Electrical and Thermal Modeling of a Large-Format Lithium Titanate Oxide Battery System

Timothy P. Cleary, Harshad Kunte, and Jim A. Kreibick

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SJSU Research Center
210 N. Fourth St., 4th Fl.
San José, CA 95112

Tel // 408.924.7560
Fax // 408.924.7565

transweb.sjsu.edu

The future of mass transportation is clearly moving toward the increased efficiency of hybrid and electric vehicles. Electrical energy storage is a key component in most of these advanced vehicles, with the system complexity and vehicle cost shifting from combustion engines to battery and electric drive systems. To assist engineers and technicians in this transfer, the Mineta National Transit Research Consortium partnered with the Battery Application Technology Testing and Energy Research Laboratory (BATTERY) of the Thomas D. Larson Pennsylvania Transportation Institute in the College of Engineering at The Pennsylvania State University and with an advanced bus manufacturer to study lithium titanate oxide battery chemistry for use in transit buses. The research team found, other than proprietary data/models, scant technical information or research on electrical and thermal modeling of this advanced chemistry.

Study Methods

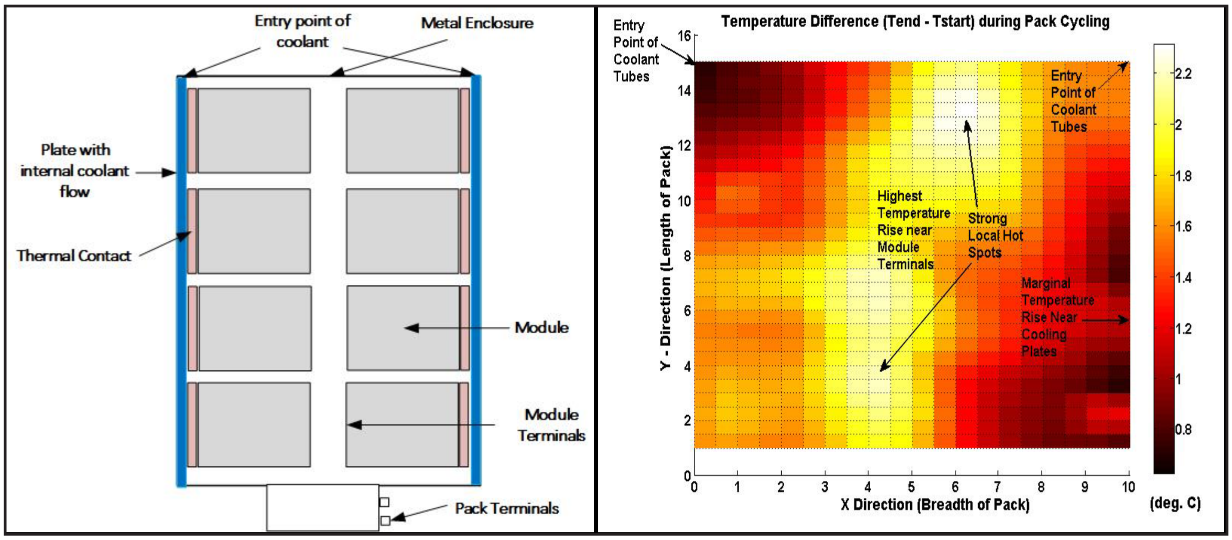
The research team developed lithium titanate oxide modules to study their characteristic behaviors and produce state-of-charge estimators capable of running on the limited embedded processing power and memory of a typical battery management system. The team also investigated the thermal performance of this chemistry in the large format, producing a physics-based empirical thermal model for use in system-level simulations. This model predicts pack-level thermal behavior by reporting the minimum, maximum, and average temperatures within a system typically used for large automotive applications, as testing was concentrated on transit bus usage profiles.

This work supports battery system integration and management. The tools produced are intended to assist automotive engineers to achieve optimal system performance and ultimately a more efficient vehicle.

Findings

In the course of about one year of testing and development, a large quantity of data was gathered on both the electrical and thermal performance of a liquid-cooled battery system. First, this produced an example of how a laboratory can be set up to evaluate and develop battery systems, including the equipment configuration and sensor suite. Secondly, battery management systems were discussed, including methods of state-of-charge estimation and battery characterization. Then a sensor sensitivity study was performed, with results showing how accurate current measurement is necessary for accurate state-of-charge estimation. Following characterization results, a dual-polarization battery model was produced and validated based on measured data and modeling by the research team. Then a non-linear battery model was developed and extended Kalman filtering was used to improve state-of-charge estimation. This work concluded with the development of an improved model and estimator for state-of-charge prediction for lithium titanate oxide cells. This work was performed and validated on a full-size system capable of providing the power required to operate an all-electric passenger bus.

Following the electrical model generation and validation, an extensive study of the chemistries' thermal performance was executed. A full-scale battery pack was cycled in various temperature environments under several loading conditions. Then a cool-down study was performed. All of the thermal testing and analysis fed into the assembly and validation of a pack thermal model. This model was generated to simplify the complexity of such a model so that it could be run in real time on embedded systems to support improved thermal management. The images below represent the battery configuration, on the left, and an example of measured temperature data, on the right, during an electrical cycling loading scenario.



Policy Recommendations

The research conducted in this project supports an effort to better understand the thermal and electrical performance of advanced batteries used in today's public buses. Understanding these responses and comparing them in real time with validated models can help to better predict battery failures and provide quicker response in thermal events. This work supports the ability for manufacturers to provide validated safety systems in these battery systems. A means of evaluating these systems to ensure their safety should be required by the FTA and performed by an independent agency. At a component level, these systems can be evaluated for thermal and electrical performance and safety mechanisms tested.

About the Authors

Timothy Cleary is the director of the Battery Application Testing and Energy Research Laboratory (BATTERY) at the Thomas D. Larson Pennsylvania Transportation Institute at Penn State. Harshad Kunte (previously a BATTERY research assistant) is a systems design/architecture engineer at Tesla Motors. James Kreibick is a graduate research assistant with BATTERY.

To Learn More

For more details about the study, download the full report at ***transweb.sjsu.edu/project/1150.html***

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