Modelling of distributed time constants in carbon based supercapacitors

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Modelling of Distributed Time Constants in Carbon Based Supercapacitors

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EPSRC funding

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Overview

- Goals of ELEVATE project
  
  *ELECTrochemical Vehicle Advanced TEchnology*

- Modelling and simulation of supercapacitors
- Application to working devices
- MatLab / SIMULINK to model non-ideal systems
- Conclusions
- Further studies / future work
Goals of ELEVATE Project

- Develop supercapacitors for use in electric vehicles based on:
  - ionic liquid electrolytes
  - porous carbon electrodes

- Develop a successful equivalent circuit model of supercapacitor performance
  - simulation and fitting
  - characterisation
Modelling Supercapacitors

Previously modelled supercapacitor performance using simple equivalent circuit model

Modelling Supercapacitors (cont)

Model implemented in both hardware and software

Can account for voltage decay after charging and voltage ‘rebound’ after discharging at short circuit
Equivalent Circuit for Supercapacitors

Equivalent circuit consisting of parallel network of RC components

Hardware Equivalent Circuit

Equivalent circuit built using solid state polymer film capacitors exhibiting near ideal behaviour

- 22 μF PE film
- 1 kΩ in series
- 50 mV s⁻¹
- step pot. 1 mV
- 8 scan average
Software Validation of Model

Hardware equivalent circuit validated in software (Matlab / Simulink)
Distributed Time Constants in Commercial Device

Voltage rebound from commercial NEC 10 mF device exhibits non-exponential behaviour corresponding to log Gaussian model.

OCP after:
- charge 1 V for 2 s
- short circuit for 2 s
A.C. Impedance of Equivalent Circuit

A.C. impedance of equivalent circuit and fitting performed with floating parameters (no bias)
A.C. Impedance of Commercial Device

A.C. impedance of NEC 10 mF device shows strong evidence for distribution of pore resistance.
%% System Dynamics
figure('Name','System Dynamics','InvertHardcopy','off','Color',[1 1 1]);
set(gcf,'DefaultAxesColorOrder',map);
clearvars -except fig_count map dataset my_type;
load(dataset);

[hAx,hLin1,hLine2] = plotyy(tout, v_cc,...
tout, i_cc);
title(strcat('System Voltage & Current', ', ',' (',
xlabel('Time /s');
ylabel('Power loss /W');
ylabel(hAx(1),'Voltage /V') % left y-axis
ylabel(hAx(2),'Current /A') % right y-axis
set(hLin1, 'Color', 'Red');
Non-Ideal Capacitor Equivalent Circuit

Series resistor (current limiter)

Parallel inductor (high freq only)

Ideal capacitor

Parallel resistor (self discharge)
Making the Pascal Model – One Rung

NB:
Making the Pascal Model – Full

NB:

Row 1
1 1 1
Row 2
1 2 1
Row 3
1 3 3 1
Row 4
1 4 6 4 1
Row 5
1 1 1
Charge then OCV

Voltage across 'ideal caps'

Voltage across resistors

NB:
Charge, SC then OCV

**Voltage across `ideal caps’**

**Voltage across resistors**
Conclusions

- Carbon based supercapacitors can be represented by a parallel ladder RC network
- Pseudo-ideal components can be used to model this in hardware
- ‘Ideal’ components can be used in software and a greater understanding obtained
- A greater understanding enhances higher level vehicle models
Further Studies / Future Work

• Integrate the new model into the Electric Vehicle model

• Understand the impact of these phenomena on vehicle performance compared to a `traditional’ capacitor model

• Task for the Chemists:
  • Develop a non-Gaussian distribution with a specifiable `fast’ or `slow’ performance
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