Electric and Hybrid Vehicles

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Land transportation over the past two centuries has experienced astonishing advancement. Up until the 1860s, it took more than six months to get from the East Coast to the West Coast of the United States. Today, it may take only three days by automobile. We are even considering flying cars and there are air-taxi startup companies that have announced going public [1]. Vehicle propulsion electrification is at the core of this modern land vehicle revolution. However, the concept of electric vehicle traction is not new.

This Special Issue provides a comprehensive overview of the most recent development in electric and hybrid vehicles, and the key components and enabling technologies.

For example, in 1897, the Electric Vehicle Company began operating electric traction taxicabs in New York City. In London, Electrical Cab Company also began operation that year. Further, in 1899, the Compagnie Française des Voitures Électromobiles began operation in Paris.

These electric vehicles offered welcomed advantages over the horse-drawn vehicles. They were clean and quiet and their novelty also appealed to the wealthy and the avant-garde. They paid 30 cents a mile, more than $9.75 in today's money, while horse-drawn cabs charged 50 cents a mile, according to business historian and management professor David Kirsch of the University of Maryland.

Back in 1900, a third of all cars on U.S. roads were electric, and there were plenty of electric vehicles driving around in the 1910s. Fig. 1 shows a newspaper ad in 1915 from an electric car company. It wasn't until the 1920s when gasoline had truly won out as the fuel of choice for motorists. However, people of the 1920s would probably be astonished that we are using fossil fuels to power our cars a 100 years later.

Then, the premature technology took its toll. Short battery life proved disastrous for the London and Paris firms in a few years. In 1902, the General Carriage Company collapsed. Most of the other electric taxi services in the United States never made it.

Then, Henry Ford displaced the electric car by changing the definition of what the automobile is. The early electric taxis were the extrapolation of the 19th-century concept of transportation, such as the railroads: centralized services that charged fixed prices to serve fixed routes on fixed schedules. Thus, consumers would rather pay others to drive them than to drive themselves. In contrast, Ford helped consumers to think of the car as a personal transportation product that they could personally own and operate, rather than a service someone else offered. The personal car could offer freedom of travel time and place.

This change of paradigm was made possible by the improvements in the power and range of the gasoline engines, combined with their low price. The Model T, in 1908, was introduced at $850. This was roughly one-third of the price of electric cars at the time. Thus, millions of people could own a vehicle that gave them a sense of control over travel time and place.

Modern introduction of the electric vehicle, EV, faces similar challenges as before. Of course, the technology of the EV has significantly improved. Furthermore, the imperatives of adopting EV, such as tailpipe emissions and global warming carbon emissions, have changed. However, the gasoline engine cars have also had a century of advancements and improvements to become very good products.

This helps explain the market reluctance to dominant adoption of the EV, over the past two decades. For example, less than 2% of the

Digital Object Identifier 10.1109/JPROC.2021.3075306

Fig. 1. ***1912 Baker Electrics—The Baker Motor Vehicle Company, Cleveland, Ohio, May 1912. Courtesy: Cosmopolitan magazine, page 110, Baker Electric Car Ads by Vogel Marketing Solutions LLC.***

about 17 million cars sold annually in the United States are EVs. This is in contrast with the dominance of other recent products, such as smartphones, that were clearly superior to the existing products, during the same time period.

Among the present handicaps of the EV products, relative to the existing gasoline engine vehicles, are shorter range, higher initial and lifetime costs, larger ratio of charge to discharge times, and limited continental charging facilities. Hybrid electric vehicles, HEVs, have been offered as a compromise between the advantages and disadvantages of the EV and the gasoline vehicles. However, their modest penetration of the vehicle market, over the same two decades, indicates that they too are not yet superior products, compared to the conventional car.

If the electrified vehicles are to be considered as the stepping stone to carbon emission-free land transportation, then clearly, the best approach for EV and HEV dominance is a technical improvement. The EV must become a better product than the conventional gasoline vehicle, with the HEV as a transitional product. Top-down government mandates that are in contrast to better products and prices cannot be a successful strategy for this transition in long term.

This Special Issue is meant to review the state of the art in EV and HEV technologies and introduce some of the current research to overcome the handicaps of the EV for consumer adoption. Leading international researchers have been invited to contribute to this Proceedings issue after their work was rigorously reviewed by their peers. We hope this Special Issue inspires further exploration of various new technologies for the future of electric transportation systems.

The ten articles of this Special Issue cover a wide variety of topics of electric and hybrid vehicles and are organized into three groups. The first article provides an overview of the past, present, and future of electric, hybrid electric, and fuel cell vehicles (EV/HEV/FCEVs). The next four articles dive into the key components and technology of EV/HEV. Article five reviews the reliability issues of power electronics for EC/HEV. The remaining four articles deal with applications of electric vehicle technology in commercial vehicles, fuel cell vehicles, aircraft, and for smart buildings.

State of the Art and Trends in Electric and Hybrid Electric Vehicles
by M. Ehsani, K. V. Singh, H. O. Bansal, and R. T. Mehrjardi

Electric, hybrid electric, and fuel cell vehicles (EV/HEV/FCEVs) can revolutionize road transportation by significantly lowering or eliminating fuel consumption and toxic and greenhouse emissions. Commercial success and performance of these vehicles are highly dependent on the selection of their power-train architectures and component technologies, such as their traction motors, power converters, energy storage systems, and power management strategies. In this article, these important topics have been discussed in some detail. Various present challenges and breakthroughs have been discussed. The solution options are summarized in tables for choosing the appropriate structures and methods for best designs. This material will serve as a general reference for scholars and engineers who wish to advance the technologies of EV/HEV/FCEVs.

Revolution of Electric Vehicle Charging Technologies Accelerated by Wide Bandgap Devices
by S. Li, S. Lu, and C. C. Mi

This article reviews the wide bandgap devices (WBGs) and their impact on the development of electric vehicle charging equipment. It introduces the charging method and the charging equipment for the EVs which are constantly evolving to improve efficiency, power density, and power capacity while reducing costs. Then, the WBGs based on SiC and GaN are discussed and compared with the Si-based devices from the aspects of material basics, cost, device performance, driving issues, and reliability concerns. The WBGs have exceeded the performance of Si-based devices in almost all aspects. The impact of the emerging WBGs on electric vehicle charging equipment, such as onboard chargers, fast-charging stations, and wireless charging, are discussed. It shows that higher efficiency and higher power density can be achieved using WBGs, and WBGs have become the predominant power devices in wireless chargers. A figure-of-merit for wireless power transfer (WPT) systems is proposed, which represents the power density of a WPT system while considering efficiency and transfer distance. The future trends of WBGs adoption in onboard chargers, DC fast chargers, and wireless chargers are also summarized.

A Critical Review of Advanced Electric Machines and Control Strategies for Electric Vehicles

by C. Liu, K. T. Chau, C. H. T. Lee, and Z. Song

The main scope of this article is to review advanced electric machines and their corresponding control strategies, particularly for electric vehicle (EV) applications. New design ideas, topologies, structures, methodologies, control strategies, pros and cons, foresight for advanced electric machines, and the implementation of ideas into practical EV applications have been investigated. This critical review can provide a blueprint and roadmap for engineers and researchers who are interested in this field of machine design and control.

Status and Gaps in Rechargeable Lithium Battery Supply Chain: Importance of Quantitative Failure Analysis

by Y. Zhang, R. T. Nguyen, and B. Liaw

Rechargeable lithium battery technology is rapidly transforming microelectronics, transportation, and energy sectors today. However, the supply chain of this technology continues to face critical challenges in durability, reliability, and safety to satisfy market demands. To sustain the market growth, more efficient use of the resources in the battery, including critical material recovery, extended useful life, and risk mitigation, becomes important. In this article, we provide a critical review of these topics. A key concept is proposed to use quantitative failure mode and effect analysis to advance battery design-prototyping-production-deployment cycle in order to meet future cyclic economy and techno–economic–social transformation. A viable method is explained to enable physical principles-based technology assessment using quantification, qualification, verification, and validation to resolve durability, reliability, and safety issues in the battery supply chain.

Electric Drive Technology Trends, Challenges, and Opportunities for Future Electric Vehicles

by I. Husain, B. Ozpineci, Md S. Islam, E. Gurpinar, G.-J. Su, W. Yu, S. Chowdhury, L. Xue, D. Rahman, and R. Sahu

The electric drivetrain technologies to facilitate the transition to electric road transport technologies are presented in this paper focusing on the emerging concepts while reflecting on the state-of-the-art technologies. The enhanced electrification requirements are translating to a demand for power dense and high-efficiency electric traction drive systems that lead to better fuel economy for a given battery charge. The article discusses the electric drive technology trends for passenger electric and hybrid electric vehicles with commercially available solutions in terms of materials, electric machine and inverter designs, maximum speed, component cooling, power density, and performance. The emerging materials and technologies for wide bandgap power electronics and heavy rare-earth free electric motors are presented, identifying the challenges and opportunities for even more aggressive designs to meet the need for next-generation electric vehicles. Some innovative drive and motor designs with the potential to meet the Department of Energy's 2025 targets are also discussed.

Reliability of Power Electronic Systems for EV/HEV Applications

by F. Blaabjerg, H. Wang, I. Vernica, B. Liu, and P. Davari

This article focuses on the power electronic systems reliability in electric vehicles (EVs) and hybrid EVs (HEVs) where both their reliability requirements and challenges are highlighted for the used power electronics technology. The advances in power electronic components to address the reliability challenges are discussed in detail as they individually contribute to the overall system reliability. A reliability-oriented design methodology is described and applied for two cases: an EV onboard charger and a drive train inverter. An outlook in terms of research opportunities in power electronics reliability related to EV/HEVs ends the article.

Hybrid and Electric Vehicle (HEV/EV) Technologies for Off-Road Applications

by M. A. Masrur

Hybrid and electric vehicle (HEV/EV) technology is reasonably well known now, with a few millions of vehicles around in the world, and there is a significant amount of literature in the public domain on this subject. However, the literature is not that abundant on the application of HEV/EV technology for off-road and nonground (water and air-borne) vehicles. This article presents the topic and its current status. One additional important item is also emphasized in the article, which pertains to the issue related to a decision-making process before the HEV/EV technology is introduced for any particular situation. This is to ensure that the technology will bring benefit from an overall holistic perspective, if applied for a particular purpose.

Toward Holistic Energy Management Strategies for Fuel Cell Hybrid Electric Vehicles in Heavy-Duty Applications
by T. Rudolf, T. Schürmann, S. Schwab, and S. Hohmann

This article presents an extensive review regarding energy management strategies (EMS) and its methodologies for heavy-duty fuel cell hybrid electric vehicles (FCHEVs). It introduces an overview as well as the pertinent literature of drivetrain topologies, the relevant components, and the modeling with a focus on fuel cell hybrid electric trucks. Further, methodologies for EMS are structured and summarized. The corresponding challenges and opportunities are discussed and a new taxonomy for dynamic optimization-based approaches is suggested from a control engineering perspective. The transition toward holistic EMS by leveraging a layered model predictive control approach is motivated. It concludes that the inclusion of velocity planning, degradation effects, and auxiliaries into an intelligent EMS can significantly improve the capability of heavy-duty FCHEVs and sustainability of transportation.

Electric/Hybrid-Electric Aircraft Propulsion Systems
by P. Wheeler, T. S. Sirimanna, S. Bozhko, and K. S. Haran

The idea of electric propulsion for transportation is not new, indeed the first cars, nearly 200 years ago, were electric. However, our dependency on fossil fuels over the last 100 years is now being questioned, and as a global society, we are moving toward more electric transportation solutions. Electric propulsion of aircraft is part of this trend, either all electric or through a large variety of proposed hybrid propulsion systems. This article considers some of these systems, their technological requirements, and the ongoing research and development in motors and drives necessary to make this technological change a feasible option for the future of passenger flight.

Electric Vehicles for Smart Buildings: A Survey on Applications, Energy Management Methods and Battery Degradation
by S. Nazari, F. Borrelli, and A. Stefanopoulou

The main subject of this survey is behind the meter energy management with vehicle to building (V2B). This article focuses on different V2B application ideas and reviews energy management methods in smart buildings with V2B integration. Recent findings on battery capacity fade resulting from bidirectional flow of power and extra discharging cycles with V2B are reviewed and methods for integrating the battery degradation in energy management formulation are discussed. Finally, the main findings of this review and research gaps are summarized and clarified.

The authors would like to thank Jo Sun, Senior Publications Editor, and Vaishali Damle, Managing Editor of Proceedings of the IEEE, for their advice and support during the entire publication process. Their valuable help is much appreciated. ■

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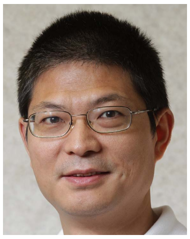

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