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Review

Optimal parametrization of electrodynamical battery model using model selection criteria

Andrés Suárez-García [a, *], Víctor Alfonsín [a], Santiago Urréjola [a], Ángel Sánchez [b]

[a] Defense University Center, Naval Academy, Marín, Pontevedra 36920, Spain
[b] School of Industrial Engineering, University of Vigo, Vigo, Pontevedra 36310, Spain

HIGHLIGHTS

- Optimal dynamic electric modeling of a commercial 40 Ah $LiFePO_4$ battery.
- Component modeling based on point-wise selection in current–voltage curves.
- Mathematical modeling using R squared (R2), Akaike (AIC) and Bayes (BIC).
- AIC and BIC selected simpler mathematical models than R2.
- Voltage simulations of AIC and R2 were similar. BIC sim was the worst of them.

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ABSTRACT

This paper describes the mathematical parametrization of an electrodynamical battery model using different model selection criteria. A good modeling technique is needed by the battery management units in order to increase battery lifetime. The elements of battery models can be mathematically parametrized to enhance their implementation in simulation environments. In this work, the best mathematical parametrizations are selected using three model selection criteria: the coefficient of determination (R^2), the Akaike Information Criterion (*AIC*) and the Bayes Information Criterion (*BIC*). The R^2 criterion only takes into account the error of the mathematical parametrizations, whereas *AIC* and *BIC* consider complexity. A commercial 40 Ah lithium iron phosphate (*$LiFePO_4$*) battery is modeled and then simulated for contrasting. The OpenModelica open-source modeling and simulation environment is used for doing the battery simulations. The mean percent error of the simulations is 0.0985% for the models parametrized with R^2, 0.2300% for the *AIC* ones, and 0.3756% for the *BIC* ones. As expected, the R^2 selected the most precise, complex and slowest mathematical parametrizations. The *AIC* criterion chose parametrizations with similar accuracy, but simpler and faster than the R^2 ones.

1. Introduction

Nowadays, electrochemical batteries are indispensable. They consist of one or more electrochemical cells that convert stored chemical energy into electrical energy. They are used everyday in countless applications. It is hard to imagine society nowadays without them.

Battery modeling is a very important discipline. There are multiple types of battery modeling and each one has a specific utility: physical-electrochemical [1] [2] and bond graph battery models [3,4] are used for studying the physical and chemical characteristics of the batteries; thermal battery models are used to analyze thermal behavior [5,6]; empirical battery models are used to predict battery lifetime [7,8]; electric battery models are used in simulations of electrical systems [9–11], etc. All of them help to improve battery design and usage.

In the present work, a commercial 40 Ah lithium iron phosphate (*$LiFePO_4$*) battery was modeled using an electro dynamical model. The main advantage of the electrical model is its versatility. The developed model could be easily reused in complex electrical systems. *$LiFePO_4$* technology has been chosen because of its important role in the automotive industry. Its market acceptance is caused by its low cost, safety characteristics, non-toxicity and specific capacity

* Corresponding author.
E-mail addresses: asuarez@cud.uvigo.es (A. Suárez-García), valfonsin@cud.uvigo.es (V. Alfonsín), urrejola@cud.uvigo.es (S. Urréjola), asanchez@uvigo.es (Á. Sánchez).

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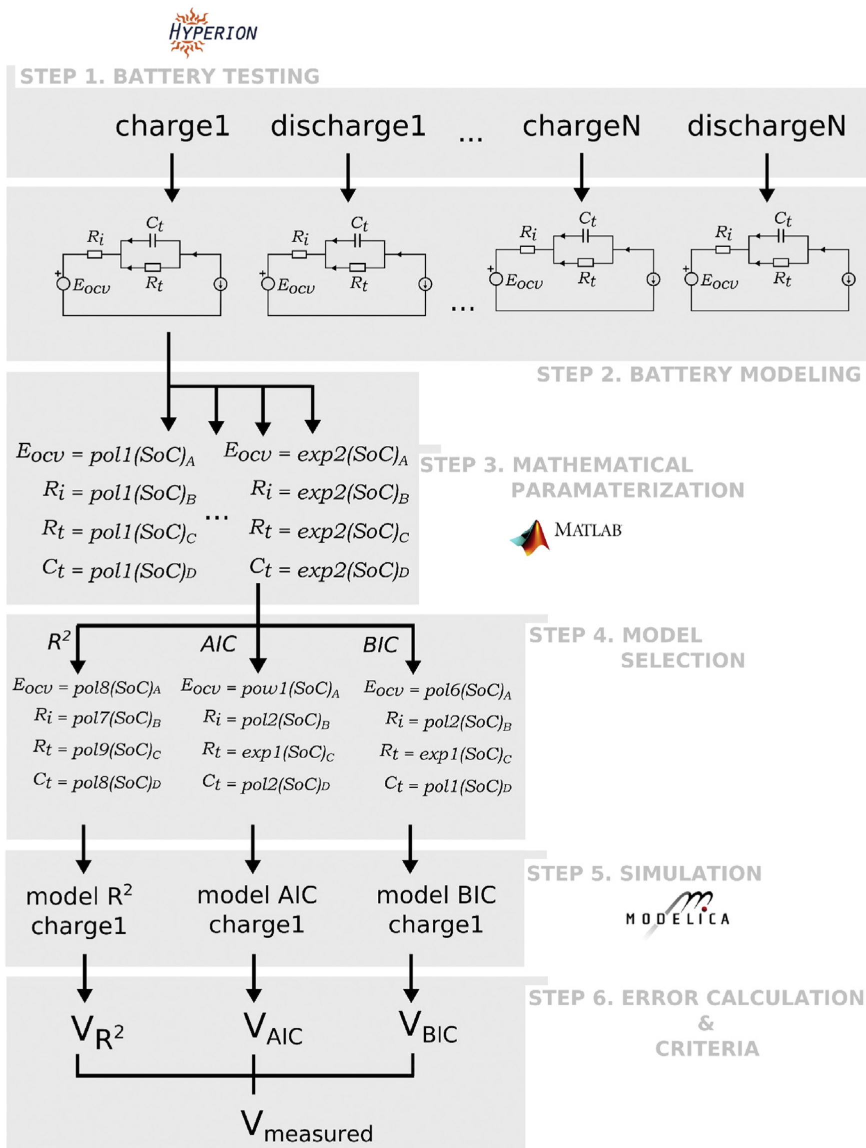

Fig. 1. Work-flow diagram of the present paper.

(170 $mAhg^{-1}$), amongst other positive features [12].

The mathematical parametrization of the model is an important step in the modeling process. In simulation environments, the elements of the battery models can be defined using look-up tables or mathematical functions. The principal drawback of using look-up tables is the large number of points needed to characterize the elements of the model precisely. This often makes it difficult the implementation of the model's elements. A mathematical function solves this issue because it succinctly describes the different elements of the battery models.

Optimal mathematical parametrization is not usually taken into account in the battery modeling process. There is a great number of works on battery parametrization using polynomial [13–15] or exponential [16,17] functions. However, there is almost no justification of why the selections are made.

In this work, three different model selection criteria were contrasted: the coefficient of determination (R^2) [18], the Akaike Information Criterion (*AIC*) [19] and the Bayes Information Criterion (*BIC*) [20]. All of them will serve to indicate how well the mathematical functions fit the empirical results. Furthermore, the *AIC* and *BIC* also take complexity into consideration and try to minimize it. These model selection criteria have been successfully used in wildlife biology [21,22] and molecular systematics [23]. *AIC* is generally preferred because it has its roots in Information Theory [24], a branch of applied mathematics, electrical engineering and computer science that is widely used. However, some prefer *BIC* because it selects simpler models [25] than *AIC*. These model

Table 1
Specifications of the *$LiFePO_4$* battery.

Manufacturer	Winston battery
Model name	WB-LYP40AHA
Technology	*$LiFePO_4$* doped with Ytrium
Capacity	40 Ah
Charge voltage	2.8 V
Discharge voltage	4.0 V
Optimum charge current	20 A
Maximum charge current	120 A
Optimum discharge current	20 A
Maximum discharge current	120 A