U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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A Segmented Drive System with a Small DC Bus Capacitor

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Project ID: apep_08_su

2009 DOE Hydrogen Program and Vehicle Technologies AMR

Overview

Timeline

- Start – Oct. 2008
- Finish – Sept. 2011
- 15% complete

Budget

- Total project funding
  - DOE share – 100%
- Funding received in FY08
  - None (new start)
- Funding received for FY09
  - $376K
- Funding requested for FY10
  - $741K

Barriers

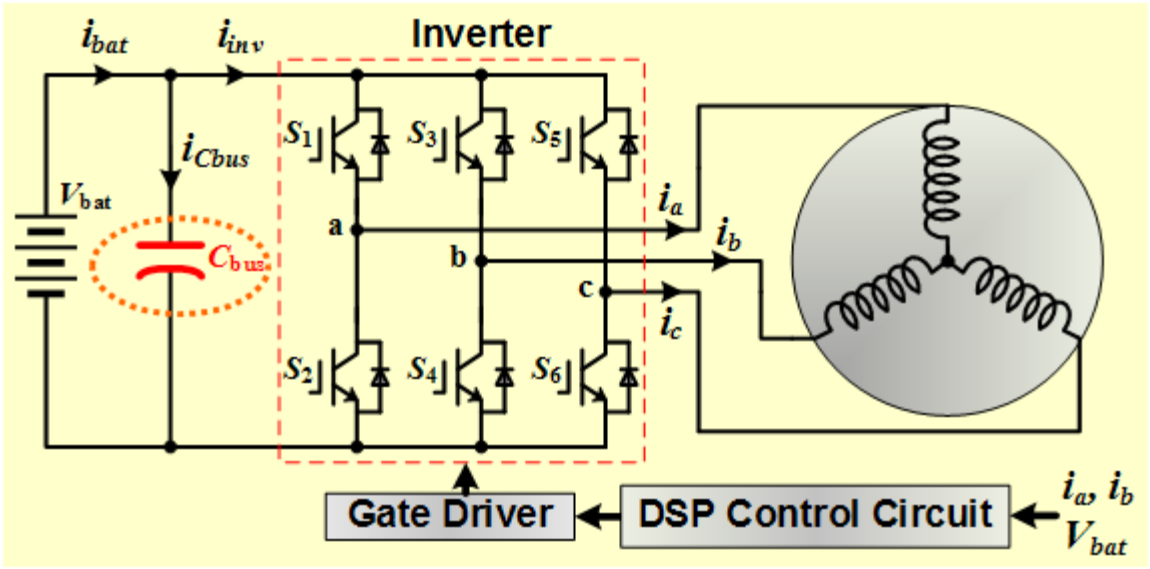
- DC bus capacitor presents significant barriers to meet the targets of cost, volume and weight for inverters. Currently, it contributes
  - Cost and weight, up to 23% of an inverter
  - Volume, up to 30% of an inverter
- Ability of film capacitors to operate at higher temperature deteriorates rapidly, leading to significant increases in cost, weight and volume
- Vehicle technology program targets
  - 2015 targets: $5/kW, 12 kW/kg, 12 kW/l, 105°C coolant

Partners

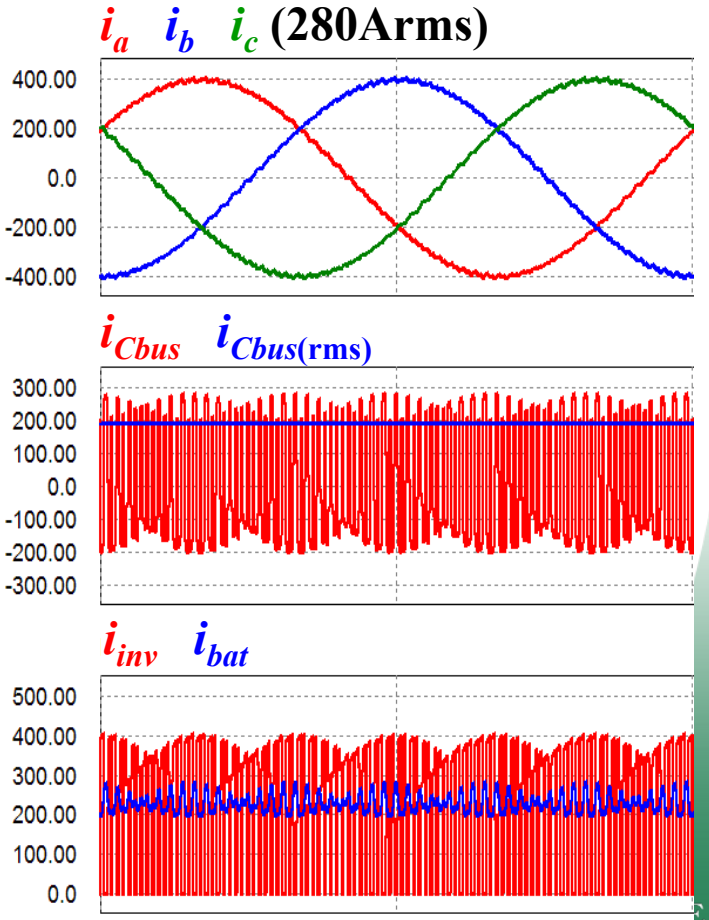
- No external partners to date

Barriers

- A typical 55 kW inverter requires a large dc bus capacitor of about 2000 µF to handle large ripple currents (250 Arms).
- Switching frequency and thus motor ripple current have little impact on the magnitude of the bus capacitor ripple current.
  - Increasing switching frequency will not impact the amount of bus capacitance required.

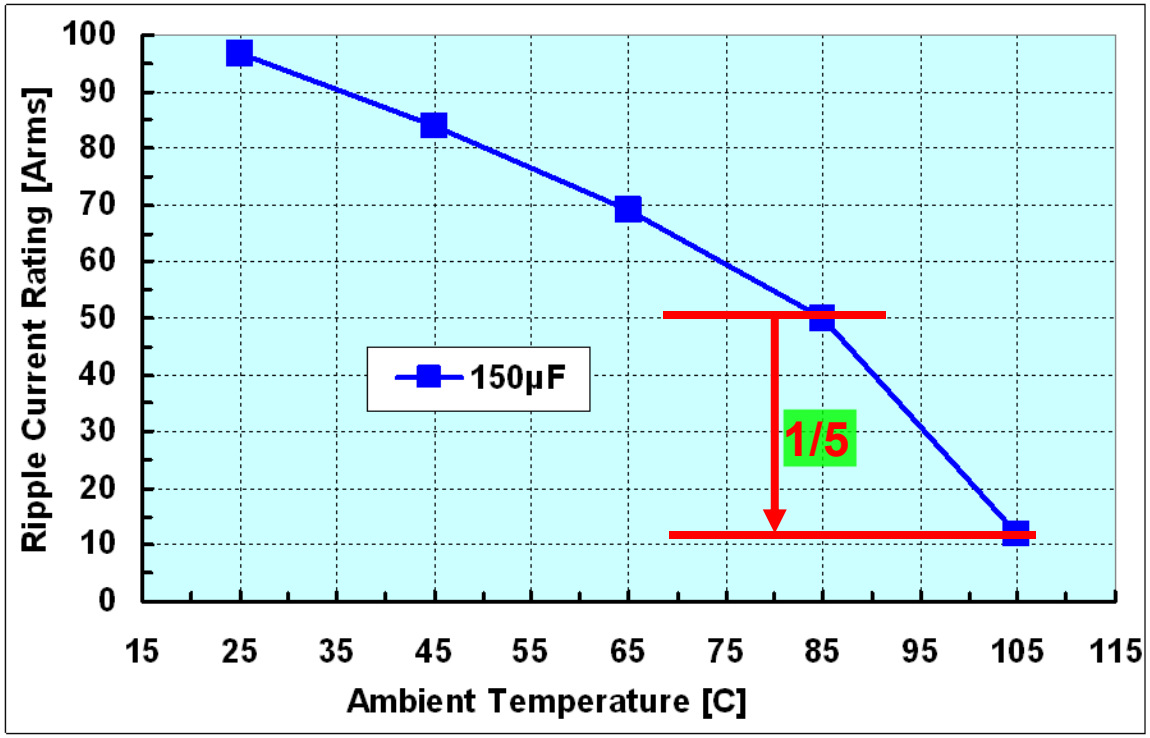


Standard VSI based drive system



Barriers (contd.)

- High Temperature Operation Challenge for the Bus Capacitor
  - Film capacitor ripple current and voltage capability decreases rapidly with temperature
    - 50% linear voltage derating from 85ºC to 105ºC
  - Non-benign failure modes are concerns for ceramic capacitors



Electronic Concepts
UL31 Series, 600 V
Diameter: 83.3 mm

For example, as temperature rises from 85 to 105°C, weight, volume and cost of capacitors could increase by a factor of 5

Source: http://www.eci-capacitors.com/product_details.asp?productid=29

Objective

- **Develop a 55 kW inverter prototype that can reduce the bus capacitance by at least 60%**

- **Objective for FY09**
  - **Perform a simulation study to assess the effect of various PWM schemes on the reduction of ripple current**
  - **Complete a conceptual design for a 55 kW prototype**

Milestones

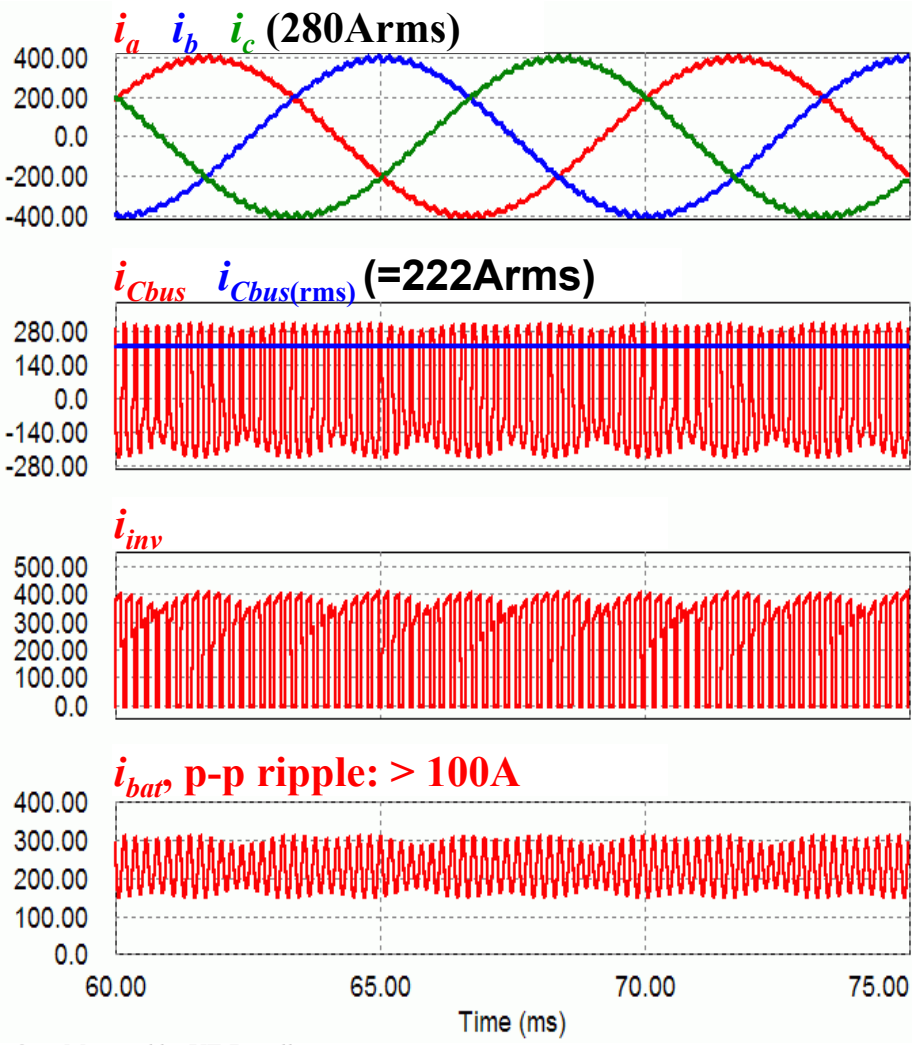
Month/Year	Milestone or Go/No-Go Decision
Jun-09	Milestone: Complete simulation study of various PWM schemes on the impact of capacitor ripple current.
Sept-09	Milestone: Complete a conceptual design for a 55 kW prototype. Go/No-Go Decision: Based on the potential for capacitor ripple current reduction, a decision will be made on whether to continue pursuit of the proposed approach or if modifications in the design will be necessary in FY10.

Approach

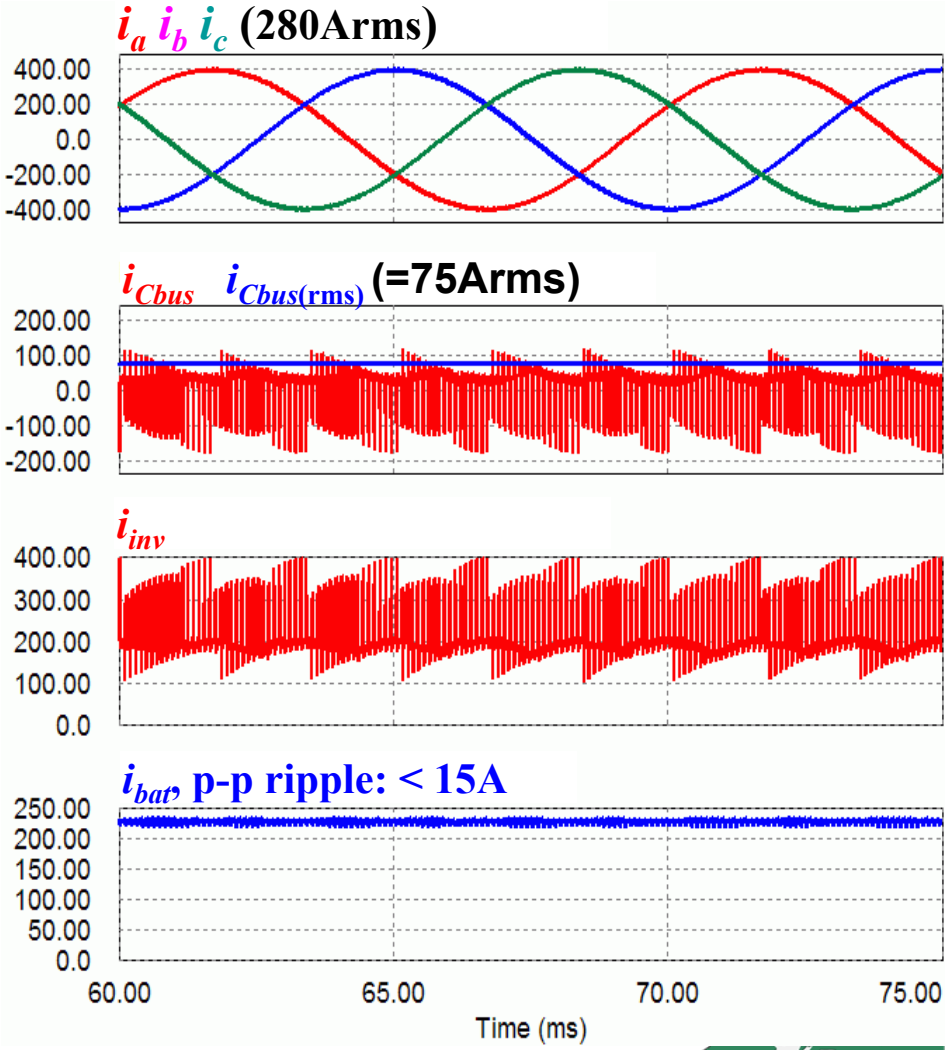
- Use a segmented drive system topology that does not need additional switches or passive components but will enable the use of optimized pulse width modulation (PWM) schemes to significantly reduce the dc link ripple current and thus the capacitance
- Perform simulation study of various PWM schemes
  - Various carrier-based & space-vector PWM techniques will be simulated using PSIM to assess their impact on the capacitor ripple current
- Build and test a 55 kW prototype to experimentally validate the simulation study

Technical Accomplishments

- **Preliminary Simulation Results**
  - Capacitor ripple current: 222Arms to 75Arms, 66% reduction
  - Battery ripple current: greater than 100Ap-p to less than 15A



Standard VSI



Proposed Topology

Future Work

- **Reminder of FY09**
  - **Complete the simulation study of various PWM schemes on the impact of capacitor ripple current.**
  - **Complete a conceptual design for a 55 kW prototype.**
- **FY10**
  - **Design, build, and test a 55 kW inverter prototype for operating with a 70ºC coolant**

Summary

- The proposed technology involves modifying the standard drive topology and optimizing the PWM scheme to significantly reduce the ripple current flowing into the capacitor
  - *without* additional silicon or passive (L or C) components
  - *without* additional sensors
  - *without* control complexity
- Impacts
  - Substantially reduce the bus capacitance (at least 60%) and thus inverter volume and cost
  - Reduce battery losses and improve battery operating conditions by reducing battery ripple current
  - Significantly reduce the motor torque ripples (up to 50%), or reduce switching losses by 50%.
  - Increase inverter reliability
  - Enabler for high temperature inverter operation
- Initial simulation results have shown a significant reduction of ripple current