***Dynamic Detection of Different Battery Chemistry Using Neural Networks***

Subtitle as needed ***(paper subtitle)***

Hector K. Lopez

Computer Science and Electrical Engineering

Florida Atlantic University

Boca Raton, FL. United States

hlopez5@fau.edu

Authors Name/s per 2nd Affiliation (*Author*)

line 1 (of *Affiliation*): dept. name of organization

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*Abstract*—Lithium-iron-phosphate (LiFPO4), Nickel-metal-hydride (Ni-MH), and a Lead Acid battery are simulated without aging or temperature effects. A constant load is placed on the batteries and the discharge curves are used to train a neural net. The simulation is repeated for many discharge curves. Three feed-forward back-propagation neural net methods are analyzed: Single hidden layer, Double hidden layer and radial basis transfer function. The neural nets are trained at the various discharge curves to improve pattern recognition performance.

Keywords—Neural Networks; Lithium-Ion; NiMH; Lead-Acid; Battery Modeling; Pattern Recognition; Radial Basis

# Introduction

The popularity of battery storage systems has been on the rise in recent years. The similar rise in residential battery storage, and electric vehicle has led to interest in smart-grid applications where these potentially shared resources are managed in a dynamic way. For example, a fleet of various electric vehicles can be plugged into the same grid and then managed to provide energy storage services for homes in a neighborhood. One potential opportunity for a system like this is to detect the battery chemistry of any connected battery storage device and detect the battery chemistry. This paper is focused on the attempt to classify three different battery chemistries from each other using different neural network methods. The goal of this paper is to provide research on the accuracy of certain neural networks to detect the battery chemistry from just the voltage and state of charge of the battery. The experiment begins with basic battery models discharged at a constant load for one hour. A neural net is trained on the voltage response of each battery as the batteries discharge. The neural net is then validated for performance and a mean-squared-error (MSE) is established to grade the neural networks performance at that discharge rate. The discharge rate is increased by increasing the constant load. The simulation is repeated for increasing rates of discharge. In the end, a sweep of different load currents provides neural net MSE at each discharge rate. The paper then explores adjustments to the neural network to improve performance.

The battery models are analyzed to see the performance against similar commercial battery manufacturer published discharge curves.

# Battery Modeling

The battery is modelled using a simple controlled voltage source in series with a constant resistance. The model assumes the same characteristics for the charge and discharge cycles. The open voltage source is calculated with a non-linear equation based on the actual SOC of the battery. [1]

A generic dynamic battery model is represented in figure 1. The model shows the charge and discharge equations used.

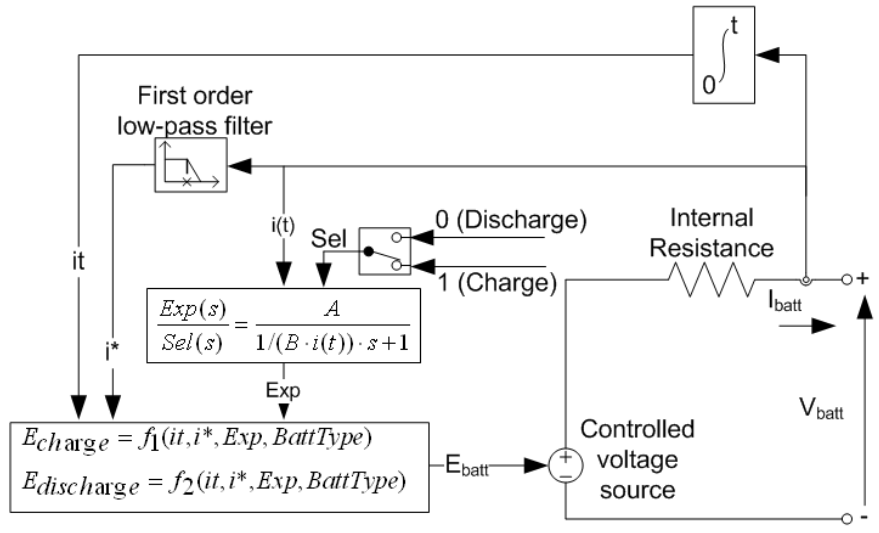


Figure 1

## The Battery Model

The discharge equations for the Lead-Acid and Ni-MH battery models are shown in equation (1) . The Lithium Ion discharge curve can be modeled using equation (2). These equations model the exponential curve at the beginning of discharge.



In the equations:

* is nonlinear voltage, in V.
* is constant voltage, in V.
* is exponential zone dynamics, in V.
* represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.
* is polarization constant, in Ah−1, or polarization resistance, in Ohms.
* is low frequency current dynamics, in A.
* is battery current, in A.
* is extracted capacity, in Ah.
* is maximum battery capacity, in Ah.
* is exponential voltage, in V.
* is exponential capacity, in Ah−1.

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use “(1),” not “Eq. (1)” or “equation (1),” except at the beginning of a sentence: “Equation (1) is ...”

## Modeling Circuit

Battery modeling can be done using several different methods. [1] reference battery modling papers here\*. The battery models used in this paper do not factor in the temperature effects or aging effects when trying to train the neural nets.

## Model Validation

Experimental validation of the model shown a maximum error of 5% (when SOC is between 10% and 100%) for discharge (current from 0 through 5 C) dynamics.

## Model Assumptions

* The internal resistance is assumed constant during the charge and discharge cycles and does not vary with the amplitude of the current.
* The capacity of the battery does not change with the amplitude of current (No Peukert effect).
* The self-discharge of the battery is not represented.
* The battery has no memory effect.

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# Training Neural Networks

The battery model is used to simulate the discharge current applied to the batteries for 1 hour the data is recorded for training by the neural network. Patternnet is a matlab function used to build feedforward networks. The input and target arrays are built and used to train a neural net. The neural net then uses the input again to measure the MSE and MAPE and benchmark the performance of the NN to detect each battery chemistry given the input. Each discharge current is measuered an the individual NN performance is analyzed for all discharge currents. The NN is then modified to use a different method and the process repeats. In the end we have a picture of what NN method is best and what discharge current htat the NN can classify the batteries best.

The multilayer feedforward network can be trained for function approximation (nonlinear regression) or pattern recognition. Through backpropagation the error is reduced and the network biases and weights are set to values that keep the error to a minimum given any new inputs by using what was learned from the training data.

scaled conjugate gradient backpropagationFinally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

## NN Single Hidden Layer

The multilayer feedforward network can be trained for function approximation (nonlinear regression) or pattern recognition. Through backpropagation the error is reduced and the network biases and weights are set to values that keep the error to a minimum given any new inputs by using what was learned from the training data.

## Back Propagation NN with Double Hidden Layer

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

## Radial Basis NN

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*a**b*    

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## Some Common Mistakes

* The word “data” is plural, not singular.
* The subscript for the permeability of vacuum **0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o.”
* In American English, commas, semi-/colons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
* A graph within a graph is an “inset,” not an “insert.” The word alternatively is preferred to the word “alternately” (unless you really mean something that alternates).
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* There is no period after the “et” in the Latin abbreviation “et al.”
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Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include ACKNOWLEDGMENTS and REFERENCES, and for these, the correct style to use is “Heading 5.” Use “figure caption” for your Figure captions, and “table head” for your table title. Run-in heads, such as “Abstract,” will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

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1. Table Styles

| Table Head | Table Column Head | | |
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| Table column subhead | Subhead | Subhead |
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1. G. Eason, B. Noble, and I.N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955. (*references*)

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1. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.
2. I.S. Jacobs and C.P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.
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