Temperature-Dependent Battery Models for High-Power Lithium-Ion Batteries

Valerie H. Johnson, Ahmad A. Pesaran
National Renewable Energy Laboratory

Thomas Sack
Saft America

NREL National Renewable Energy Laboratory

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

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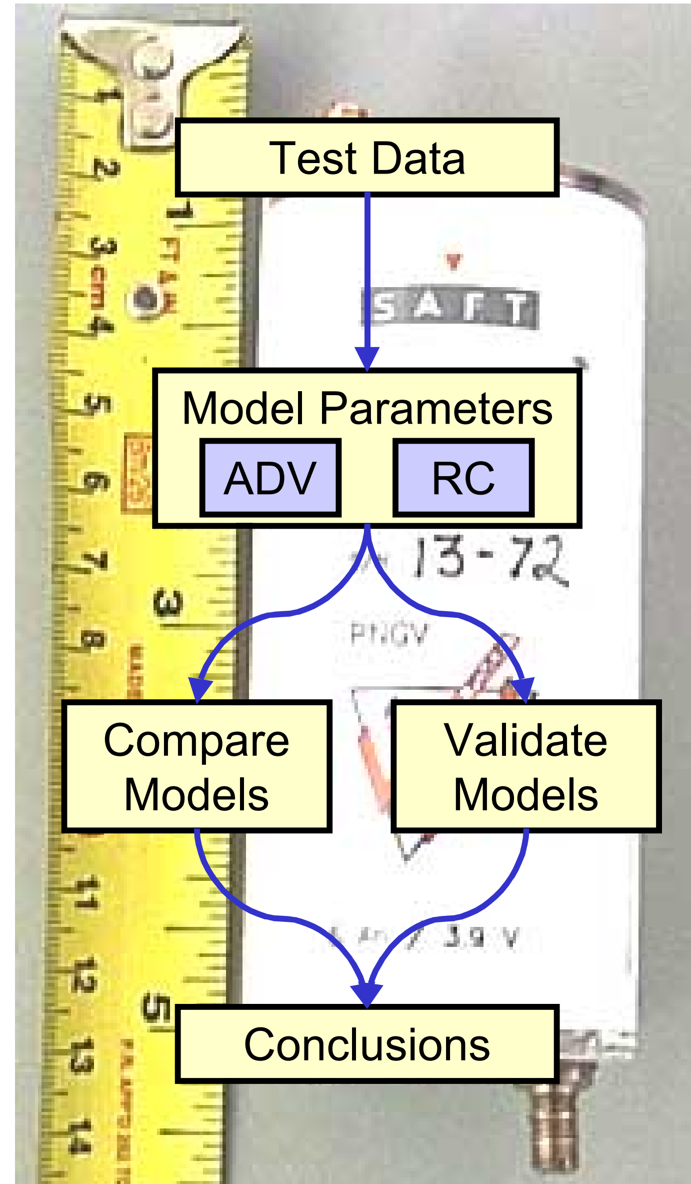
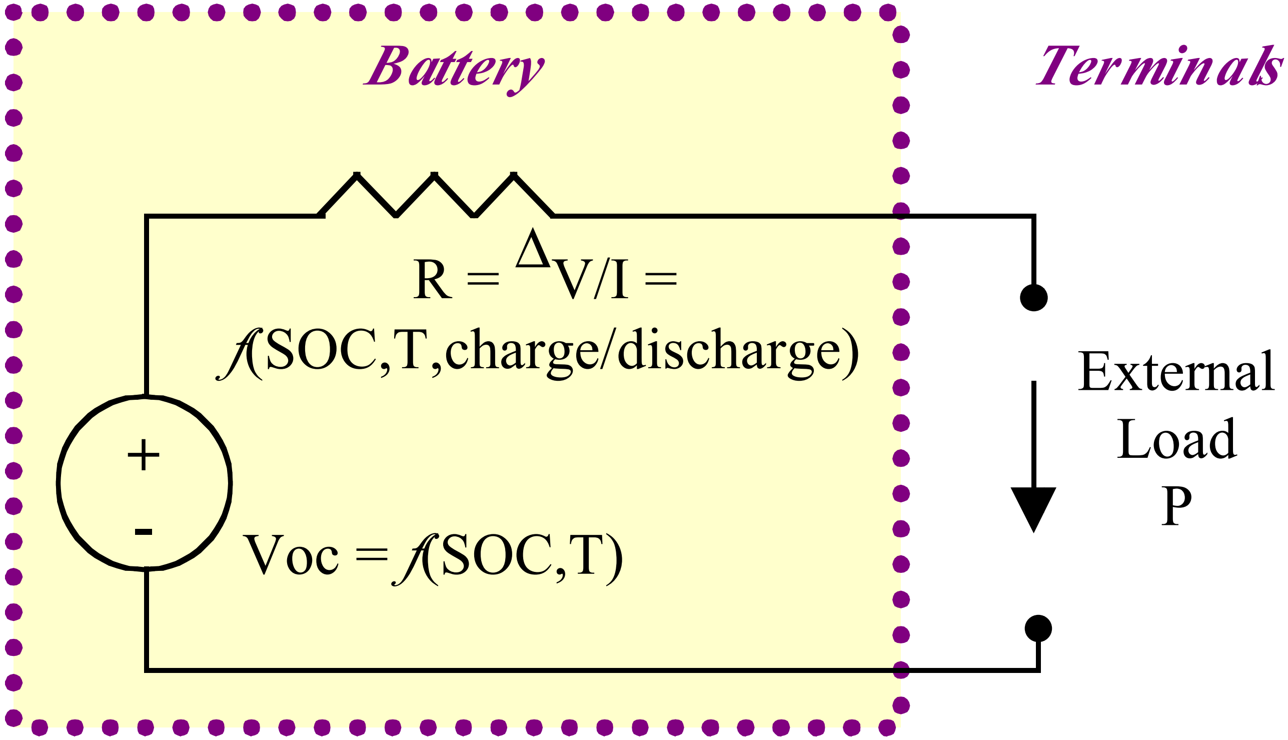
At-A-Glance

- What?
  - Two battery models (Matlab/Simulink environment) for a high-power 6 Ah lithium-ion battery
  - Initial model based on available model from NREL's Advanced Vehicle Simulator (ADVISOR)
- Who?
  - National Renewable Energy Laboratory (NREL) and Saft America, under DOE's PNGV program
- Why?
  - To be used in simulations of hybrid-electric vehicles
- When?
  - Testing in Spring 1999
  - Model development through Summer 2000
- Where?
  - NREL, Golden, Colorado

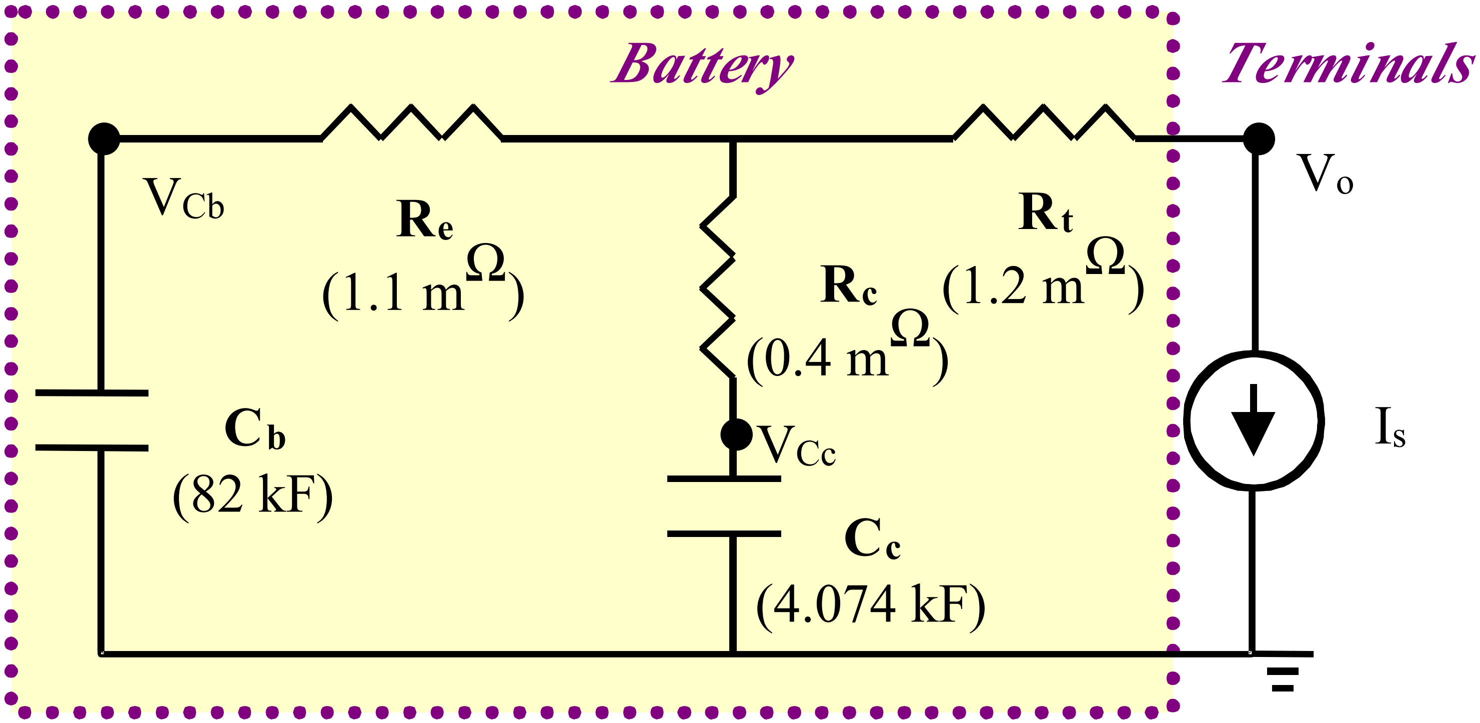


Resistive Model (ADV)



- Model consists of an open circuit voltage (Voc) and an internal resistance (R)
  - parameters are functions of State Of Charge (SOC), Temperature (T), and direction of current flow (Rint only)
  - SOC: $SOC = \frac{Ah_{max} - Ah_{used}(\eta_{coulomb})}{Ah_{max}}$ where $Ah_{used} = \int_0^t \eta_{coulomb} A\,dt$ for $A > 0$ discharge, $A < 0$ charge
- External load is a power request
- Called ADV model, stands for ADVISOR

Capacitance Model (RC)



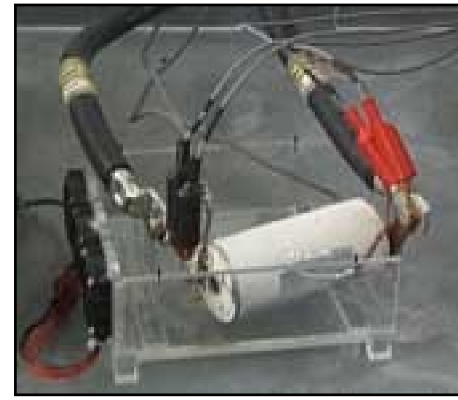
- Model consists of two capacitors (Cb,Cc) and three resistors (Re, Rc, Rt)
  - parameters are constant
  - SOC estimated from capacitor voltage (Vcb)
- External load is a current request
- Called RC model
- State-space representation in Simulink

Laboratory Test Setup

- Testing gives parameters for either the ADV or RC model

Bitrode Battery Tester

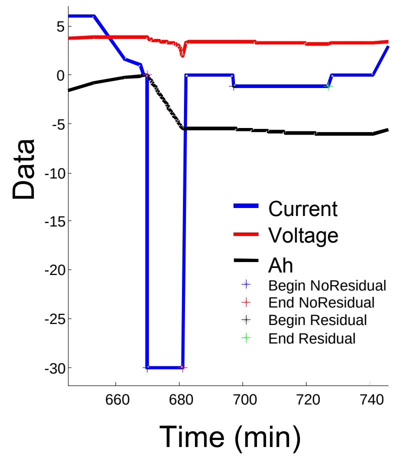
Ambient Testing



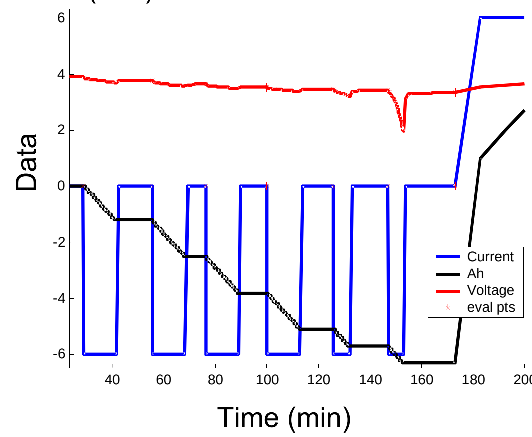
Temperature Testing in NESLAB Liquid Bath

Test Procedures

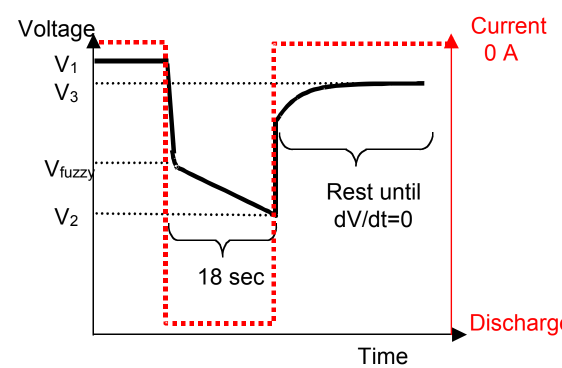
1. Residual Capacity Test
   for maximum Ah capacity



2. Open Circuit Voltage Test
   for Voc versus SOC



3. Internal Resistance Test
   for:
   - Rint (ADV)
   - potentially R and C values (RC)



$$R_{int} = \frac{V_{oc} - V_{terminal}}{I}$$
$$= \frac{V_3 - V_2}{I}$$

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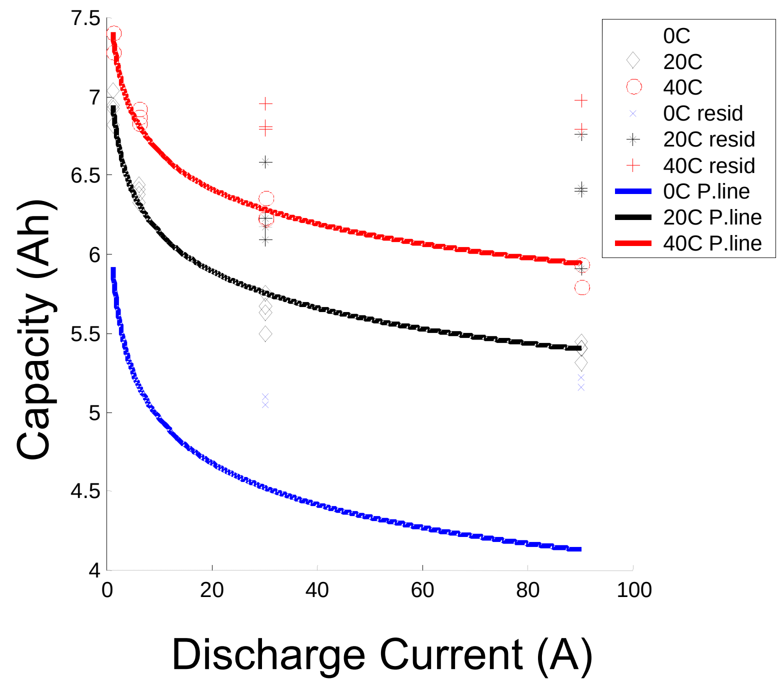
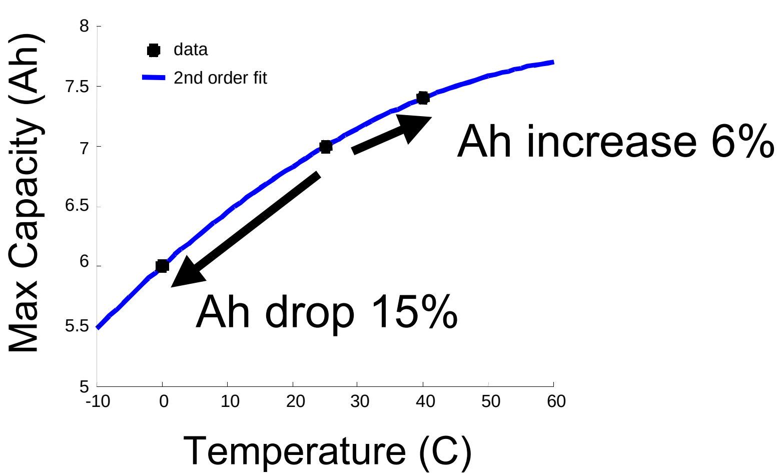
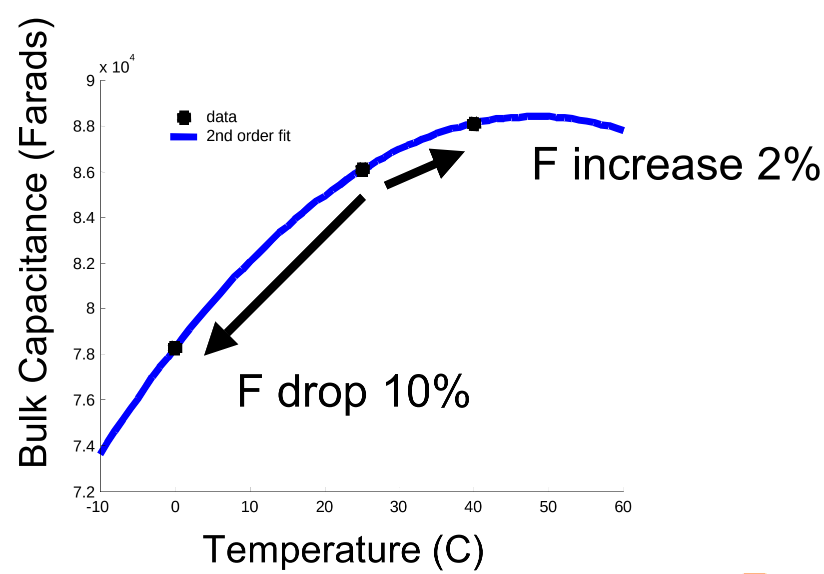
Model Parameters vs. Temperature

Capacity

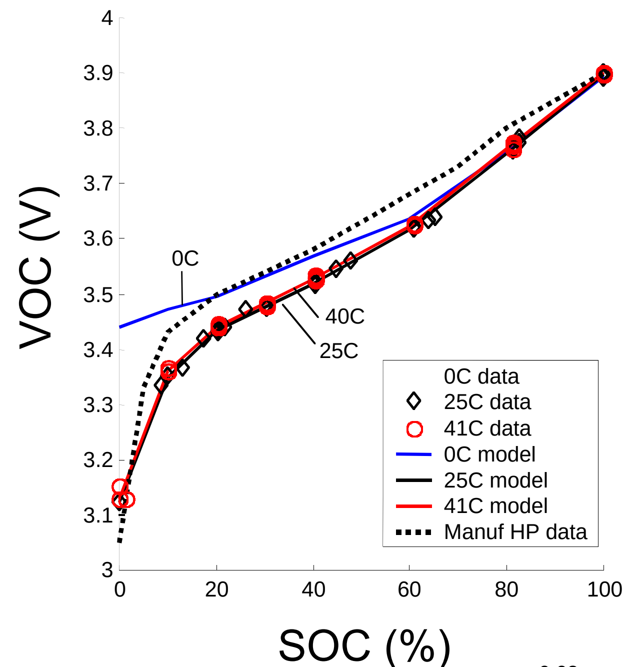




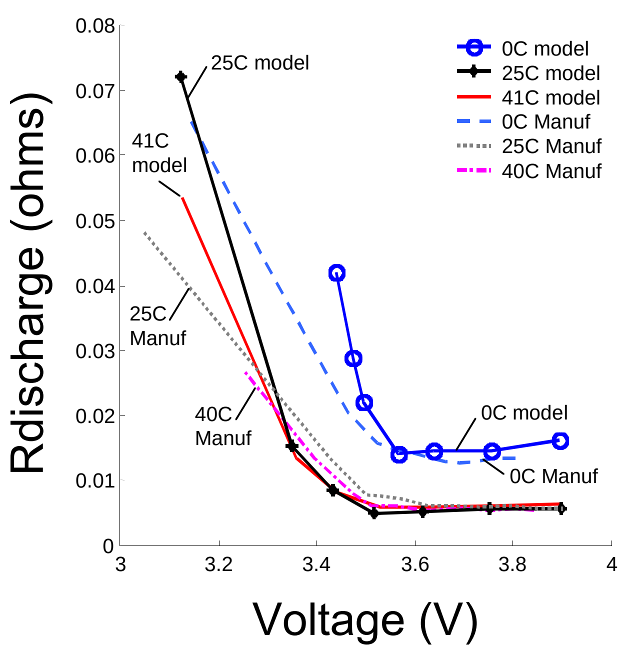


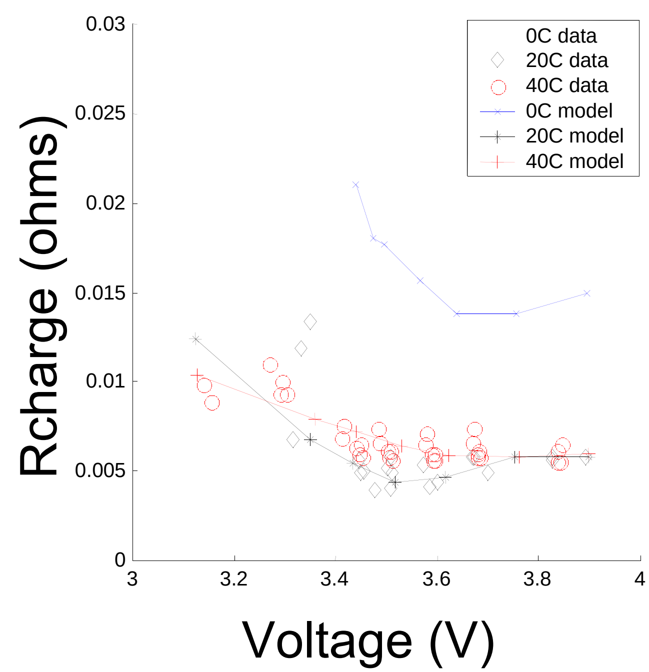
Model Parameters vs. Temp, cont.

Open Circuit Voltage

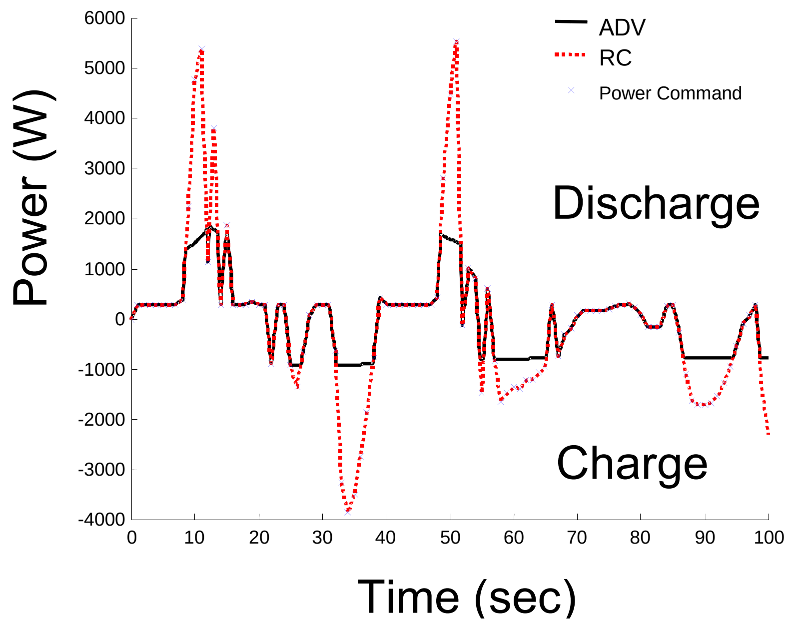


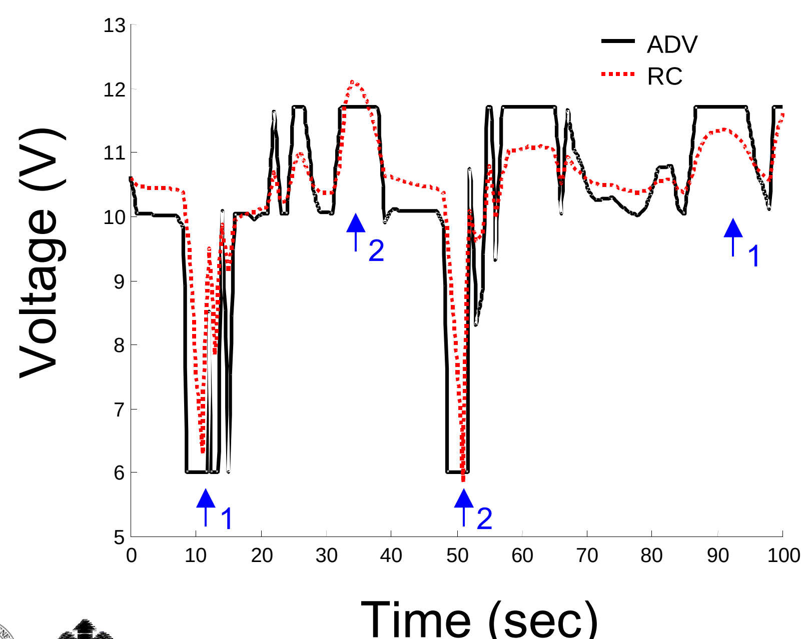
Internal Resistance





Model-to-Model Comparison





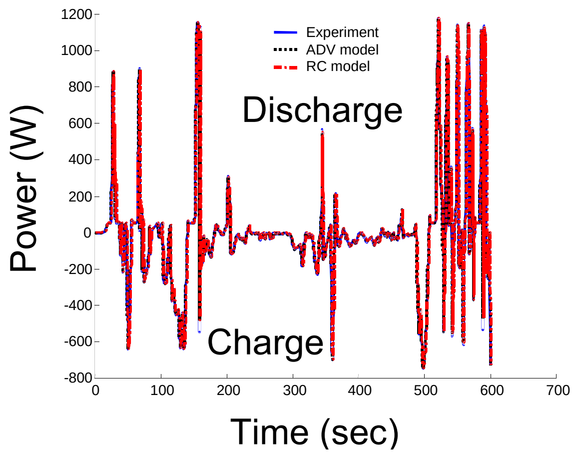
Overview

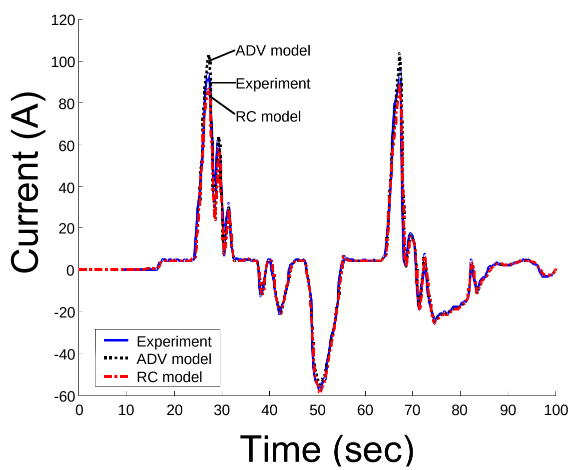
- A demanding power request was given to the battery
- ADV model reached voltage limits, while RC model doesn't currently include voltage limits
- RC predicts higher resting voltages

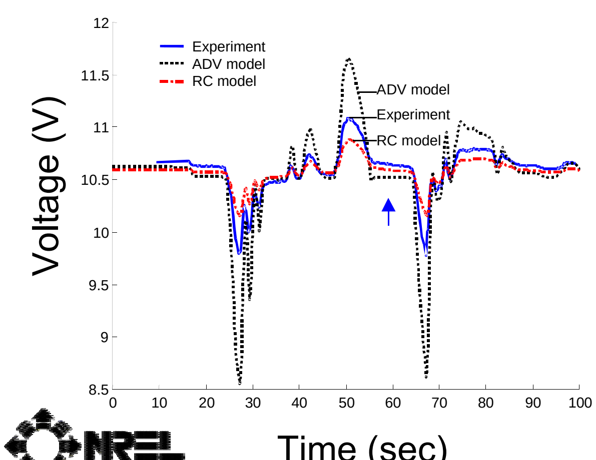
Limiting Cases

- The RC voltage stays within the allowable voltage range
  1. discharge at 10 seconds and charge 90 seconds
- The RC voltage exceeds the allowable safe voltage range
  2. discharge at 51 seconds and charge at 35 seconds

ADV & RC Model Validation







- US06 derived battery power profile

Observations

- The experimental values lie between the ADV model and the RC model
- Neither discharge (6 V) nor charge (11.7 V) voltage limits are exceeded
- The ADV model substantially overshoots the experimental voltage on both discharge and charge
- During rests (e.g. 56 - 64 sec), the RC voltage slowly drops, as does the experimental voltage, while the ADV model is constant as it has no time dependent behavior
- During rests, the ADV voltage is slightly lower than experimental values

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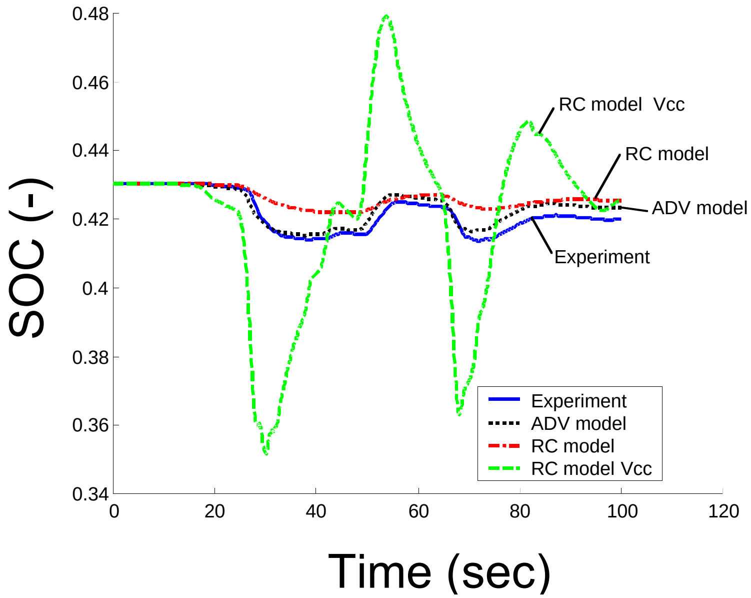
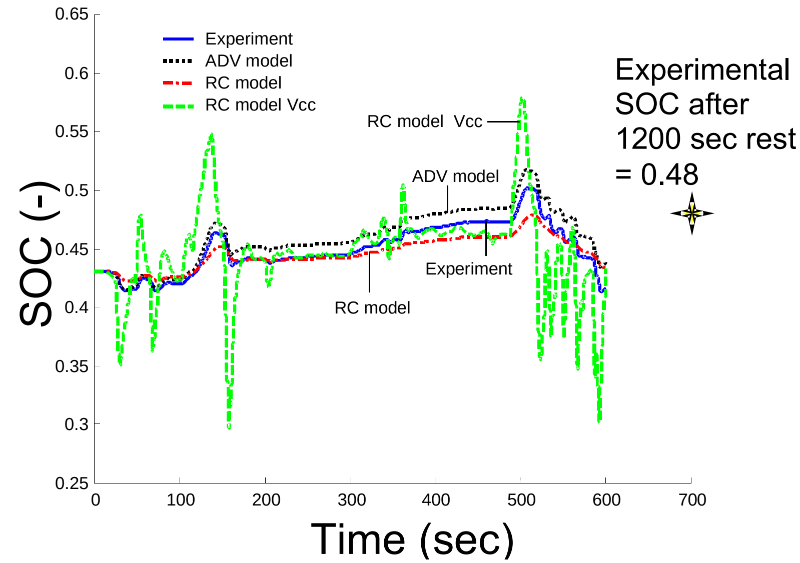
Model Validation, cont.





Observations

- ADV more accurately predicts instantaneous SOC than RC
- Final ADV SOC was closer to the true SOC than the RC model

Cycle Validation	ADV model	RC model
Overall US06 cycle (600 seconds) ***Voltage Error***	Avg: 1.4% + Std dev 2%, Max: 15%, over-predict voltage swings	Avg: 1.2% + Std dev 0.7%, Max: 5%, under-predict voltage swings
Instantaneous SOC	Close tracking, slightly over-predict SOC	Slower tracking, similar behavior patterns
Final SOC *(after resting)*	3% below	3.7% below

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Results & Future Work

- NREL plans on developing a capacitance-based model in ADVISOR
  - Advantages of including cap's: smooth performance behavior, better voltage tracking
- Issues to address with the future Saft/ADVISOR Model:
  - SOC estimation
  - Model to work on a power request basis (not a current request)
  - Operation within safe voltage limits
  - Maintain ADV's parameter (R and C) variation with temperature and SOC
- Saft approved release of the current Saft model in ADVISOR 3.0, available free on the web: www.ctts.nrel.gov/analysis