Abstract

The hybrid electric vehicle aims to minimise energy consumption and CO_2 emission. This goal should be achieved without compromising battery operating limits to avoid the risk of thermal runaway and to minimise ageing. Accurate state of charge (SOC) estimation plays a crucial role in reducing this risk and in decelerating battery ageing. A model-based SOC estimator is designed with a sigma point Kalman filter (SPKF) and experimentally validated under dynamic load conditions with an estimation root means square error (RMSE) of 2.2%.

The state of health (SOH) of the battery is monitored at regular intervals to keep track of the battery health status and to improve SOC estimation accuracy across the battery cycle life. As a starting point, SOH estimation is experimentally analysed under constant load conditions using the parallel layer extreme learning machine (PL-ELM) at room temperature. This solution demonstrates an improved generalisation of SOH estimation for the set of cells in a battery pack. Optimum RMSE of 0.064% to 0.473%, and the mean absolute error of 0.034% to 0.355% are verified. The algorithm was tested on a Texas F28379D microcontroller unit (MCU) board with an average execution speed of 93 μs in real-time, and 0.9305% CPU occupation.

Furthermore, SOH estimation is analysed under dynamic load conditions using the ANN-based classifier at room temperature. The classifier is validated experimentally under dynamic varying load, constant load, and step load conditions. The model accuracies for validation data are 96.2%, 96.6%, and 93.8% for the respective load conditions. It is further demonstrated that the model can be applied to multiple cell types of similar specifications with an accuracy of about 96.7%. The classifier was tested on a Texas F28379D microcontroller unit board. The result shows that an average real-time execution speed of 8.34 μs is possible with a negligible memory occupation.

Finally, to achieve the HEV goal of minimising energy consumption and CO_2 emission, an electro-thermal model of a lithium-ion battery is developed for energy storage and for defining the battery operating constraints. Energy optimization is performed in presence of these constraints for P2 HEVs using an adaptive model predictive control (MPC) strategy. The simulation results of the HEV SUV (Mazda CX9 2016) demonstrate that, by applying thermal constraints, energy consumption for a 0.9 kWh battery capacity can be reduced by 11.3% relative to the conventional vehicle. However, by increasing the battery capacity to 1.5 kWh (14s10p battery configuration), it is possible to reduce the energy consumption by 15.7%. Additional benefits associated with the predictive capability of MPC are reported in terms of thermal improvement.