Modern Electric, Hybrid Electric, and Fuel Cell Vehicles

Fundamentals, Theory, and Design

Mehrdad Ehsani, Texas A&M University

Yimin Gao, Texas A&M University

Sebastien E. Gay, Texas A&M University

Ali Emadi, Illinois Institute of Technology

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Preface

The development of automobiles with heat engines is one of the greatest achievements of modern technology. However, the highly developed automotive industry and the large number of automobiles in use around the world have caused and are still causing serious problems for society and human life. Deterioration in air quality, global warming, and a decrease in petroleum resources are becoming the major threats to human beings. More and more stringent emissions and fuel consumption regulations are stimulating an interest in the development of safe, clean, and high-efficiency transportation. It has been well recognized that electric, hybrid electric, and fuel cell-powered drive train technologies are the most promising solutions to the problem of land transportation in the future.

To meet the revolutionary challenge, an increasing number of North American and other engineering schools have started the academic discipline of advanced vehicle technologies in both undergraduate and graduate programs. In 1998, the principal author of this book shared his first lecture on "Advanced Vehicle Technologies — Design Methodology of Electric and Hybrid Electric Vehicles" with graduate students in mechanical and electrical engineering at Texas A&M University. While preparing the lecture, it was found that although there is a wealth of information in technical papers and reports, there is as yet no comprehensive and integrated textbook or reference for students. Furthermore, practicing engineers also need a systematically integrated reference to understand the essentials of this new technology. This book aims to fill this gap.

The book deals with the fundamentals, theory, and design of conventional cars with internal combustion engines (ICEs), electric vehicles (EVs), hybrid electric vehicles (HEVs), and fuel cell vehicles (FCVs). It comprehensively presents vehicle performance, configuration, control strategy, design methodology, modeling, and simulation for different conventional and modern vehicles based on mathematical equations.

This book includes vehicle system analysis, ICE-based drive trains, EV design, HEV configurations, electric propulsion systems, series/parallel/mild hybrid electric drive train design methodologies, energy storage systems, regenerative braking, fuel cells and their applications in vehicles, and fuel cell hybrid electric drive train design. It emphasizes the overall drive train system and not just specific components. The design methodology is described by step-by-step mathematical equations. Furthermore, in explaining the design methodology of each drive train, design examples are presented with simulation results.

This book consists of 13 chapters. In Chapter 1, the social and environmental import of modern transportation is discussed. This mainly includes air pollution, global warming, and petroleum resource depletion associated with the development of modern transportation. In this chapter, the impact of future vehicle technologies on the oil supplies is analyzed. The results are helpful for the future development strategy of the next-generation vehicles. In addition, the development history of EV, HEV, and FCV is briefly reviewed.

In Chapter 2, the basic understanding of vehicle performance, power source characteristics, transmission characteristics, and equations used to describe vehicle performance are provided. The main purpose of this chapter is to provide the basic knowledge that is necessary for understanding vehicular drive train design.

In Chapter 3, the major operating characteristics of different heat engines are introduced. As the primary power source, the engine is the most important subsystem in conventional and hybrid drive train systems. A complete understanding of the characteristics of an engine is necessary for the design and control of conventional cars and HEVs.

In Chapter 4, EVs are introduced. This chapter mainly addresses the design of electric propulsion systems and energy storage devices, the design of traction motor and transmission, the prediction of vehicle performance, and simulation.

In Chapter 5, the basic concept of hybrid traction is established. Various configurations of HEVs are discussed, such as series hybrid, parallel hybrid, torque-coupling and speed-coupling hybrids, and other configurations. The major operating characteristics of these configurations are presented.

In Chapter 6, several electric propulsion systems are introduced, including DC, AC, permanent magnet brushless DC, and switched reluctance motor drives. Their basic construction, operating principles, and control and operating characteristics are described from the traction application point of view.

In Chapter 7, the design methodology of series hybrid electric drive trains is presented. This chapter focuses on the power design of engine and energy storage, design of traction motor, transmission characteristics, and control strategy. A design example is also provided.

In Chapter 8, the design methodology of parallel hybrid electric drive trains is provided. This chapter includes driving pattern and mode analysis, control strategy, design of the major components (engine, energy storage, and transmission), and vehicle performance simulation.

In Chapter 9, the design methodology of mild hybrid drive trains is introduced with two major configurations of parallel torque coupling and series–parallel, torque–speed coupling. This chapter focuses on operation analysis, control development, and simulation.

In Chapter 10, different energy storage technologies are introduced including batteries, ultracapacitors, and flywheels. The discussion focuses on power and energy capacities. The concept of hybrid energy storage is also introduced in this chapter.

In Chapter 11, vehicular regenerative braking is introduced. In this chapter, different controls of regenerative braking are analyzed, including braking force distribution on the front and rear wheels, amount of braking energy in various driving cycles, and the amount of energy that can be recovered by regenerative braking.

In Chapter 12, different fuel cell systems are described, mainly focusing on their operation principles and characteristics, technologies, and fuel supplies. Vehicular applications of fuel cells are also explained.

In Chapter 13, the systematic design of fuel cell hybrid drive trains is introduced. First, the concept of fuel cell hybrid vehicles is established. Then, its operating principles and control of the drive train are analyzed. Lastly, the design methodology is described, focusing on the power design of the fuel cell system, electric propulsion, and the energy storage system. A design example and its corresponding simulation verification are also provided.

The material in this book is recommended for a graduate or senior-level undergraduate course. Depending on the background of the students in different disciplines such as mechanical and electrical engineering, course instructors have the flexibility to choose the material or skip the introductory sections/chapters from the book for their lectures. This text has been taught at Texas A&M University as a graduate-level course. An earlier version of this text has been revised several times based on the comments and feedback received from the students in this course. We are grateful to our students for their help.

This book is also an in-depth source and a comprehensive reference in modern automotive systems for engineers, practitioners, graduate and senior undergraduate students, researchers, and managers who are working in automotive-related industries, government, and academia.

In addition to the work by others, many of the technologies and advances presented in this book are the collection of many years of research and development by the authors and other members of the Advanced Vehicle Systems Research Program at Texas A&M University. We are grateful to all members of the Advanced Vehicle Systems Research group as well as the Power Electronics and Motor Drives group, especially Dr. Hyung-Woo Lee and Mr. Peymen Asadi, who made great contributions to the brushless DC and switched reluctance motor drive sections, respectively. Switched reluctance motor vibration, acoustic noise, and design sections draw heavily from the Ph.D. dissertation of Prof. Babak Fahimi, which is gratefully acknowledged. In addition, we would like to express our sincere gratitude to Prof. Hassan Moghbelli, who thoroughly reviewed the earlier version of the manuscript and provided his valuable suggestions to improve the quality of the book.

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