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Sandia National Laboratories

High-Reliability Ceramic Capacitors to Enable Extreme Power Density Improvements

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Sandia National Laboratories

Project Overview

Timeline

Start – FY19

End – FY23

10% complete

Budget

Total project funding

DOE share – 100%

Funding received in FY18: $75K

Funding for FY19: $ 0

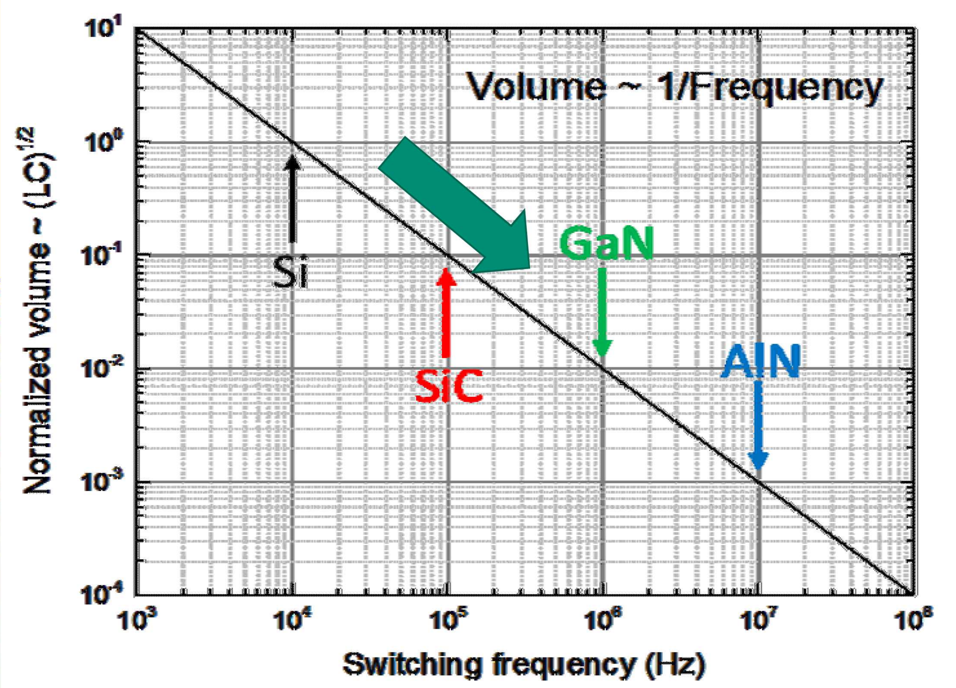
System Goals

- Power Density = 100 kW/L
- Power target > 100 kW (~1.2kV/100 A)
- Cost target for drive system ($6/kW)
- Operational life of drive system = 300k miles
- Relative immaturity of new passive materials (performance/reliability)

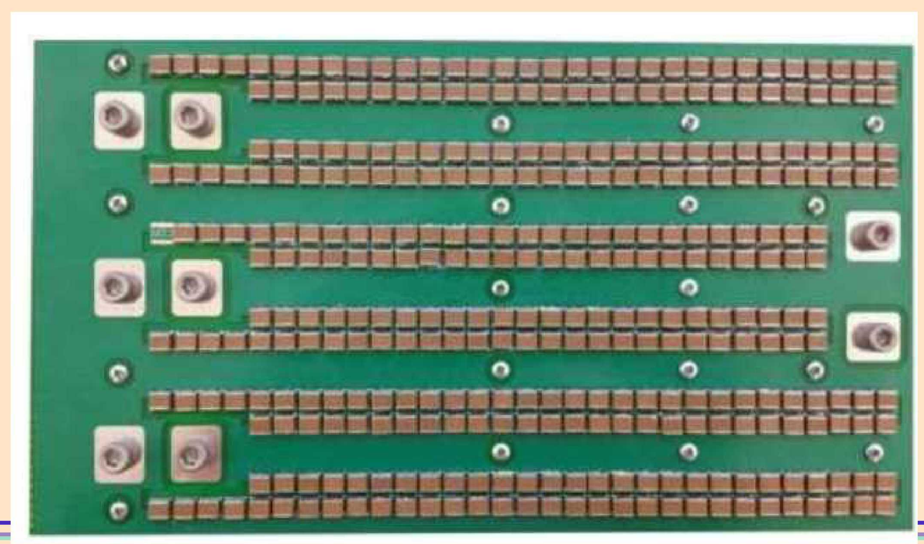
Motivation

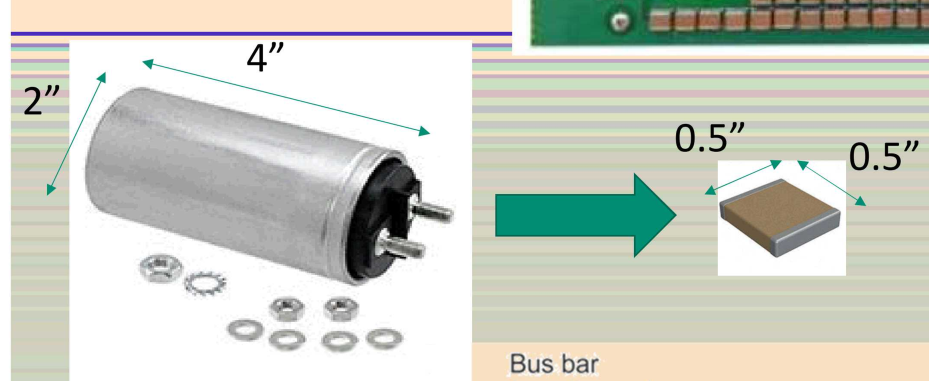
- Achieving power electronics density will require improvements in all aspects of drive train (switches, passives, etc.)
- Ceramic dielectric capacitors preferred to achieve high power density systems
  - High energy density and reliability
  - But low overall capacitance
- High frequency switching system reduces electrical size of capacitors necessary
  - Use of distributed, small capacitors on DC bus enable use of ceramic capacitors at reasonable cost
  - Increases power density through elimination of large capacitors

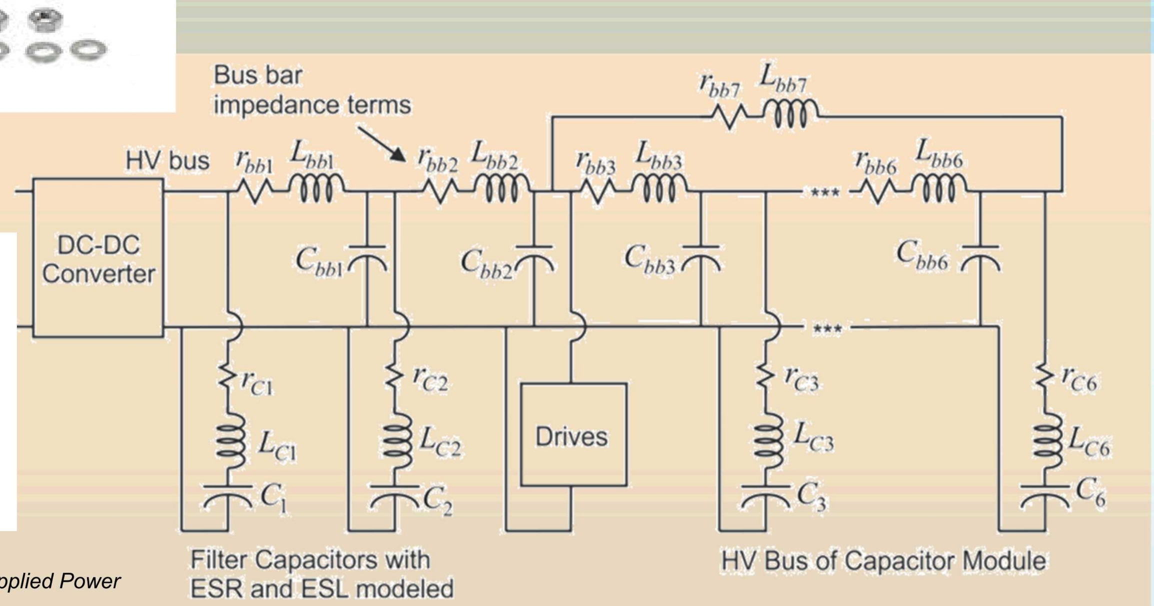
But, achieving high performance/long lifetime at high temperature has been elusive for base metal electrodes (reduced cost)



$$V_{pk}^{ripple} = \frac{V_{bus}}{32 \cdot L \cdot C \cdot f^2}$$



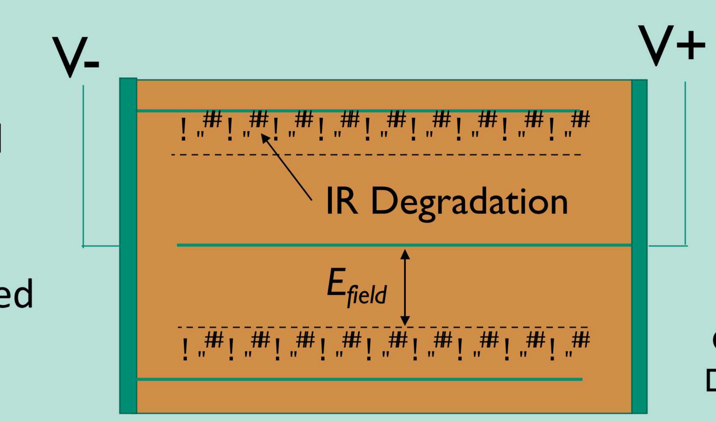


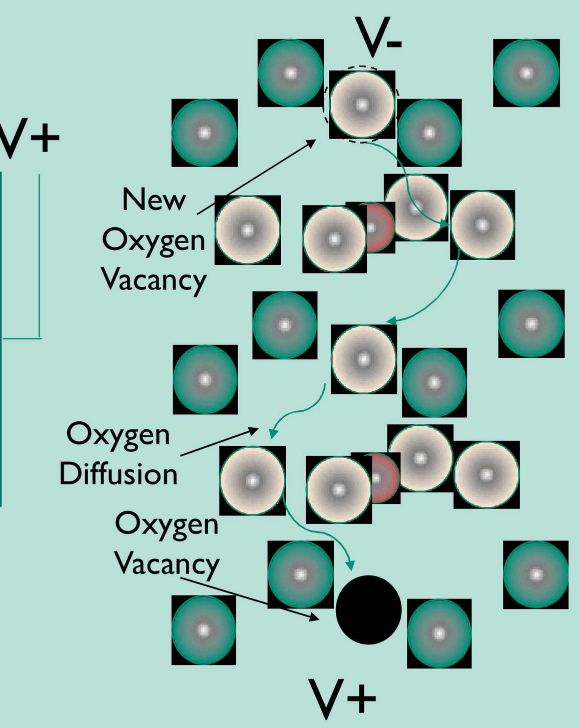


J. Stewart, J. Neely, J. Delhotal, and J. Flicker, "DC link bus design for high frequency, high temperature converters," in *2017 IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2017, pp. 809-815.

Approach

- Base metal electrodes (Ni) require reducing environment during sintering to avoid oxidation
  → oxygen vacancies are created in the ceramic
- Under applied voltage at temperature, oxygen vacancies migrate and preferentially getter at electrode/dielectric interface
  - Results in loss of insulation resistance (IR) → increased leakage
  - Increased leakage → raises temperature → more vacancies created
  - Accelerating failure mechanism
- Instead of altering fabrication or materials properties
  - Targeting oxygen vacancy transport to electrodes
  - By altering the electric field from a DC field to an AC field, we can limit transport of oxygen vacancies





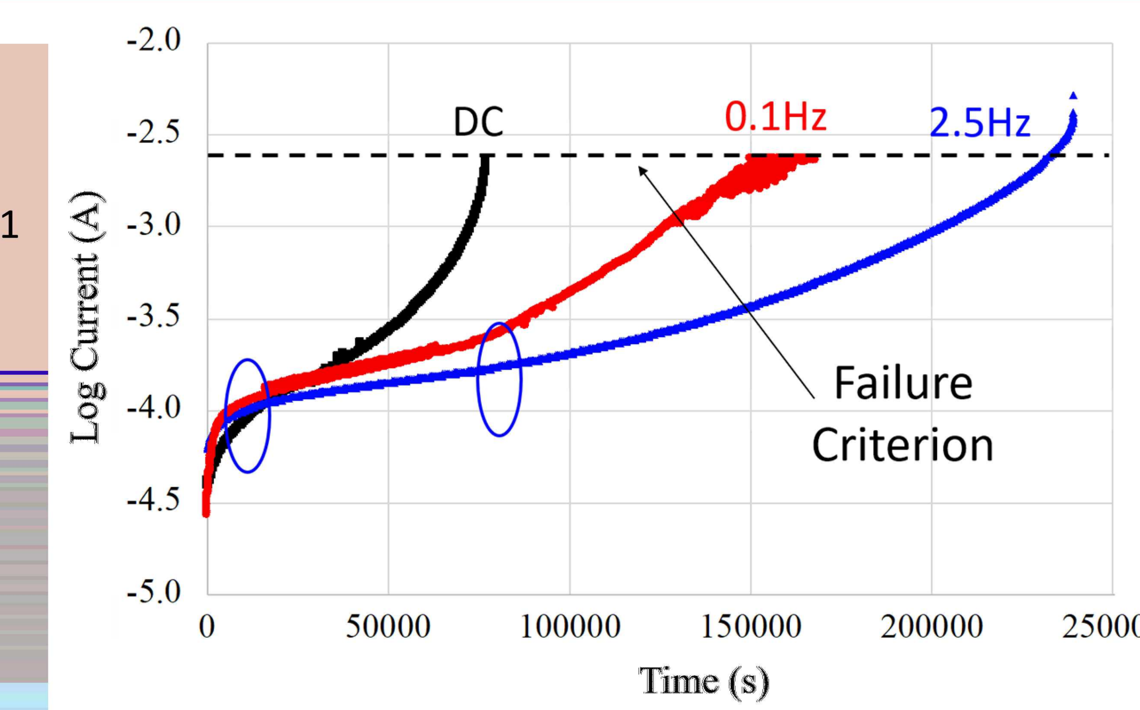
Goals

- Instead of addressing performance/reliability through material composition
  - Develop innovative bipolar switching strategy
  - Periodically clear a build-up of oxygen vacancies at electrode surfaces
  - The dynamics of this strategy will be explored and optimized
- Survey current state-of-the-art ceramic capacitors and identify technology gaps

Progress

- Carried out preliminary bipolar switching testing
  - Tested capacitor degradation at DC bias, and bipolar switching of 0.1 and 2.5 Hz
  - Applied ~10x V_{rated} at 125°C **above** T_{rated}
- Preliminary results show bipolar switching can significantly increase time to failure

Demonstrated ~4x lifetime increase with a 2.5 Hz bipolar switching scheme compared to DC



Future Work

- Survey current state-of-the-art ceramic capacitors and identify technology gaps
- Perform further experiments on bipolar switching
  - Longer term testing (less acceleration)
  - Larger capacitors appropriate for power devices
- Evaluate bipolar switching scheme compatibility with drive train technologies

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