Preface

The control of PEM fuel cell-based systems has been the subject of several papers during the last years. However, until now only few books have been devoted to analyze the various aspects of this matter. Moreover, the involved technology is quite extensive and more dedicated to specific areas. In fact, there are also many disciplines involved in this subject which have to work in a complementary way to give efficient solutions to the most common problems arising from PEM fuel cells-based systems.

The goal of this book is to present some useful tools for studying the entire system from hydrogen production through bio-ethanol reforming to power generation in the fuel-cell stack. In this context, the book tries to present a deep discussion about several aspects concerning some typical problems in PEM fuel cells-based systems and to propose alternative ways of operation through conventional and advanced control techniques in a safe manner. Aspects such as efficient energy management strategies are performed too in order to command the power split in a hybrid system such as the fuel cell stack coupled with a supercapacitor bank.

We know that an apparently appropriate control scheme for the PEM fuel cell may actually lead to an in-operable plant when it is connected to other unit operations in a process with recycle streams and energy integration. Our objective is to design a control system that provides basic regulatory control of the hydrogen production process; i.e., the plant will be at the wanted operating point despite disturbances. Above this regulatory structure we can then build fault diagnosis systems to improve plant safety performance. Although one of the methods discussed here is heuristic, we certainly recommend the use of a systematic approach that can aid the sensor network together with the plantwide control designs. However, the primary mathematical tool employed in this book is a rigorous, nonlinear model of the entire plant. This model can faithfully capture the nonlinearity and the constraints encountered in the hydrogen production process under consideration. It is considered that the control scheme for the overall system must be tested on this type of model because linear, unconstrained models are not adequate to predict many of the important plant-wide phenomena.

So mathematical modeling and simulation are vital tools in the solution of the optimal sensor location, multi-variable control, and fault diagnosis problems.

Another significant element in this book is the important place that we give to the computer-aided engineering software tools and computer horsepower that permit us to assemble a flowsheet, perform the steady-state analysis (mass and energy balances, engineering economics, and optimization), and then evaluate the dynamic performance of the plant. The commercial software packages used here, able to combine steady-state and dynamic realistic models, give us a major breakthrough in the tools available to support our studies. The concepts presented in this book can be applied at different levels such as in the conceptual development of this new process, as plant revamps and in the operation of an existing process. However, the emphasis is on the new plant design because this is the level at which the effect of considering these tools can have the most significant impact on profitability. The cost of modifying the process at the design stage is usually fairly low and the effect of these modifications on the dynamic controllability can be enormous. It is remarked here because several dynamic operability problems cannot be seen in a steady-state flowsheet.

This book is intended for use by students in senior courses of chemical, electrical-electronic and mechanical engineering in which dynamics and control are incorporated with the traditional steady-state coverage of flowsheet synthesis, engineering economics, and optimization. Practicing engineers and researchers could find in this book new proposals which can be useful too. Anyway, we assume that this book can be followed by a wide range of readers, as only basic concepts of modeling, simulation and control are necessary to have. Besides, each issue in the book is presented starting from its basic concepts, providing to the readers a guidance to follow the subject and an important review of the available literature for the different topics addressed here.

The main subjects of this book are dedicated to these new power generation systems, based on fuel-cell technology, involving diverse disciplines to be well-handled. In selecting the authors and the topics, the emphasis has been on giving the most adequate tools to achieve accurate, practical, and useful solutions. Accordingly, they are supported by several fields such as control theory, computational tools, artificial intelligence, expert systems, and experimental results, among others. Therefore, the book will give to the readers, from several areas, opportunity of learning how to handle these kind of problems and to propose new solutions too.

The book is divided into two main parts, the first one mainly is dedicated to fuel-cells systems and the second one to fuel processor systems from renewable energy sources such as bio-ethanol for hydrogen production. In both parts, modeling, simulation, advanced control, and fault diagnosis aspects are deeply analyzed. Part I includes the following issues: an introduction in Chap. 1 where the reader could have a picture about the main contents of the book and which are the reasons that justify this selection. Then, a thorough description of PEM Fuel Cells System is provided Chap. 2. In Chap. 3, two advanced control strategies based on Model Predictive Control to control the oxygen level in the cathode of a

PEM fuel-cell system are presented with the objectives of achieving high efficiency and maintaining the necessary level of the oxygen in the cathode to prevent short circuit and membrane damage. In Chap. 4, an alternative modeling approach (using partial differential equations) is presented for analysis and simulation of the thermal behavior of PEMFC, then a strategy to control the thermal behavior is proposed. Chapter 5 deals with the problem of fault diagnosis for PEM fuel-cell, presenting two strategies for fault diagnosis that are based on electrical equivalent technical and statistical approach, respectively. In Chap. 6, the fault diagnosis of PEM Fuel Cell Systems is addressed, using a model-based methodology. Besides, in this chapter it is addressed the Fault-Tolerant control based on Model Predictive Control. In Chap. 7, it is approached the study of fuel-cell hybrid systems with some energy storage, showing the important advantages of hybridization in Fuel Cell Hybrid Vehicles. In Chap. 8, three energy management strategies, based on the fuel-cell efficiency map, are presented and validated through an experimental setup to control the energy flow between the fuel cell, the energy storage system, and the electrical load in Fuel Cell Hybrid Vehicles.

Part II is dedicated to Fuel Processors Systems with Bio-Ethanol to produce the necessary hydrogen to supply a PEM fuel-cell system. This part includes the following chapters. Chapter 9 deals with the synthesis of an integrated bio-ethanol processor for PEM fuel-cell and a first proposal of control structure based on more heuristic concepts. Chapter 10 approaches the control-oriented dynamic model of the bio-ethanol processor system useful to test different strategies of control and fault diagnosis. Chapter 11 contains several details about the three software packages used to construct the nonlinear pseudo-dynamic model presented in Chap. 10. Hence, it addresses the model implementation issue for simulation purposes and is intended for those readers who have some previous knowledge on programing issues. Chapter 12 covers the development of a systematic approach for solving the optimal sensor location and plant-wide control for the fuel processor system with PEM fuel-cell. Finally, Chaps. 13 and 14 are dedicated to give insight about new tools for improving systems for fault diagnosis through the use of principal component analysis. Hence, Chap. 13 approaches the fault detectability index for optimal monitoring system design and, Chap. 14, considers the use of delay adjustment are addressed. Chapters 13, 12 and 14 need to use genetic algorithms for solving the combinatorial problem that arise from this kind of large-scale system. It allows testing several potential solutions and avoiding adopt decisions based on heuristic considerations.

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