Introduction

The fuel cell is a potential candidate for energy storage and conversion in our future energy mix. Indeed, a fuel cell is able to directly convert the chemical energy stored in fuel (e.g. hydrogen) into electricity, without undergoing different intermediary conversion steps. In the field of mobile and stationary applications, it is considered to be one of the future energy solutions.

Currently, the production costs of fuel cells are still relatively high, and there remain problems that must be dealt with before they can be mass-produced (e.g. life expectancy, electrolyte, degradation, catalyst cost, etc.).

Among the different fuel cell types, the proton exchange membrane (PEM) fuel cell has shown great potential in mobile applications, due to its low operating temperature, solid-state electrolyte, and compactness. Currently, it is still in the research & development stage, but already shows great promise for its potential applications in the stationary and mobile domains. However, many problems persist, which are slowing its launch onto the market:

– its life expectancy must be improved in order to reach 500 hours of operation in automotive applications;

– its cost must be reduced to under 40 EUR per kilowatt (cost of an internal combustion engine);

– its auxiliaries, especially the air compressor and power converters, still require considerable optimization in terms of performance and compactness;

– clean, competitive solutions for the production and distribution of hydrogen must be put into place and generalized.

Many experts considered the low-temperature PEM fuel cell to be the future of embarked energy, especially for terrestrial transportation. Intensive research in this field has led to new modeling methods for the fuel cells and system design. The mathematical models must be based on the description of the physical phenomena occurring within the fuel cell, and require detailed knowledge of the microscopic processes of chemical and electrochemical reactions.

The fuel cell modeling is a solution which allows us to better understand the physical phenomena occuring during fuel cell operation. A better understanding of its operation can improve its design (e.g. more compact stacks), performance, and life expectancy on the one hand, and help us to consider control laws on the other hand.

This book offers a guide to mathematical modeling of PEM fuel cells and a fairly detailed theoretical description of fuel cell physics, with particular emphasis on multiphysical modeling. The models discussed in this book can be used by researchers, engineers, and industrialists in order to access information on the dimensioning and design of fuel cells.

Therefore, the main objective of this book is to provide the tools that are used in the modeling of PEM-type fuel cells by adopting a systemic approach. It was written for engineers, students, or postgraduates who wish to develop a multiphysical fuel cell model quickly without *a priori* extensive fuel cell knowledge.

The authors' experience in the fields of fuel cells, either as teachers or researchers, has enabled them to write this book in a structured, pedagogic, and accessible manner.

Part 1 of this book introduces the fundamental principles of fuel cells, along with different existing fuel cell technologies thereby providing the fundamental elements and the vocabulary used in fuel cell modeling. This part also proposes a classification of the different fuel cell modeling criteria following a structural and functional approach. On the basis of these criteria, Chapter 5 offers a classification of different models recently published in the literature.

Part 2 of this book presents the fundamental elements of fuel cell modeling on three different levels: the stack level (stack of cells), the single cell level (stack of individual layers), and the individual layer level (membrane, diffusion layers, bipolar plate, etc.). Physical phenomena are detailed, along with the fundamental or empirical equations published in the literature.

Part 3 of this book presents a complete model for a commercial fuel cell (Ballard Nexa stack), based on equations shown in Part 2. The presented model is a dynamic, 1D, multiphysical PEM fuel cell stack model, which covers the electrical (or electrochemical), fluidic, and thermal physical domains. The proposed modular modeling structure will enable easy improvement of the model in any of the levels or physical domains without requiring the rectification of the other parts: readers will thus be able to adapt this model to different PEM fuel cells. Chapter 12 is dedicated to the experimental validation and temporal/spatial analysis of the developed model.

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