LITHIUM BATTERY AND ULTRA-CAPACITOR AGING
Electrification of
- Passenger vehicles
- Public transportation via bus, train or even hyperloop (possible)
- Commercial shipping via trucks

Improving emissions out of tailpipe

Less depended on fossil fuels as energy source

How to Improve?
- Extend battery life**
- Develop new power sources for vehicles
- Improve existing sources of power**
OBJECTIVE

- Model a vehicle with a battery
- Supplement the battery with an ultra-capacitor, UC
- Compare amount of battery life cycles with and without UC’s
- Determine if aging of either battery or UC is significant

Source: https://learn.sparkfun.com/tutorials/capacitors

Source: https://www.orbtronic.com/batteries-chargers/panasonic-3400mah-18650-li-ion-battery-cell-ncr18650b
SIMULATION BASED RESEARCH

- Allows for
  - Ease of quick results
  - Compare different data entries
  - Dynamic complex calculations done easy
  - Calculations can be made a function of time

- Use of MATLAB
  - Simulink used to build models within MATLAB
  - Multiple models integrated together
Dynamic model
- Uses outputs from pre determined drive cycle, function of time
- Forces taken into account
  - Gravity
  - Inertia
  - Rolling
  - Drag
- Manhattan Drive cycle used

Source: Mallon, K.

Source: https://www.dieselnet.com/standards/cycles/nybus.php
- $P_{req}$ is electrical power required by the bus on set drive cycle
- $P_{req}$ can also be negative, regenerative braking
- Backwards facing model
**ENERGY STORAGE**

**Battery model**
- Stores most of energy on board vehicle
- Internal capacitance, resistance based on changing SOC
- Aging applied within model, State of Aging
- Peak shaving
- Charge/discharge at 1C
  - Keep aging to a minimum

**Ultra capacitor, UC**
- Stores limited energy
- Takes power demand away from battery
- Can quickly put power back into system
- Aging applied within model, State of Health
- Power fluctuation minimized
- 100 cells in series, 100 cells in parallel is one UC bank
- Simplified battery schematic
- 2nd order
- \( SOC = \frac{Q}{Q_{\text{max}}(SOH)} \)
- Resistance, capacitance function of SOC
- **Hysteresis Effect**
  - Internal capacitance, resistance creates hysteresis
  - Delay before charging/discharging current can be at fullest
- **Why is this important?**
  - Increases fidelity for more accurate aging model results
Different order Ultra Capacitor, UC models simulated, (Dougal, R. et. al)

4th order chosen
- Closer, less error, to real world applications than 1st or 2nd order

Tested with 1 amp 15s duration
AGING MODELS

- Battery aging
  - Resistance and capacitance increase as function of SOC
  - (Erdinc O. et. al)

- Capacitor aging
- Aging: \( C_{out}(SOA) = 0.95C_i - 0.15SOA \)
- SOA is function of temperature and voltage
  - High temp, low voltage aging, (Kovaltchouk et. al)
MATLAB function within Simulink

- Function of
  - SOC of Battery
  - SOC of UC bank
  - Preq
    - Electrical power required by vehicle

- Outputs
  - Power to/from battery, Pbat
  - Power to/from UC, Pcap

- Function only allows power to battery within maximum (+-)
  - 1C charge/discharge
  - UC sized to take the rest

- Function allows UC to charge/discharge under extreme conditions while SOC remains between ~20-50%
TESTS RUN

- **Test 1**
  - Battery model with aging
  - No UC’s

- **Test 2**
  - Battery Model with aging
  - 1 UC bank, no aging

- **Test 3**
  - Battery model with aging
  - 1 UC bank with aging

- **Test 4**
  - Battery model with aging
  - 4 UC banks with aging
- Battery life cycles increase with help from UC
- Increased efficiency of battery

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<thead>
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<th>Type of System</th>
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More capacitors, increased battery cycles

Aging Caused by:
- Anode resistance
- Loss of active Lithium
- Thermal stress
  - Mostly UC

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RESULTS

- Battery SOC
  - Aging vs no aging
  - UC aging insignificant
RESULTS

Capacity Fade % in Capacitor

- Battery w/ 1 UC Aging: 22%
- Battery w/ 4 UC’s Aging: 10%

Capacity Fade % in Battery

- Battery: 19.9%
- Battery w/ 1 UC no Aging: 20.3%
- Battery w/ 1 UC Aging: 20.3%
- Battery w/ 4 UC’s Aging: 20.2%
RESULTS

- UC aging not significant compared to battery aging
- By adding more UC’s to the energy system
  - Decreased UC aging, take on larger load from battery
  - Decreased battery aging
- By adding 3 UC’s for a total of 4
  - UC life is ~2.2 times longer
  - Battery life is ~1.44 times longer
IMPROVEMENTS

- Model a high fidelity system
  - More accurate results
  - Longer computation time
  - Compare to current model results

- Looking at more advanced control for UC’s
  - Not use peak shaving method

- Build and test bench model
  - Program a controller
  - Controller works with test bench
  - Compare results

- Cost Benefit analysis
  - Find optimum amount of UC cells, added life equal to cost
Thank you!

References:

Erdinc, O., Vural, B., Uzunoglu, M. A dynamic lithium-ion battery model considering the effects of temperature and capacity fading. 2009 International Conference on Clean Electrical Power, ICCEP 2009. 383 - 386. 10.1109/ICCEP.2009.5212025.
