# A New Nonlinear Double-Capacitor Model for Rechargeable Batteries

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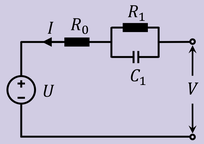
## Introduction

Batteries are not only indispensable for our life today but also a key technology for moving the world forward into a sustainable energy era.

Batteries are vulnerable to over-dis/charge, temperature effects and abusive ambient conditions. Battery management is a must to ensure the safety, performance and longevity of the batteries.

Practical real-time battery management systems often require the use of equivalent circuit models, which are structurally concise and computationally efficient. Despite some existing models, there is a continual demand for equivalent circuit models capable of capturing complex battery behavior at high accuracy.



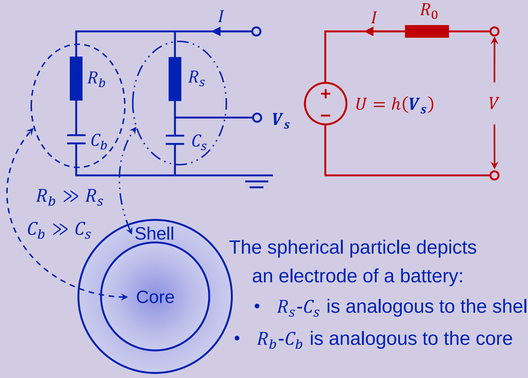

Thevenin model

**Research motivation:** Develop a new equivalent circuit model that can emulate the charge transfer within an electrode and the nonlinear voltage response simultaneously.

Our effort transforms an existing linear equivalent circuit model to be a nonlinear one that can offer higher accuracy.

## Modeling

The **new** nonlinear double-capacitor (**NDC**) model is




The spherical particle depicts an electrode of a battery:

- $R_s$-$C_s$ is analogous to the shell
- $R_b$-$C_b$ is analogous to the core

In the NDC model:

- The double capacitors provide storage for electric charge like an electrode depicted as the above spherical particle. When parallelly connected, they simulate charge migration between the shell and the core region in the electrode.
- Nonlinear function $h(\cdot)$ enables the NDC model to capture the nonlinear relationship between state of charge and open-circuit voltage.

**Advantages** of the NDC model:

- Concise structure
- Physical reasonableness
- High predictive accuracy

**Prospective applications** of the NDC model:

- State of charge estimation
- State of health estimation
- Fast charging protocol design
- Aging prognostics

## Experimental Validation

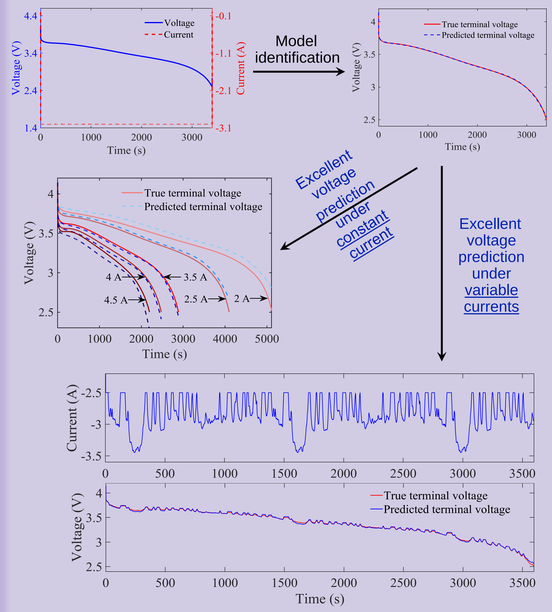

Experimental facility

- PEC® SBT4050 battery tester
- Support dis/charging with arbitrary current-, voltage- and power-based loads up to 40 V and 50 A
- Run with a server that configures tests and collects data

Experimental battery

- Panasonic NCR18650B, 3.25 Ah

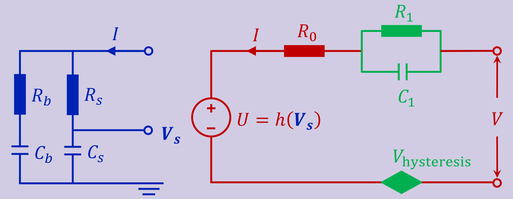
Validation of the predictive capability of the NDC model




## Ongoing & Future Work

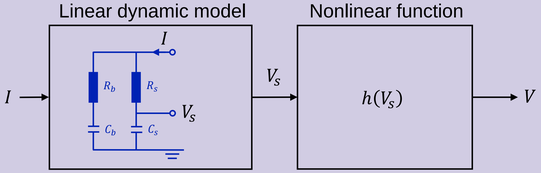
Enhanced NDC model

- We include hysteresis effect and one more $R$-$C$ circuit to further improve the NDC model's predictive capability.




Parameter identification from a Wiener-model perspective

- The NDC model has a structure similar to the block-oriented Wiener model.
- Wiener-based NDC identification can be applied to arbitrary current/voltage profiles, making the NDC model much more convenient in practice.




[1] N. Tian, H. Fang and J. Chen, "A new nonlinear double-capacitor model for rechargeable batteries," *IECON18*.
[2] N. Tian, H. Fang and Y. Wang, "Parameter identification of the nonlinear double-capacitor model for lithium-ion batteries: From the Wiener perspective," *ACC2019*, under review.

For more information about our work, please visit *www.issl.space*.