SUPERCAPACITOR PERFORMANCE CHARACTERIZATION FOR RENEWABLES APPLICATIONS

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WHAT IS A SUPERCAPACITOR?

- Energy storage technology
- Electrodes immersed in electrolyte
  - Energy stored electrostatically
  - Highly reversible process
- Extremely large capacitances feasible
- Cells can easily be combined to form large storage banks

PROPERTIES

SUPERCAPACITOR

- High power density
- Low energy density
- Electrostatic energy storage
- Highly reversible
- Short time-scale

BATTERY

- Low power density
- High energy density
- Electrochemical energy storage
- Limited reversibility
- Medium time-scale

- Technologies compliment each other well
- Combined, have very good applications in renewable energy

SUPERCAPACITOR LIFETIME

- End of life:
  - Cell capacitance – 80% of initial value
  - Cell ESR – 200% of initial value
- Rest period effects
  - Cell capacitance recovers as a function of rest period time
- Lifetime evolution
  - Initial exponential decrease
  - Linear decay
  - Final exponential decay
- Factors that accelerate aging
  - Temperature
  - Terminal voltage
  - Duty cycle

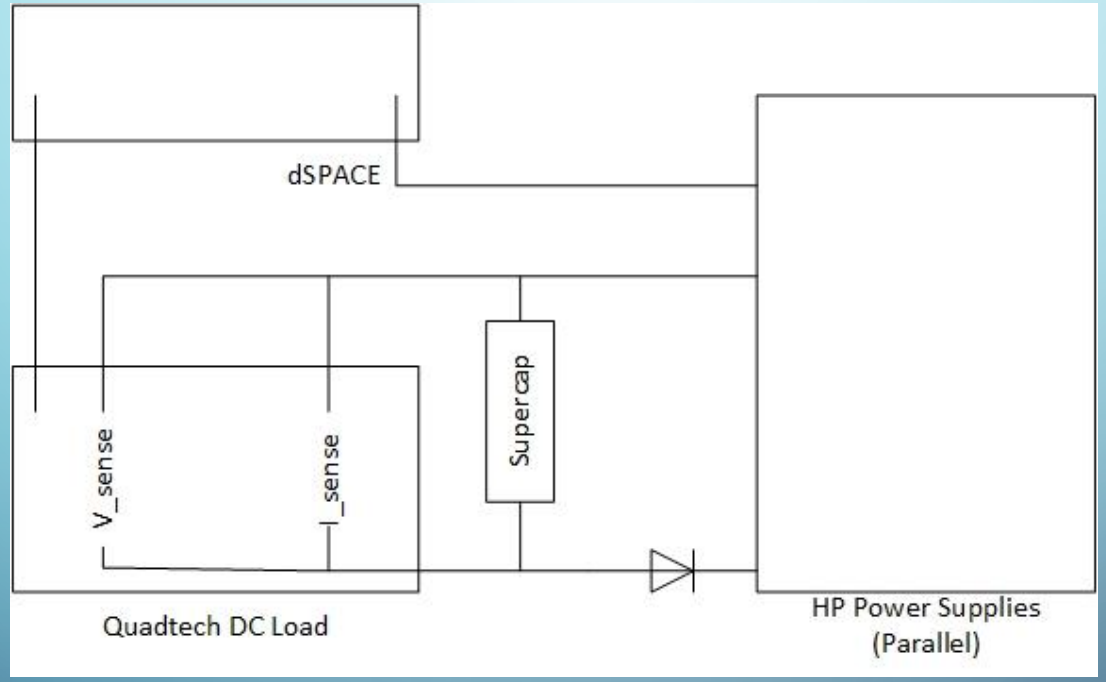
PURPOSE

- Experimentally predict, under rated conditions:
  - Lifetime under continuous cycling
  - Evolution of cell parameters
- Provide data for future prediction of supercapacitor system health

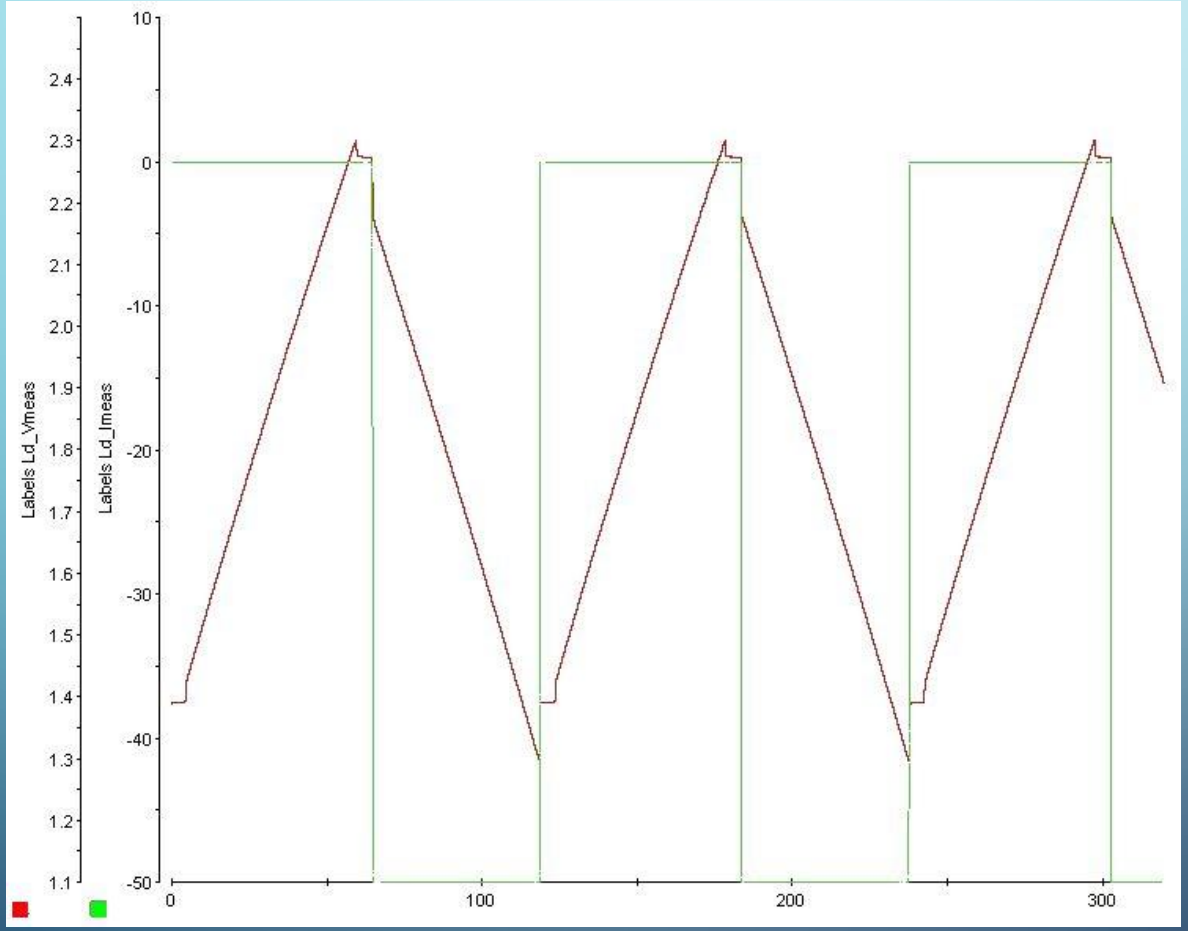
METHODS - CYCLING

- Voltage Range:
  - 1.3 V – 2.3 V
- Cycling Current:
  - 50 A
- Cycle Pause:
  - 5 sec
- Ambient Temperature:
  - ~ 22 °C
- EIS Tests After:
  - 0 cycles
  - 1000 cycles
  - 5000 cycles
  - 25000 cycles
- Rest periods minimized as much as possible

TESTING SETUP

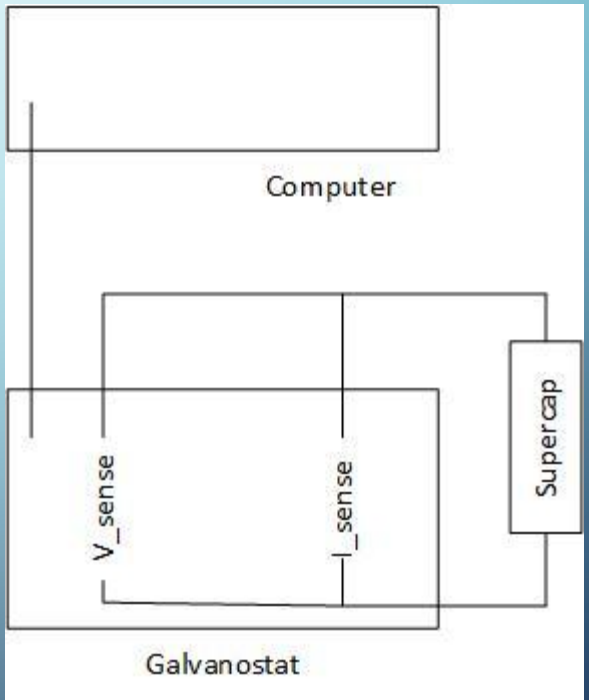


CYCLING PROCEDURE

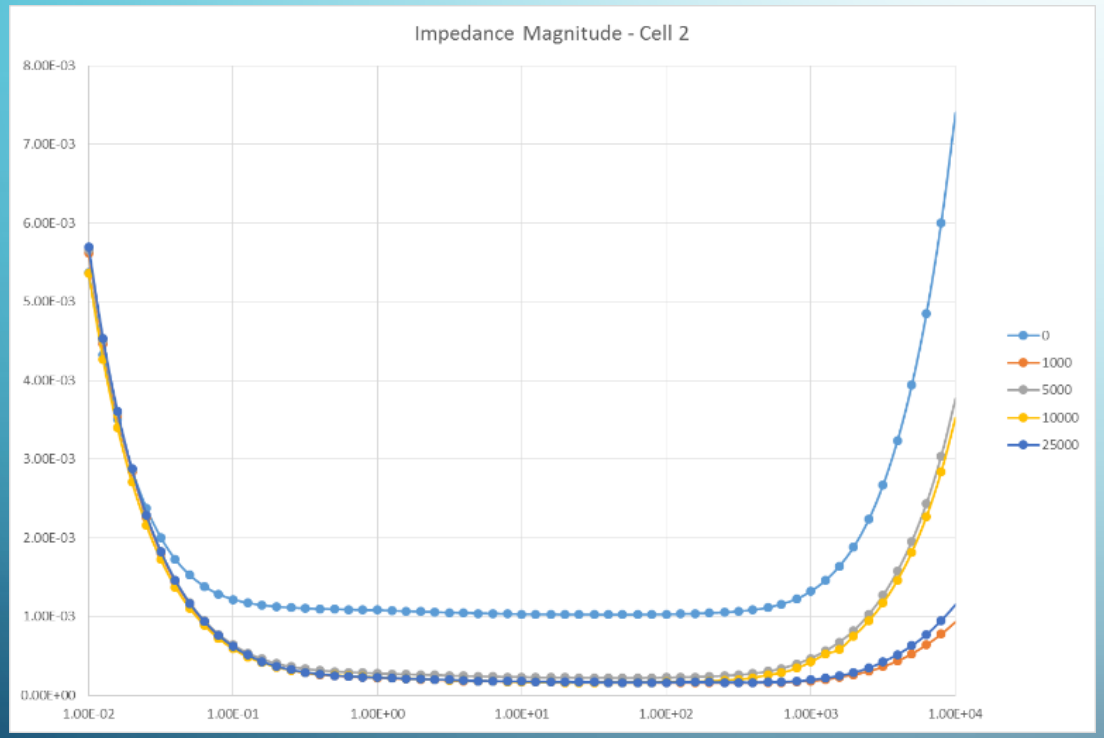


METHODS – EIS TEST

- Gamry 3000 Potentiostat/Galvanostat
- Frequency:
  - 10 mHz – 10 kHz
- DC Bias:
  - 1.3 V
- AC Current:
  - 1 A_{RMS}

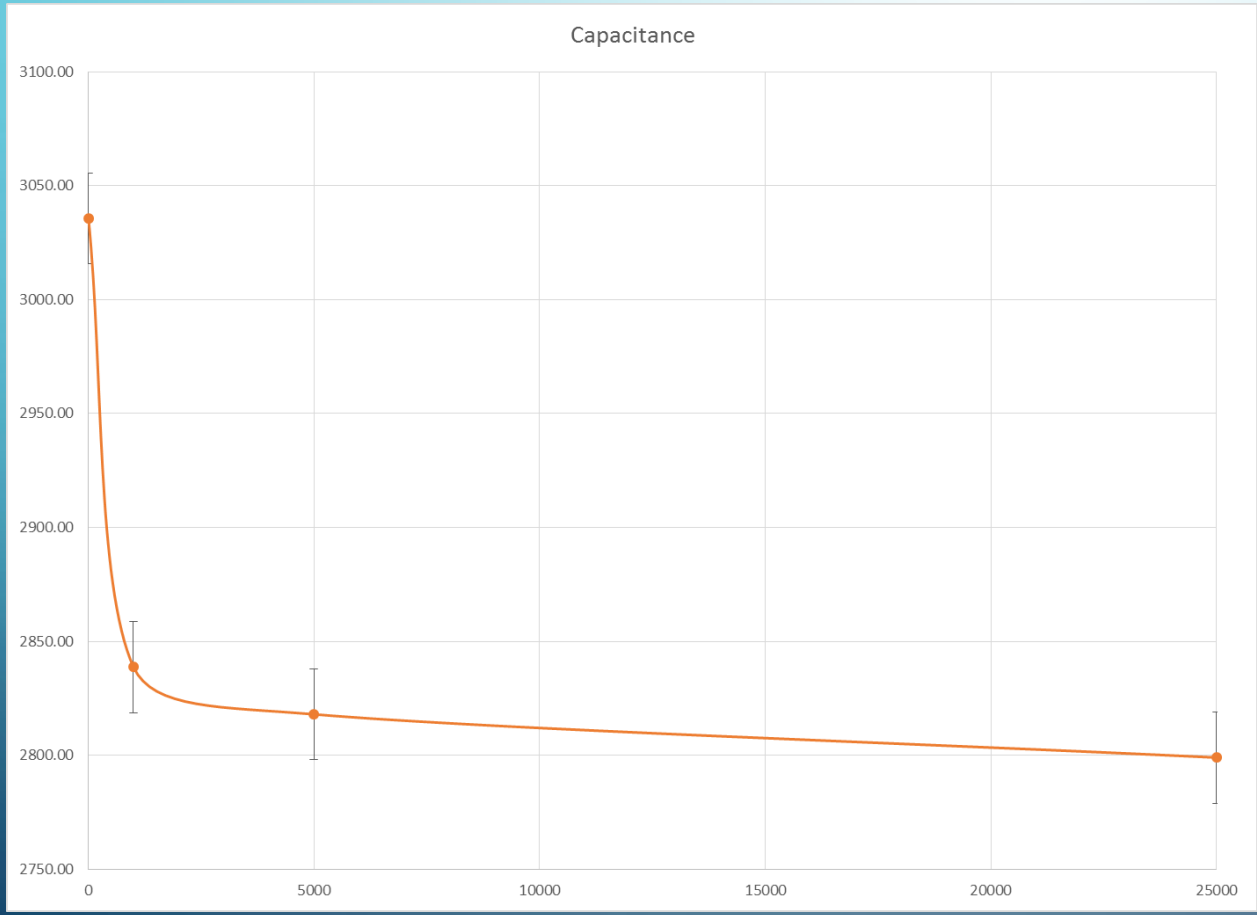


BODE PLOT


Impedance Magnitude - Cell 2
8.00E-03
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
1.00E+03
1.00E+04
0
1000
5000
10000
25000


Impedance Phase Angle - Cell 2
1.00E+02
8.00E+01
6.00E+01
4.00E+01
2.00E+01
0.00E+00
-2.00E+01
-4.00E+01
-6.00E+01
-8.00E+01
-1.00E+02
1.00E-02
1.00E-01
1.00E+00
1.00E+02
1.00E+03
1.00E+04
0
1000
5000
10000
25000

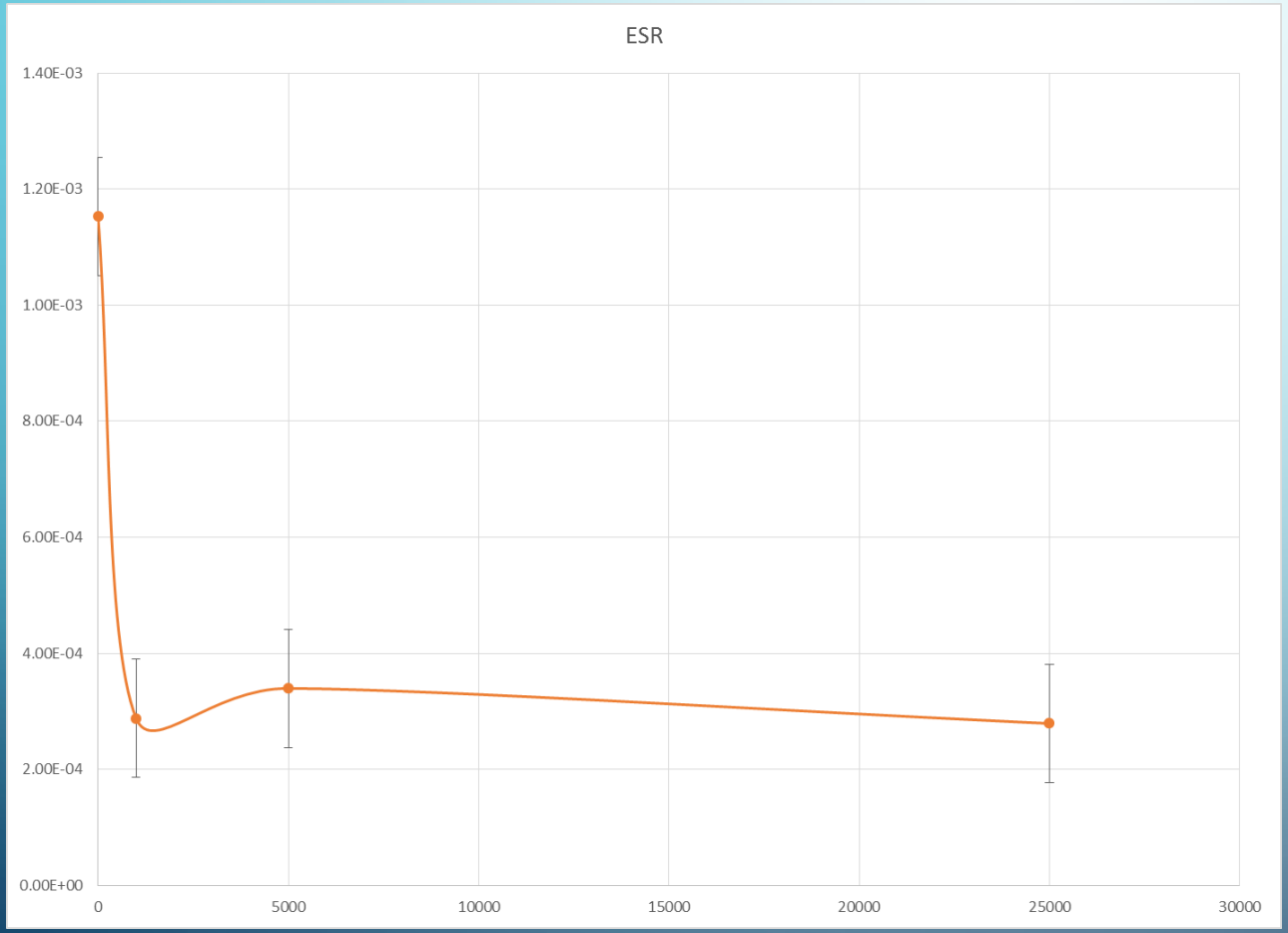
CELL CAPACITANCE



Cycle	Cell Capacitance (F)
0	3035
1000	2838
5000	2818
25000	2799

Lifetime Estimation:
639,000 cycles

CELL ESR



Cycle	ESR (mΩ)
0	1.15
1000	0.288
5000	0.339
25000	0.279

CONCLUSIONS

- Capacitance
  - Identified initial exponential decrease
  - Approaching/at linear decrease regime
- ESR
  - Initially high
  - After minimal cycles, ESR well below specification
- Current lifetime estimate: 639,000 cycles
  - Based on cell capacitance

PV SMOOTHING ALGORITHMS

POWER SMOOTHING

- Low pass filter
- Source or sink power to smooth power generation

RAMP REDUCTION

- Identify ramp event
- Source or sink power to counteract

CONCLUSIONS (CONT.)

- Based on previous Supercapacitor Energy Storage System (SESS) work:
  - Power smoothing algorithm (1646 cycles / month): 32 years
  - Ramp reduction algorithm (339 cycles / month): 157 years
- Typical solar panel life is 20-30 years
- Indicates SESS predicted lifetime feasible for energy storage/buffering and renewables integration

FUTURE WORK

- Increase number of cycles
- Increase number of cells cycled
- Application to supercapacitor systems

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QUESTIONS?