Electric car battery leakage detection system

PhD thesis - summary

Author: MSc, Eng. Grzegorz Wójcik
Dissertation advisor: PhD, DSc, Eng. Piotr Przystałka, Associate Professor
Industry supervisor: PhD, Eng. Wojciech Sebzda
Silesian University of Technology, Faculty of Mechanical Engineering
Dräxlmaier Group

The rapid growth of the battery electric vehicles (BEVs) market has brought lithium-ion battery packs (LIBs) to the forefront due to their superior power and energy density properties. However, these benefits come with inherent safety challenges. LIBs operate within a narrow safety window and are highly susceptible to environmental factors, operating conditions, and manufacturing inconsistencies. Because of that, modern battery packs utilize Battery Management Systems (BMS) and Battery Thermal Management (BTM) systems to prevent the battery cells from damaging or aging too quickly.

Battery faults, both external and internal, pose significant risks, including overheating, accelerated degradation, and the potentially catastrophic thermal runaway, that could be initiated even by smaller faults, propagating further into a chain reaction of cascaded failures. Such smaller faults could be in the form of intruded water, which gathers in the battery pack due to e.g., damage to the heat exchanger, potentially causing corrosion and short circuits in the high voltage areas. BMS and BTM designs are thus crucial to ensure system safety and longevity, particularly under high current demand scenarios in EVs. The state-of-the-art solutions utilize either conductometric or capacitive electronic circuits (depending on chosen BTM approach), which present some major drawbacks if employed inside the high-voltage areas of the battery pack.

Aiming to address these challenges, this doctoral dissertation focuses on the development of an electric car battery leakage detection system, which is seen as a liquid leakage and intrusion detection system for immersion-cooled EV LIBs. Utilizing optical rather than electrical signals in high-voltage areas, this novel approach is designed to improve the safety of EV battery packs by adding a new fault detection mechanism, enhanced by computational intelligence and machine learning, and mitigating some of the drawbacks of the current solutions.

The work carried out to achieve this goal resulted in the design of an Optical Liquid Detection System (OLDS), a solution necessitating extensive research and development in several domains, including mechanical engineering, hardware, software, and optical. This comprehensive effort resulted in the fabrication of an evanescent wave absorption polymer optical fiber sensor and the development of custom mechatronics system and its software. This led to the prototype of a tailored hardware and software platform used to collect datasets with the system exposed to laboratory and road conditions under faultless and fault states (liquid leakage, water intrusion) in an iterative way. Based on the recorded datasets, a set of model-based detection methods using LSTM and RAE-GRU neural networks was proposed, formulated, and then verified offline. The performance of methods was evaluated using the recorded datasets under faultless states and under simulated fault states through specific model performance indicators as well as detection performance indicators.

The results of this dissertation provide a significant contribution to the safety and reliability of EV lithium-ion battery packs. The optical liquid detection system, coupled with the developed model-based fault detection methods based on computational intelligence approaches such as shallow and deep neural networks, promises to substantially decrease risks associated with liquid intrusion or leakage in battery packs, contributing to the wider adoption and customer acceptance of electric vehicles. Future work could further refine these methods and extend their applicability to an even broader range of conditions.