Abstract

The long charging time of Li-ion batteries in comparison to ICEV (Internal Combustion Engine Vehicle) refuelling time is a barrier to the adoption of Li-ion-based EV. The electric vehicle industry believes that increasing the current rate (C-rate) will reduce charging time, but this increases the cell degradation rate. As a result, the need of the hour is to develop a health-aware battery fast charging strategy. Numerous research was conducted to develop an optimal charging algorithm, but the high complexity of the algorithms attracted fewer industries to adopt these strategies. The prevailing battery fast charging strategies employ open-loop charging, which leads to exponential degradation in battery health. EV battery chargers ought to generate tailored charging approaches to attain optimal efficiency, contingent upon the battery's condition. The aforementioned task is accomplished by utilizing a closed-loop battery charging mechanism. The health-aware battery fast charging (HABFC) methodology considers various degradation phenomena, such as temperature, lithium layer formation, and SEI layer formation, to accelerate the battery's charging process pack.

This work proposes the use of a zonal battery charging technique by providing a schematic layout for establishing a charging technique that increases the life of the battery pack. The closed-loop charging strategy has been realised by tracking the degradation using a robust cell model and dividing the charging phase into three zones, namely: pre-charging, boost charging and end charging. Thus, the project proposes the following contributions to achieve a robust HABFC. Firstly, the study introduces an innovative equivalent circuit model (ECM) for continuous battery condition monitoring during rapid charging cycles. By analysing anodic behaviour via diffusion coefficient and charge transfer resistance, it maps performance decline relative to the state of charge (SoC) to identify degradation causes. The proposed tri-zoned ECM (TZ-ECM) calculates solid phase diffusion dynamics and incorporates thermal, electrical, and aging characteristics into the thermo-electric ageing cell model (TEACM). Validated through cell cycling tests, the TEACM accurately predicts voltage (98.14%), current (97.95%), and aging (98.35%), demonstrating superior performance compared to benchmark methods. Secondly, the pre-charging strategies have been investigated. An electrochemical study demonstrates that

abruptly applying a high charging current to batteries induces an internal shock, resulting in suboptimal ion diffusion. The proposed method, pulse amplitude width modulation (PAWM), enhances ion excitation and diffusion during fast charging. Comparative analysis with established benchmark charging strategies shows that PAWM offers superior performance, improving ion diffusion efficiency.

Next, the boost charging strategies have been investigated, and the dual-step constant-current constant-temperature (DS-CC-CT) charging technique is proposed which addresses battery deterioration by managing thermal performance. It consists of two stages: charging at a constant current until a temperature threshold is reached, followed by charging at a controlled lower temperature. This process is repeated until a higher voltage threshold is met, effectively reducing degradation and extending battery lifespan. Compared to the 1C-CC-CV method, DS-CC-CT reduces cell charging time by 31% and increases cell cycle life by 66%. Finally, the study explores optimising the constant voltage (CV) phase by transitioning to CV mode at a low C-rate before reaching the voltage threshold limit. This method enhances ion passage, maximising charging capacity and extending cell longevity. Compared to the CC-CV method, it incurs a 4.22% increase in charging time but improves cell cycle life by 51.77%. Integrating this approach with pre-charging and boost charging makes the additional time negligible.

The results suggest that adopting the proposed method results in a decrease of 17.64% in charging duration and an improvement of 17.23% in the lifespan of the battery cycles compared to the conventional charging method. The proposed technique is validated by comparing results with benchmark charging strategies. The fast-charging rate, low battery degradation, and low complexity will facilitate faster industrial adaptation and encourage consumers to switch to EVs.