational model of the BPS with PEMFC for steady state and dynamic models. In this chapter, the authors describe in great detail how to construct the steady-state model of the BPS and then how to move to a dynamic model step by step. All the units used in the model are explained and the conditions of each stream are justified. For this purpose, matrix laboratory (MATLAB), hypothetical system (system hypothesis) (HYSYS) and advanced vehicle simulator (ADVISOR) software packages were used. The reader needs prior knowledge of these systems in order to get the most out of the chapter. However, some references for their use are recommended in the text for those who are unfamiliar with the different software packages.

In Chapter 12, written by Lucas Nieto Degliuomini *et al.*, the dynamic model described in Chapter 10 is considered for simultaneously addressing the optimal sensor network and plant-wide control structure for BPS with PEMFC.

Fault Detection

The last two chapters of the book are dedicated to fault detection for the BPS with PEMFC. Due to the complexity of the problem, the use of genetic algorithms is needed. First, in Chapter 13, David Zumoffen *et al.* (CAPEG-CIFASIS-(CONICET-UNR-UPCAM) and FRRo-UTN, Argentina) integrate the methodology used for fault detection into the model for the optimal sensor network and control structure selection described in Chapter 12. The authors show that the detectability function can be calculated based on the combined results of an optimal selection of signals and, as consequence, a comparable or even better detection performance can be obtained to that derived from the complete set of signals. This methodology has been tested on seven critical faults, and constitutes a new strategy to solve problems in process industries.

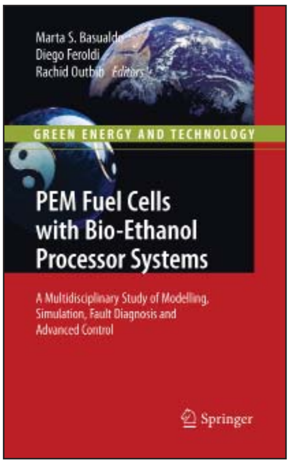
Subsequently, in Chapter 14, Estanislao Musulin and Marta Basualdo (CAPEG-CIFASIS-(CONICET-UNR-UPCAM) and DCC-FCEIA-UNR, Argentina) go one step further and take into account time delays in order to improve the model. For that purpose, a genetic algorithm-based optimisation is presented that improves the principal component analysis methodology. The improvements of the model proposed in Chapters 13 and 14 were successfully tested, indicating that the new methodology is able to give satisfactory fault detection especially for systems in which safety aspects must be taken into account.

Conclusions

The authors state that the aim of the book is to present useful tools for studying the entire system from hydrogen production by bio-ethanol reforming to power generation in the fuel cell stack. This objective has been achieved in full, with the book presenting the most challenging control problems in the fuel cell system and proposing new ways of operation using advanced control techniques. Some of the new methodologies proposed in the book have never before been addressed in the literature for this kind of system, which makes the book much more interesting and recommended.

The writing style is clear and all the concepts and procedures are explained in detail, which allows the reader to follow the book easily. However, the reader is required to have a general understanding of thermodynamics and, for some of the chapters, a prior knowledge of MATLAB, HYSYS and ADVISOR software.

Overall, the book covers a topic of much interest for a wide audience, both for people involved in academia, for teaching purposes in simulation and control techniques,and for people working in industry who are interested in applying the new methodologies to their systems. The book's authors have studied PEMFC systems using different methodologies for their control and fault diagnosis in order to improve the operation of these systems, independently of the catalysts that are used.



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The Reviewer

Laura Calvillo was awarded her degree in Chemical Engineering from the University of Zaragoza, Spain, in 2004. She obtained a European PhD in Chemical Engineering from the same university in December 2008. In 2009 she moved to the University of La Laguna, Spain, with Professor Elena Pastor, and in 2010 she began work at the University of Southampton, UK, with Professor Andrea E. Russell where she was awarded a Marie Curie Intra-European Fellowship. Her work is focused on the study of new materials for fuel cells: new synthetic carbon supports and electrocatalysts based on platinum with different nanostructures.

