Online power prediction for lithium-ion batteries by integrating physics-based modeling and machine learning

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Abstract

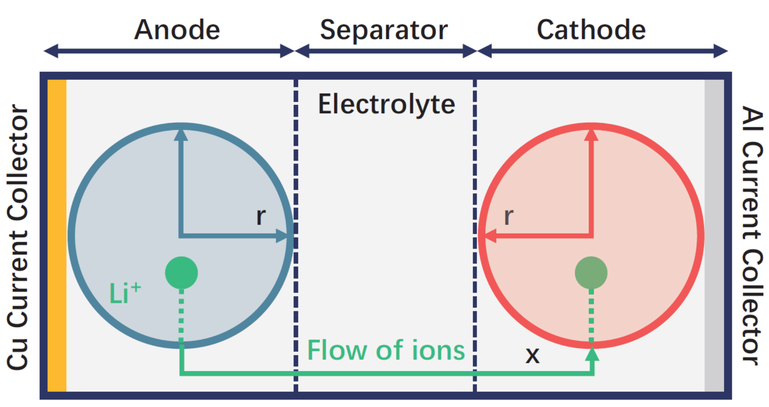
The knowledge of the dynamic available charging and discharging power is essential for the safety and longevity of the battery systems. In this work, an electrochemical model-based online state-of-power prediction algorithm under different time horizons is developed for a safer and more reliable operation of lithium-ion batteries. The safety constraints, which define the safety operation area for the power prediction, are designed based on not only the terminal voltage but also battery internal electrochemical states.

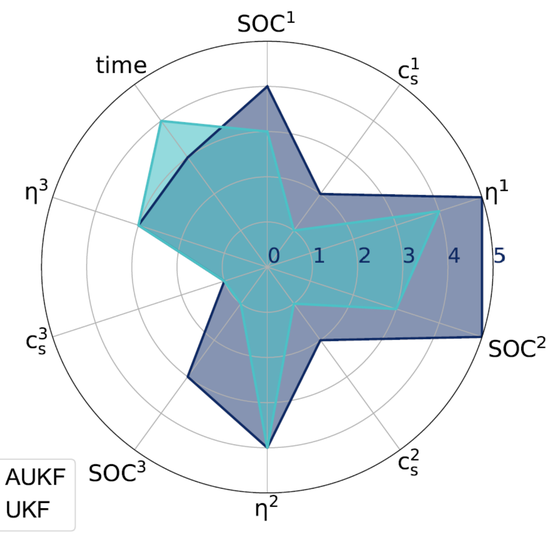
Conclusion

In this work, an electrochemical model-based power prediction method was proposed under real-world operations, coupled with a machine learning model for online applications. By combining Gaussian process regression with the model-based power prediction algorithm, the computation time was decreased by more than 50% without any influence on the prediction accuracy, removing the largest obstacle towards the online applications of electrochemical models in battery management systems.

Physics-based modeling and state estimation

- Lithium-ion battery cell
  - NMC/graphite, Kokam SLPB75106100
- Extended single particle model
  - Electrochemical dynamics with partial differential algebraic equations
  - Model-order reduction for online implementation
  - Electrolyte dynamics included
- State estimation
  - Adaptive unscented Kalman filter (AUKF)
  - Validated numerically and experimentally
  - Robust under sensor noise





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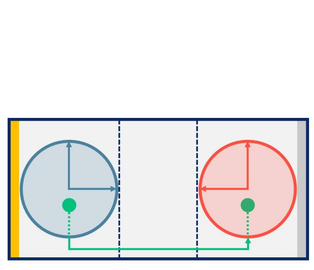

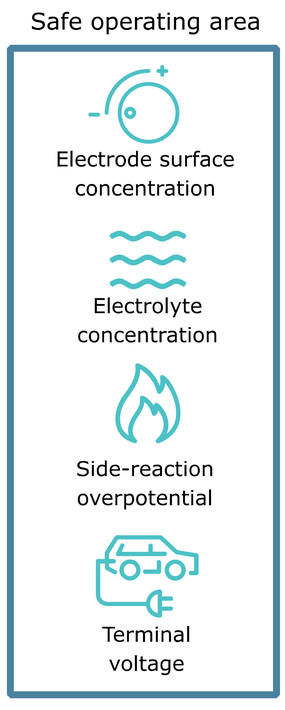

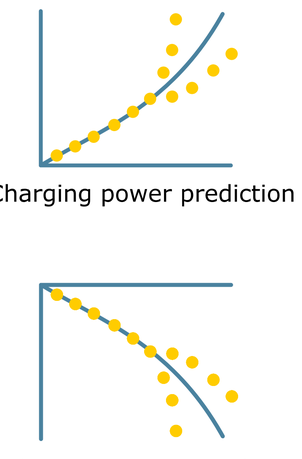

Power prediction with machine learning

- Safe operating area
  - Electrode surface concentration
  - Electrolyte concentration
  - Side-reaction overpotential
  - Terminal voltage
- Nonlinear iterative power prediction
  - Different predictive time horizons, i.e., 1 s, 10 s, 30 s
- Acceleration with Gaussian process regression
  - Non-parametric Bayesian approach
  - 95% confidence interval as interval prediction bounds
  - Narrows the searching area of the iterative algorithm

Validation test and results

- Validation test under real-world driving cycles
- Maximum power is determined by different internal electrochemical states at different times
- Side-reactions, e.g., lithium-plating, are restrained
- Avoid safety issues in extreme conditions compared to state-of-the-art power predictions
- Improvement of the computational efficiency by 50%, enabling the online application
- Significant difference in maximum power under 1 s, 10 s and 30 s

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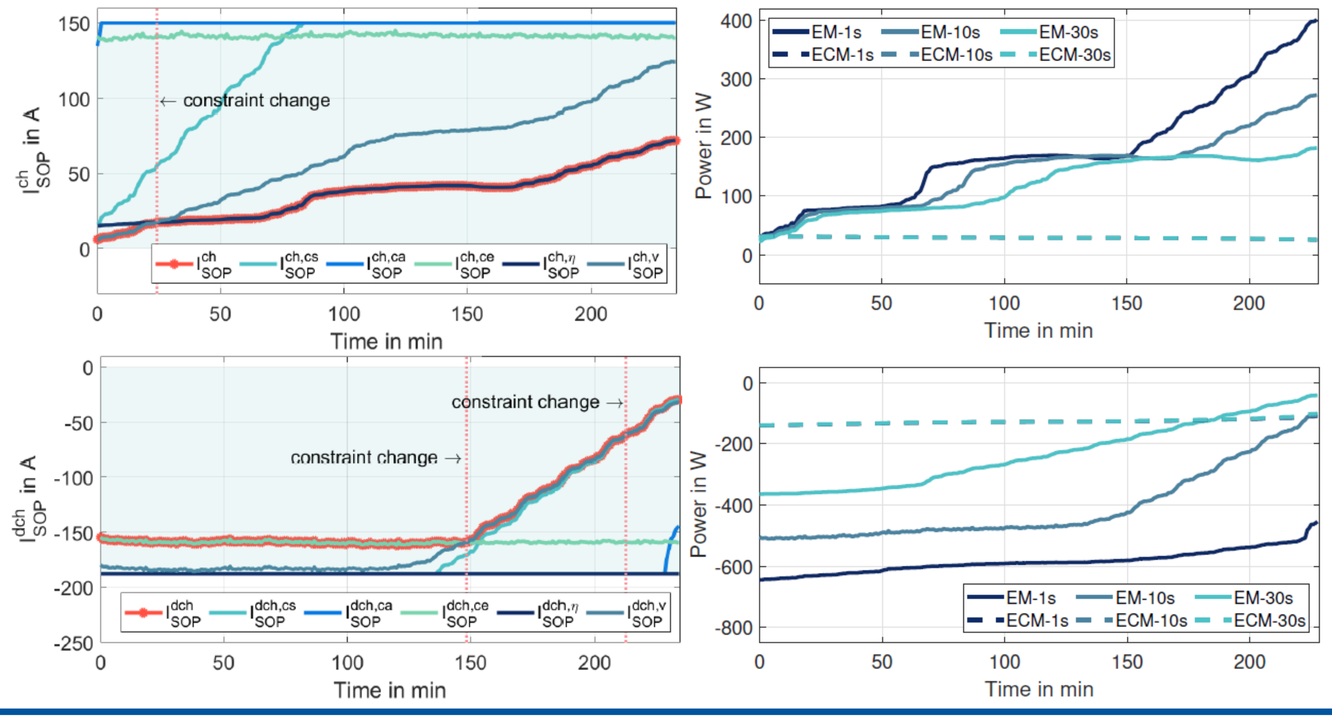

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