Low Cost, High Temperature, High Ripple Current DC Bus Capacitors

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APE032

Overview

Timeline

- **Start date:** August 1, 2008
- **End date:** August 31, 2010
- **Percent complete: 85%**

Budget

- **Total project funding:** $750,000
- **DoE share:** 100%
- **Funding received in FY09:** $375,000
- **Funding for FY10:** $375,000

Barriers

- **Barriers addressed:**
  - Extremely limited material parameter data available for model/simulation
  - Reducing Trise to enable qualifying PP Film Capacitors for useful DC Link application in 105°C coolant power conversion systems.

Targets

- A 105°C Coolant DC Link Capacitor with 100Arms capability and 10,000 hour life

Partners

- **Interactions/collaborations:** FieldMetrics – Active Precision - ORNL
- **Project lead:** Terry Hosking

Phase II Study Objective

The objective of this study is:

"to develop novel, low-cost annular ring capacitor structures and packaging using environmentally friendly metallized polymeric insulating films to replace electrolytic capacitors in hybrid vehicle DC bus filtering applications by increasing the upper operating temperature 50% and raising the effective capacitance density by up to 200% compared to conventional polymer film capacitors."

2009-2010 Milestones

Month/Year	Milestone
Initial Design Decisions	March 2009
Completion of Material Parametric Data	June 2009
Initial Comparison Testing of Design	June 2009
Initial Model Conclusions on Life	September 2009
Life Test Design and Set Up	December 2009
Model Completion	January 2010
Model Validation & Final Design Decision	June 2010
Life Test Data Collection	February – July 2010
Life Test Analysis	August 2010
Final Report	September 2010

Approach/Strategy

- Model the MPP DC link film capacitor using directly obtained parametric data for “AS WOUND” capacitors

  The following materials parameters were measured as functions of temperature:

  - Film TCE, radial/axial thermal conductivity [anisotropic], specific heat.
  - Electrode TCR as function of metallization thickness.
  - Electrical leakage current as a function of voltage and temperature.
  - Terminals/interconnect carefully modeled, with closed form solutions used where valid to verify simulation predictions.

Approach/Strategy

- Validate model in simulated automotive conditions to verify temperature rise.
  - Use measured parameters to carefully create models of the complete capacitor assembly.
  - Use the models to simulate capacitor performance with various terminals, interconnect structures, winding thicknesses and current profiles.
  - Build capacitors reflecting simulation results.
  - Test the capacitors to validate the simulation results.

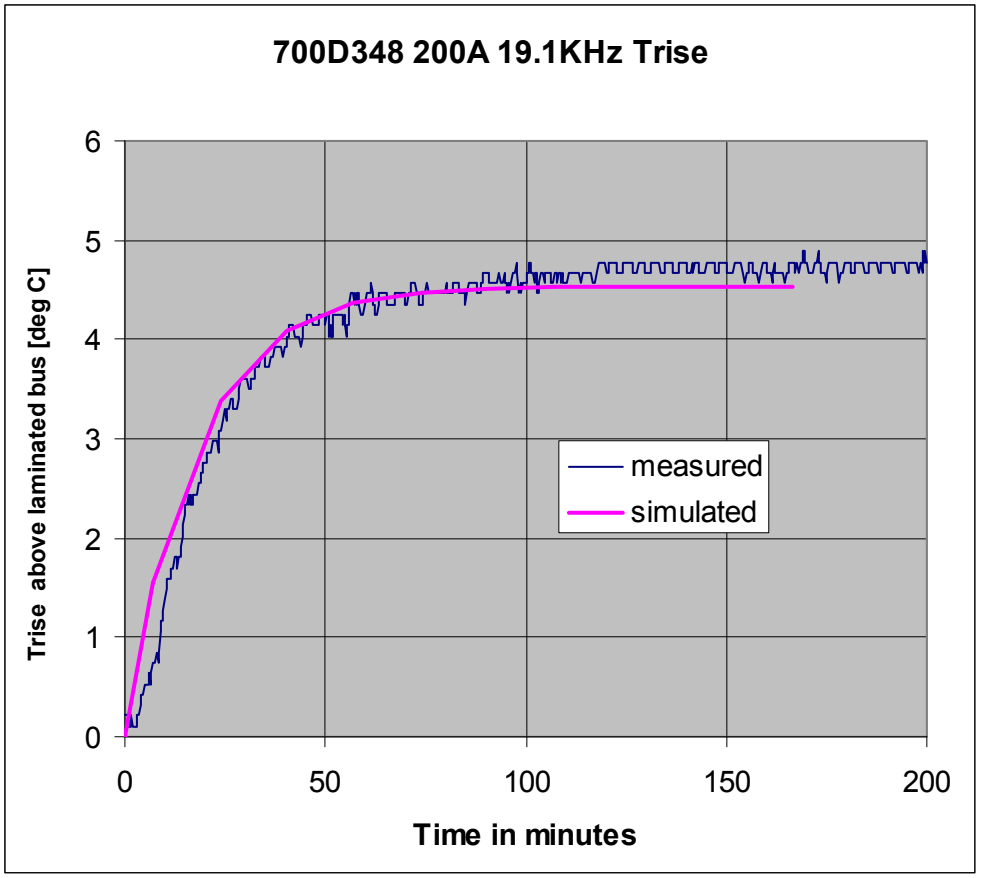
Approach/Strategy

- Perform life testing for at least 2 Million unit hours focusing on the most likely failure condition:
  - Dielectric breakdown at elevated voltage and temperature
  - ~450 1000µF capacitors on test at 107°C and at several “useful voltages” determined by a preliminary voltage and temperature test matrix.
  - 220 capacitors at 90°C at an application-specific voltage
  - As of 20Apr10, over 500,000 unit hours with no failures.

Technical Accomplishments

- A working modeling/simulation tool for SOA capacitors to accurately predict [using 2010 film capacitor materials parameters] :
  - Temperature rise given input current profile, temperature boundary conditions for application ambient and interconnect.
  - Internal isothermal plots to define hot spot locations.
  - ESR [includes temperature related terminal losses and eddy current effects] as well as winding contributions.
  - ESL when connected to a suitable laminated DC bus.

Technical Accomplishments



Technical Accomplishments

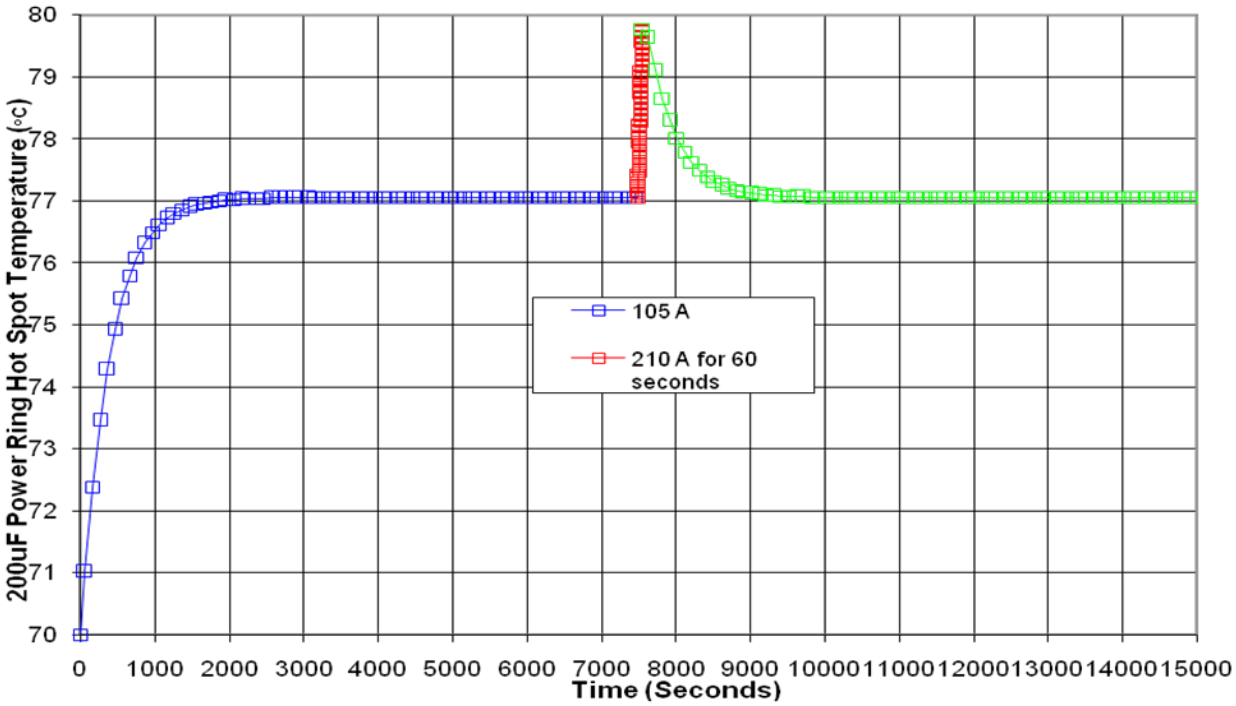
- ESR vs. temperature. ~750ppm/°C for metal chosen
- ESL measurements closely match simulation results, with predicted ESL ~99% of measured value. This is very close approximation for a distributed element part with ESL in the ~3nH range especially given the measurement challenges.

Temperature rise, thermal time constants can be obtained to predict response to various thermal environments.

- Simulations have capability to predict capacitor temperature rise for various drive cycle derived load current profiles.

Technical Accomplishments

Sample of annular capacitor transient Trise simulation result



Technical Accomplishments

- 100Arms temperature rise of 2 – 5°C for a DC link capacitor using equivalent film capacitor volumetric density to a traditional approach that would result in 20 – 30°C Trise.

  This is made possible by:

  – A terminal structure to provide uniform current density in the capacitor winding.
  – A very long film length reduces ESR for a given metallization thickness.
  – A short axial thermal path for efficient heat removal.

Technical Accomplishments

Creation of a resource intensive reliability life test based on the most likely capacitor failure mechanism: dielectric degradation.

- The purpose of this test is to explore the high temperature reliability of metallized polypropylene capacitors.
- Target is to demonstrate 10,000 hour capacitor life when used in a vehicle environment at 105+°C
- Over 500,000 unit hours logged at 107°C as of 20Apr10 with no failures to date.

Collaborations

- Fieldmetrics
  - Model development and materials analysis
- Active Precision
  - Winding equipment development for high speed, accurate, low cost production of annular rings
- Oak Ridge National Labs
  - Independent comparison testing of annular ring vs. traditional DC link capacitor designs

Proposed Future Work

- Completing the milestones of SBIR Phase II through September 2010
- Comparative testing and simulation of annular approach vs. traditional designs in common inverter component layouts and approaches
- Additional investigation of failure mechanisms to define where they might influence MTBF calculations
- Cost reductions of bus connection materials and methods
  - Utilize simulation tools to efficiently evaluate ideas

Summary

- An R & D effort to produce a 105°C coolant DC Link Capacitor for long term operation
- All element analyses of PP are complete
- Models have indicated success and products produced correlate to the models
- Life testing is on going and will be complete in 3Q10
- Modelling tools will facilitate industry adoption
- Full package of data and analysis will be made available to industry in 3Q10