# ENERGETICS

## Ammin/Teoresi - Advanced Estimation Techniques for SOC and SOH in Battery Management Systems and Integration with Thermal Control Strategies

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| **Contact** | |
| **Context of the research activity** | The main objective of this research project is to advance the state-of-the-art in Battery Management Systems (BMS) through the development of accurate, adaptive, and computationally efficient methods for the estimation of State of Charge (SOC) and State of Health (SOH) of lithium-ion batteries. Additionally, the research will address the often-overlooked integration between the BMS and Battery Thermal Management System (BTMS), which is essential for safe and efficient operation in real-world conditions. |
| | Robust SOC and SOH Estimation<br>Conventional SOC and SOH estimation techniques rely heavily on model-based approaches such as the Extended Kalman Filter (EKF) and simple equivalent circuit models. While these methods are well-established, they are sensitive to model inaccuracies, temperature variations, and battery aging. This project proposes a hybrid framework that combines physics-based models with data-driven approaches (e.g. linear regression, neural networks) to achieve real-time adaptability and improved accuracy across a wide range of operating conditions.<br>The research will also explore advanced estimation techniques such as:<br>• Adaptive filtering methods (Kalman filters with on-line adaptation of tuning parameters of the filter, such as the process and measurement noise covariances)<br>• Alternative filters (e.g., Unscented Kalman Filters, Particle Filters)<br>• Data augmentation with virtual measurements based on data-driven regression models<br>• Online learning methods to update model parameters in response to aging and usage patterns<br>• Multi-cell aggregation algorithms for scalable battery pack health inference<br><br>The novelty lies in ensuring the robustness of the estimation algorithm based on both operational data and temperature/aging feedback using innovative methodologies.<br><br>Integration with Thermal Management Systems |

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| **Objectives** | SOC and SOH estimation accuracy is strongly influenced by thermal conditions. Current BMS implementations treat thermal management as an ancillary system, rather than as an integrated part of the control strategy. This research aims to establish a bidirectional communication framework between the BMS and BTMS, allowing SOC/SOH estimators to incorporate thermal feedback and, conversely, enabling the BTMS to make predictive cooling/heating decisions based on battery degradation forecasts.<br><br>Key goals in this domain include:<br><br>• Proposing optimal control algorithms (e.g., MPC) that jointly manage electrical load and thermal dynamics to extend battery lifetime and safety<br>• Evaluating the benefits of integrating thermal-aware estimators in extreme ambient conditions (e.g., high-speed charging or cold starts)<br>• Implementing co-simulation strategies using real-time platforms such as Simulink and dSPACE<br><br>Validation and Technology Transfer<br>The proposed estimation and control strategies will be validated in both simulated and experimental environments. Hardware-in-the-loop (HIL) testing and real-world driving cycle data will be used to benchmark the performance and scalability of the developed techniques. Furthermore, the project will aim for technology transfer opportunities with industrial partners in the automotive and energy storage sectors.<br><br>Broader Impacts and Innovation Potential:<br>This research addresses two key challenges in battery technology: uncertainty in battery state estimation and aging. By creating more intelligent and resilient estimation techniques, and by tightly coupling thermal considerations into BMS operation, the project contributes directly to goals of electrification and carbon footprint reduction of transportation systems. The integration of data-driven techniques with traditional control theory offers a novel, forward-looking approach aligned with global trends in intelligent control systems and transportation electrification. |

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| **Skills and competencies for the development of the activity** | • Theoretical background on the modeling and control of electrified powertrains<br>• Experience with MATLAB/Simulink and multi-physics simulation environments such as Simscape<br>• Familiarity with battery equivalent circuit models and electric vehicles thermal systems<br>• Experience of working in interdisciplinary topics (electrical, mechanical, and thermal systems) |