Trends in EV Propulsion Components and Systems

By Silva Hiti and Khwaja Rahman

TODAY, THERE ARE MORE THAN 1.5 MILLION plug-in-hybrid and (battery) electric vehicles (EVs) on the roads worldwide, a number you'll find cited in a few of the articles in this issue. For comparison, in 2005, EV volumes were still measured in hundreds. The steep rise in the number of EVs is the result of the joint efforts, over the past decade, of governments and the automotive industry worldwide. Now, Bloomberg New Energy Finance predicts that, by 2040, EVs will take 35% of the market share of new car sales globally.

This is an exciting time for engineers in the EV industry; EV engineering veterans can finally witness their long-term efforts come to fruition, and newcomers are getting a chance to join an industry that is taking off. However, before you make your choice to join or to leave the EV industry, read the in-depth, historical (and magical) analysis by Peter Savagian of whether we are finally in an era destined to bring commercial success to EVs offered in the "Technology Leaders" column.

In the rest of the issue, we bring you a selection of articles from industry and university experts on the latest development trends in EV components and systems. The articles describe the state-of-the-art and incoming technologies and design trends for major components of the electric propulsion: electric motors, power electronics, and batteries.

The first article on motor technologies "Getting Rare-Earth Magnets Out of EV Traction Machines" by Jahns offers a trade-off analysis on the selection of motor types for an EV propulsion system, and it makes a strong case on why the interior-permanent-magnet (IPM) synchronous machine is still the favorite choice for production passenger EVs. As always, it is the application requirements, such as low acoustic noise, torque ripple, high torque, and power densities, that drive this

Digital Object Identifier 10.1109/MELE.2017.2649239
Date of publication: 7 March 2017

Digital Object Identifier 10.1109/MELE.2016.2644240

selection. Magnets used in IPM synchronous machines in automotive applications contain a significant amount of rare and a (smaller) amount of heavy rare-earth elements. In the past, the price of rare-earth and heavy rare-earth elements showed significant volatility, prompting researchers in industry and academia to look for solutions to reduce the usage of these elements in magnets for EV applications.

The follow-up article on motor technologies, "Grain-Boundary-Diffused Magnets" by Thompson et al. explains the process of grain boundary diffusion used to reduce the heavy rare-earth components' content in EV motor magnets and the methods of characterizing the magnets developed by using the process. Understanding the magnet characteristics produced by this process is essential for the design of electric machines as well as the accurate predictions of the IPM behavior under the fault conditions in the EV propulsion system.

A typical EV power distribution network is a high-voltage, direct-current (dc) network. The dc power provided by the battery is converted by the power inverters into the three-phase power usable by electric motors. Although the three-phase voltage source inverter is widely used in a broad range of industrial and commercial applications, the EV application poses some unique requirements on the power inverter. The component and the inverter system requirements are typically driven by the vehicle mission profile, mounting location in the vehicle, and operating temperatures, among others. The EV inverter must satisfy these requirements as well as low weight, size, and cost demands. The article on the inverter design "Exploring the High-Power Inverter" by Schulz describes the main requirements for the EV inverters and the major technological trends in the most significant inverter components.

Similarly, the article on the on-board charger (OBC) design, "A Closer Look at the On-Board Charger" by Cesiel and Zhu follows the design process for a particular OBC design used in one of the highest volume EVs, the Chevrolet Volt, and illustrates the steps taken to insure a high-quality, low-cost solution.

It is an undisputed fact that the improvements in automotive batteries and the introduction of lithium-ion batteries are responsible for increased EV sales and overcoming the range anxiety in battery EVs. According to Bloomberg New Energy Finance, the average battery EV in 2011–2012 had a driving range of below 100 mi and an energy density of 90 Wh/kg, while 2017 models have a driving range of over 200 mi and an energy density of 130 Wh/kg. Although EV sales are showing significant growth and reached the highest-ever monthly market share in September 2016 with 1.12% of new car sales, there are many significant remaining challenges for the EV industry on the road to the 35% market share in 2040, as predicted by Bloomberg. In other words, to compete with internal combustion engine vehicles, battery EVs need to continue on a path of lowering pack prices while increasing the pack capacity and driving range.

In the rest of the issue, we bring you a selection of articles from industry and university experts on the latest development trends in EV components and systems.

The article on trends in lithium-ion battery technologies, "Lithium Has Transformed Vehicle Technology" by Alamgir offers an excellent overview of the state-of-the-art automotive battery cells' structures, and it explains the distinctive characteristics of the cells used in battery EVs versus plug-in hybrids and micro hybrids.

Most of today's EVs use the dc power distribution network below 450 V, or the 400-V system. However, as the battery capacity increases, an opportunity will open up for utilizing the higher voltage levels, or the 800-V system. The article on the 800-V system design "Power Up with 800-V Systems" by Jung goes through a set of tradeoffs that have to be made at the system level to decide on the dc power distribution voltage level. Higher distribution voltage offers potential savings in the overall system weight, due to lower current and copper loss as well as reduction in charging times. Fast charging capability on par with the conventional vehicles' refueling time is still a far-reaching goal; however, the 800-V system offers a path of approaching that benchmark.

The current and future EV charging infrastructure and the role of utilities in developing the charging networks are described in our closing article, "The Need for Charging" by Bowermaster et al. Despite the predicted increase in charging power, the majority of EV charging will continue to take place at home, so utility programs that are cost-effective for utility customers should be designed to enable and spread EV adoption.

We hope that this issue of *IEEE Electrification Magazine* will provide you with a useful insight into the engineering challenges, state-of-the-art and incoming technological trends, and design methods for EV propulsion systems.