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A roadmap to understand battery performance in electric and hybrid vehicle operation

Matthieu Dubarry, Vojtech Svoboda, Ruey Hwu, Bor Yann Liaw *

Hawaii Natural Energy Institute, University of Hawaii at Manoa, 1680 East West Road, POST 109, Honolulu, HI 96822, USA

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Abstract

This work attempts to bridge laboratory and real-life battery testing data with a comprehensive analysis to provide a coherent approach for a realistic model to simulate battery performance, including life prediction. From electric vehicle field-testing results, we explain how to handle real-life data through driving cycle analysis to establish a scheme of "building blocks" that can be validated by test results obtained in the laboratory. We also show that a simple battery model can be built upon laboratory test data and validated by real-life duty cycles, therefore deriving a more realistic understanding and prediction of battery performance.

Keywords: Battery performance model simulation; Electric and hybrid vehicles; Life prediction; Duty cycle; Field testing; Driving cycle analysis

1. Introduction

To date, assessment and understanding of battery performance primarily rely on testing in the laboratories. Very limited effort has been put into field testing with detailed data collection and analysis. The reason that the field-testing approach was not favored is because that such testing is costly, labor-intensive, and virtually no control. On the other hand, the difficulties in conducting field testing and analysis hamper the development of suitable methodologies to gain experiences in real life for a practical understanding of battery performance. Thus, it is no surprise that experiences from field tests to date are mostly limited to statistical in nature [1–4], presenting limited value for use in technical improvements of battery design or operation.

In pursuing better understanding of battery performance in real life, we often come across three major challenges:

1. Availability of adequate test protocols and analytic tools to understand the data collected in the laboratory for life prediction.
2. Availability of viable battery modeling and simulation tools to extend our laboratory experiences to real-life duty cycles; therefore, we can predict battery performance and life in more complex and less controlled settings.
3. Capability to develop suitable protocols and analysis techniques to allow us collect and analyze data collected in the real-life operating conditions to derive battery's performance characteristics in relation to its usage.

In this work, we propose a roadmap delineating how to address these challenges and to enhance more realistic understanding of battery performance in real life. Some of the critical steps involved are listed as follows:

1. Collect relevant data in the field operation.
2. Formulate a systematic approach to analyze duty cycles according to their operating conditions and usage.
3. Analyze performance characteristics of the batteries.
4. Derive correlation between duty cycles and performance characteristics.
5. Develop a predictive model and simulation capability to allow prediction of battery performance and life based on duty cycles in real-life operation.

Before we describe the details of how to pursue this approach, it is quite important to point out the difficulty in formulating a systematic approach to analyze driving or duty cycles. First, it is important to realize that no well-documented methodology to conduct driving cycle analysis has been accepted to date. The current approach to study driving cycle is conceptualized on characterizing the driving conditions for a specific type of road (facility type) and situation (level of service), such as in

* Corresponding author. Tel.: +1 808 956 2339; fax: +1 808 956 2336.
E-mail address: bliaw@hawaii.edu (B.Y. Liaw).

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a city, highway, or urban environment to derive the classification of driving patterns for use in the industry and government, for example, for urban or emission studies. This conventional approach is however very difficult to use in driving cycle analysis. For instance, on a jammed highway with bumper-to-bumper traffic, the driving would be more like on a downtown street than on highway. To overcome this difficulty, we took a different approach using a fuzzy logic pattern recognition (FL-PR) technique, which is based on a typical perception of a "reasonable assembly" (as expressed with a fuzzy membership function) of a driving pattern that corresponds to a driving on a specific road type. Using this linguistic, qualitative expression method to classify each small section of a driving cycle enables us to classify driving patterns based on driving conditions, instead of road type and level of service. This approach makes the driving cycle analysis possible on a consistent, systematic manner. This is also applicable for duty cycle analysis.

In 2001–2003, we have evaluated a fleet of 15 Hyundai Santa Fe electric sport utility vehicles (e-SUV). We use the data collected on board in field-testing as a model system to illustrate this approach via the analyses of driving and duty cycles to reveal the performance characteristics of the vehicle and battery. We show how real-life data were collected and analyzed, performance profiles characterized, and useful correlations derived for construction of a predictive model of battery performance, potentially suitable for prediction of battery service life. Fig. 1 presents an overview of the steps involved in the development of a battery life predictive tool that can incorporate real-life data and analysis. We show that it is beneficial to have field and laboratory testing in parallel. This two-prone approach is based upon a "building block" concept that connects the laboratory and real-life data. In this concept, we analyze driving cycle and duty cycle by breaking them down to smaller blocks of well defined characteristics. These "building blocks," which we call "driving pulses" and "power pulses," respectively, for driving cycle and duty cycle, allow us to construct arbitrary driving cycles and duty cycles that can be used in laboratory testing and computer simulation. Through the analysis of the correspondence between driving pulses and power pulses, we can sort out the relationship of vehicle driving cycle versus battery duty cycle. Therefore, the stress imposed on the battery from the duty cycle can be correlated with the vehicle usage based on the driving cycle. This is a very important aspect of the building block concept that makes the connection between performance and operating conditions.

Regarding model construction and validation, it is important to derive a set of "universal" building blocks for driving and duty cycle to facilitate simulation. A large population of building blocks can be generated from field testing and systematic analyses. A small set of representative building blocks is then selected for validation using laboratory testing. This process serves as the bridging instrument between laboratory and real-life conditions. The laboratory testing allows us to develop and validate a set of "universal" building blocks with performance characteristics characterized for vehicle and battery operation. These well-defined building blocks can be used as modules in the construction of "well-behaved" driving and duty cycle for modeling and simulation. One useful aspect of these well-behaved driving or duty cycles is to employ them as "standard" test protocols for laboratory evaluation and benchmarking. For instance, we can use this process to characterize the associated stress factors on battery performance in cycle life testing and use them for life prediction. Another valuable aspect is to use these modules to synthesize arbitrary driving or duty cycles for performance prediction.

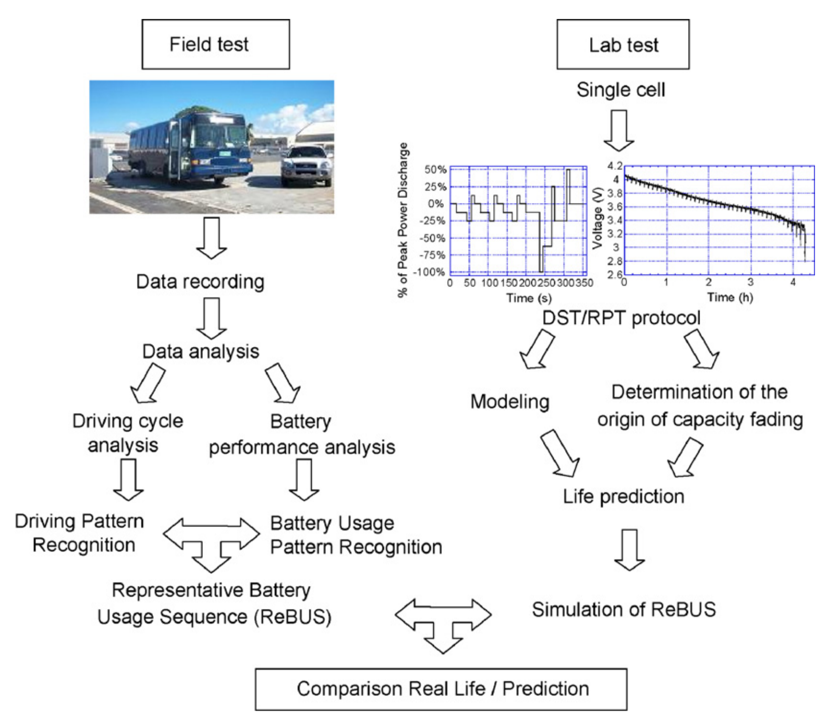

Fig. 1. Schematic of life prediction approach from field and laboratory testing.