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Multiscale Cell-to-Vehicle Electro-Thermal Hierarchical Model for an Intelligent Electric Vehicle Thermal Management System

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ABSTRACT

Electric vehicles (EVs) are expanding at a rapid pace, enabled by significant technological advances in lithium-ion batteries (LIBs) and charging infrastructure. However, current LIB technology still falls behind consumer expectations due to concerns over battery lifetime, charging speeds, driving range, and safety. Further breakthrough advances in LIB performance and lifetime require groundbreaking thermal management strategies and the hierarchical integration of complex sub-systems during modelling, design, and operation of EVs, with intimate knowledge of the electro-thermal phenomena occurring across multiple scales in the vehicle. This work demonstrates an innovative multiscale hierarchical model of an intelligent electric vehicle thermal management system that automatically transfers information from the cell level to the vehicle level. The hierarchical model is unique in integrating computational simulations across multiple physical domains and length scales. This model was implemented in Matlab Simulink and contemplates four levels: battery cell, battery module, battery pack, and vehicle. The battery cell level represents the basic model building block, informed by comprehensive experimental characterizations of the cells under a wide variety of operating conditions. The battery modules are modelled as sets of reduced-order thermal models, scalable to different battery sizes and cooling architectures at the battery pack level. The vehicle level represents the highest level in the hierarchy, simultaneously considering energy flows from the battery pack, auxiliary systems, and surrounding environment. This model is validated against experimental results from a concept EV equipped with a battery pack prototype developed by a multidisciplinary team at the University of Toronto. The final manuscript will include a parametric study to illustrate the effectiveness of the proposed multiscale hierarchical model to predict the impact of different temperature sensing strategies and cooling architectures on battery performance and energy consumption.