Study on Hybrid System

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Hybrid System

Objective

• Study on Hybrid system performance under high pulse current.
• Capacity fade study on the hybrid system.
• Mathematical model of the capacity fade phenomenon.
Hybrid System

Background

• In applications of space communications, cellular phones as well as hybrid vehicles, power sources with high-energy and high-power are urgently needed.

• Lithium ion battery provides higher specific energy than conventional batteries.

• Supercapacitor (or Electrochemical Capacitor) has high specific power and is considered to be excellent candidate in combination with Lithium-ion battery to meet the demands of both energy and power.
Hybrid System- Battery

Whole Cell Analysis

• The lithium-ion battery tested is Sony 18650 commercial battery.
• The Supercapacitor is Maxwell commercial supercapacitor.
• Charging protocol is CC+CV protocol.
• Discharging rates are 1C(1.4A), 2C(2.8A), 3C(4.2A) respectively.
• Every 50 charge & discharge cycles, the battery capacity is verified at C/2(0.7A) discharge rate.
• Ambient Temperature is 25°C.
• Arbin charger is used.
Hybrid System- Battery

Capacity Fade Data & Plots

After 300 Cycles
Hybrid System- Battery

Capacity Fade Data & Plots

Discharge Capacity (Ah)

First 50 Cycles

Cycle No.
Hybrid System - Battery

Discharge Capacity vs Voltage

[Graph showing discharge capacity vs voltage for different discharge rates: Initial Discharge, 1C Discharge, 2C Discharge, 3C Discharge, After 300 Cycles]
Hybrid System - Battery

Rate Capability

After 300 Cycles
Hybrid System - Battery

Whole Cell Impedance

0% SOC

- Fresh
- 1C Discharge Rate
- 3C Discharge Rate
Hybrid System - Battery

Whole Cell Impedance

![Graph showing impedance changes with different discharge rates and SOC](image-url)
Hybrid System - Battery

Half Cell Capacity Data - Carbon
Hybrid System - Battery

Half Cell Capacity Data – LiCoO₂

![Graph showing voltage and current over time with markers for Delithiation and Lithiation.](image-url)
## Hybrid System - Battery

**Half Cell Capacity Data**

<table>
<thead>
<tr>
<th>Capacity (Ah/Pellet)</th>
<th>Initially</th>
<th>1C 300 Cycles</th>
<th>2C 300 Cycles</th>
<th>3C 300 Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.00253</td>
<td>0.00246</td>
<td></td>
<td>0.00226</td>
</tr>
<tr>
<td>LiCoO₂</td>
<td>0.00251</td>
<td>0.00241</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 1. Capacity of Electrode Pellets initially and after 300 Cycles

<table>
<thead>
<tr>
<th>Capacity (Ah/Pellet)</th>
<th>Initially</th>
<th>1C 300 Cycles</th>
<th>2C 300 Cycles</th>
<th>3C 300 Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>1</td>
<td>2.77%</td>
<td></td>
<td>10.59%</td>
</tr>
<tr>
<td>LiCoO₂</td>
<td>1</td>
<td>3.98%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hybrid System - Battery

Half Cell Impedance-Carbon

\[ Z_{\text{Re}} (\Omega) \]

\[ Z_{\text{Im}} (\Omega) \]

- Fresh 100% Lithiation
- 1C 300 Cycles 100% Lithiation
- Fresh 100% Delithiation
- 1C 300 Cycles 100% Delithiation
Hybrid System - Battery

Half Cell Impedance – LiCoO$_2$

![Graph of Impedance vs Frequency for LiCoO$_2$ Half Cells](image.png)

- Fresh 0% SOC
- 1C 300 Cycles 0% SOC
- Fresh 100% SOC
- 1C 300 Cycles 100% SOC
Hybrid System- Supercapacitor

Cyclic Voltammetry

![Cyclic Voltammetry Graph]

- Nominal 5 F Capacitor
- Nominal 10 F Capacitor
- Nominal 15 F Capacitor
- Nominal 20 F Capacitor
- Nominal 25 F Capacitor

Scan Rate: 50 mV/s
Hybrid System- Supercapacitor

Capacitance Calibration

- Cyclic Voltammetry
- Constant Current Charge and Discharge

<table>
<thead>
<tr>
<th>Nominal (F)</th>
<th>Calibrated (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5.22</td>
</tr>
<tr>
<td>10</td>
<td>10.23</td>
</tr>
<tr>
<td>15</td>
<td>14.98</td>
</tr>
<tr>
<td>20</td>
<td>19.92</td>
</tr>
<tr>
<td>25</td>
<td>24.55</td>
</tr>
</tbody>
</table>
Hybrid System - Supercapacitor

Capacitance under AC Mode

![Graph showing capacitance under AC mode for different capacitors.](image-url)
Hybrid System - Supercapacitor

ESR Calibration under AC Mode

![Graph showing ESR vs Frequency for different capacitors]
Hybrid System - Supercapacitor

Ragone Plots

- Pulse Period: 1S On + 2S Off
- Pulse On Amplitude: 0.5 A to 3.5A
- Voltage Window: 2.5 V to 4.2 V
- Capacitors weight: Not taken into account
Hybrid System- Battery

Ragone Plots

- Discharge Energy (Wh)
- Discharge Power (W)

- Voltage Range: 2.5 V to 4.2 V
- Pulse Period: 1S on + 2S Off

Graph showing discharge power and energy under pulse and CC loads.
Hybrid System

Temporary Conclusions

• Capacity Fade is seriously effected by the discharge rate.

• The direct result of high rate discharge of battery is the increase of its inner resistance, which affects accordingly its discharge voltage platform, discharge capacity, as well as its rate capability.

• Quantitative Half cell analyses indicate that both Carbon and LiCoO$_2$ contribute to the increase of inner resistance, but the percentage due to LiCoO$_2$ Cathode outweighs that due to Carbon anode( limited to 1C rate ).

• The performance of Battery alone under high current load is poor.
Hybrid System

Future Work

• Ragone Plots of hybrid system and discharge power improvement under high current.

• Best match of battery and capacitor in light of specific energy and specific power.

• Set up circuit model to analyze voltage drop and current distribution during duty on period.

• Cycle the hybrid system and periodically check the parameters such as resistance, capacity, capacitance etc.

• Compare the capacity fade with that of battery alone.

• Try to develop diffusion model to explain this capacity fade phenomenon of the hybrid system.