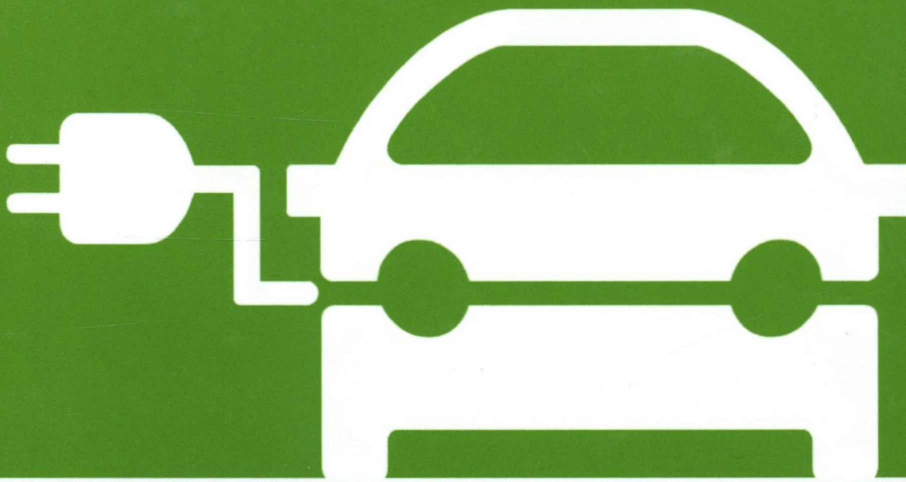

PLUG-IN ELECTRIC VEHICLE GRID INTEGRATION

İSLAM ŞAFAK BAYRAM
ALI TAJER

Power Engineering

This authoritative resource provides a comprehensive introduction to plug-in electric vehicles (PEVs) and portrays a holistic overview of the challenges associated with the mainstream adoption of PEVs at three distinct layers pertinent to the technological, economic, and social aspects. From a technological perspective, the book discusses various critical enabling technologies, such as energy storage, electric charging standards (e.g., fast, slow, and bidirectional), power converters, and telecommunication technologies. It explains how the economic layer formulates and analyzes the interface and the interactions between the charging infrastructure and PEV drivers. These include addressing architecture and modes for designing sustainable charging infrastructures, energy storage sizing, capacity planning, and optimal placement of small - and large-scale charging stations. Furthermore, the decision mechanisms for optimal charging rates under various pricing schemes and user preference models are investigated thoroughly.

This unique volume also explains how mainstream adoption of PEVs necessitates integrating relevant social aspects into the technological and economic frameworks. Readers gain insight into the socioeconomic factors influencing individual preferences toward replacing gas-powered vehicles with PEVs. Specifically, the book analyzes the current purchasing behavior via relevant and widely adopted models, such as diffusion of innovations, theory of planned behavior, and rational choice theory. Additionally, this reference helps policy makers to prioritize and adjust incentive programs that facilitate mainstream PEV adoption. The book underscores how successful PEV integration requires coinvestigating and designing all three layers in a holistic framework.

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Dedicated to my lovely wife Sinemis - Şafak

Dedicated to my family - Ali

Preface

The United States National Academy of Engineering has identified electric systems and ground transportation as the two key engineering achievements of the twentieth century. While both domains constitute crucial infrastructures and have been successfully servicing a wide range of social and economical needs, they have evolved and developed in isolation, and the interactions between them have been limited. During the past decade, however, we have been witnessing an increasing interest in promoting mainstream adoption of the plug-in electric vehicles (PEVs) due to their various economical and environmental benefits. Specifically, the major drivers for this impetus include environmental concerns due to rising carbon emissions, the increasing dependency on crude oil and the undesirable impacts of fluctuating oil market conditions, and the shift towards modernizing the electricity grids and integrating renewable energy sources.

Integrating PEVs into power grids necessitates a holistic analysis due to the various complex interactions that it brings about at the interface of the two already complex networks (i.e., electricity and transportation systems). Forming various inferential, scheduling, and management decisions involves decision mechanisms that require an interdisciplinary approach. From the electric vehicle perspective, ensuring a desirable cruising range is of utmost priority. Facilitating long ranges necessitates electric motors for vehicle propulsion to replace internal combustion engines. The two main components of electric motors are onboard batteries for storing the required energy, and advanced power electronics that enable and control effective energy conversion. The interactions between the electric vehicles and the power grid are exerted by electric chargers, which should be designed to deliver the charging needs for various durations and PEV technologies. Chargers, when equipped with bidirectional energy transfer capabilities through their batteries, can also allow vehicles to inject power back to the power grid under certain circumstances. Due to such twofold roles, hence, vehicle batteries are the key enabling components of PEV technology. The capacity, various efficiency measures, and the cost of batteries are the primary factors that influence PEV sales and penetration rate.

All the aforementioned challenges reflect on the complex nature of a single PEV. When facing transportation systems with a vast numbers of PEVs, these challenges are further coupled with several others pertinent to resource management. Specifically, since vehicles will be fueled by the power grid, designing, planning, and operating the charging facilities that manage power transfer from the grid to vehicles will have instrumental roles. If not designed properly, such facilities can underutilize the grid assets or impose strenuous conditions on the grid. Addressing such challenges suggests that charging stations may need to be equipped with ancillary support units (e.g., energy storage units) to protect the grid from excessive customer demand, which in turn adds to the design complexity. Designing networks of charging stations is also coupled with other practical constraints such nonhomogeneous customer density in different areas, in which case network operators may need to influence customers' choices by monetary incentives to defer or change their preferred locations of the service.

In addition to addressing the *technological* needs and the *economic* programs, the *human factor* should be also accounted for carefully. For instance, purchasing a PEV, for many individuals, requires changing driving routines, which might contribute to delaying or slowing down the mainstream acceptance even when PEVs are economically viable. Incentive programs focusing on the technology enthusiast may be successful at the early stages; however, mainstream acceptance requires social studies to be involved along with technological and economics studies. To that end, our approach in this book is three-dimensional and portrays a holistic picture about the challenges associated with mainstream acceptance of PEVs at three distinct layers: (1) technology layer, (2) economic layer, and (3) social layer. Chapters 1, 2, 3, 4, and 9 address challenges pertinent to the technology layer, Chapters 5, 6, 7, 8, 10, 11, and 12 focus on the issues in the economic layer, and Chapter 13 addresses challenges in the social layer. It is noteworthy that some of the chapters lie in the intersection of the three layers. For instance, Chapter 9 shows a profit optimization by considering a battery degradation of a vehicle. The details of each chapter are outlined next.

Chapter 1 provides an introduction to PEVs, discusses the advantages of PEVs over combustion engine vehicles, provides a historical background on PEVs, examines different types of PEVs, and provides an overview of current PEV models as well as market penetration tends. Chapter 2 is devoted to the enabling technologies, where the first half focuses on battery technology, and the second half is dedicated to drivetrain technologies and electric vehicle supply equipment. Chapter 3 concentrates on major roadblocks for PEV adoption and the negative impacts of PEV charging on the power grid. Chapter 4 focuses on PEV cost models (e.g., battery degradation models and different pricing mechanisms).

Chapter 5 is a transitional one that links the technology layer to the economic layer, and provides details of capacity planning, demand control, and charging rate control studies. Chapter 6 focuses on a capacity planning framework for single and multi-class customers in large-scale charging facilities, while Chapter 7 presents a study on capacity and energy storage sizing in the fast-charging station. Chapter 8 discusses pricing-based demand control in charging networks, and Chapter 9 is focused on controlling the charging rates in a fast-charging station. The topics and discussions presented up to Chapter 10 are entirely focused on settings that consist of only one charging station, while Chapter 10 considers optimal siting of a network of charging stations. Chapter 11 concentrates on a load-balancing framework in a charging network through pricing.

PEV batteries can also be used to support grid activities such as regulation, storage, and emergency backups. Motivated by this application, Chapter 12 is dedicated to vehicle-to-grid, vehicle-to-building, vehicle-to-vehicle, and vehicle-to-home energy transfer applications. The last part of the book, Chapter 13, is reserved for reviewing the social aspects involved in designing and operating PEV networks.

We would like to express our sincere gratitude to all those who helped and supported us to complete this book. Even thought they are too numerous to be listed, the authors are grateful to all. We thank the staff of Artech House Inc., and Aileen Storry for initiating this book project and her support during the time we work on the book. Last but not least, we thank the anonymous reviewers whose comments made this book better.

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