U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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An Active Filter Approach to the Reduction of the DC Link Capacitor

Burak Ozpineci

Oak Ridge National Laboratory

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Overview

Timeline

- Start date – Oct. 2007
- End date – Sep. 2009
- Percent complete – 50%

Budget

- Total project funding
  - DOE share: 100%
- Funding received in FY08: $158K
- Funding received in FY09: $294K
- Funding requested for FY10: $0K

Barriers

- **Barriers**
  - DC link capacitor problems: size (35% of the inverter volume), weight (23% of the inverter weight and cost (23% of the inverter)
  - High temperature capacitors
  - High active power filter device losses.
- **Vehicle Technology Program Targets**
  - DOE 2015 targets: 105°C Coolant
  - DOE 2015 target: 12 kW/l

Partners

- UT (literature survey, modeling and simulation)

Objectives

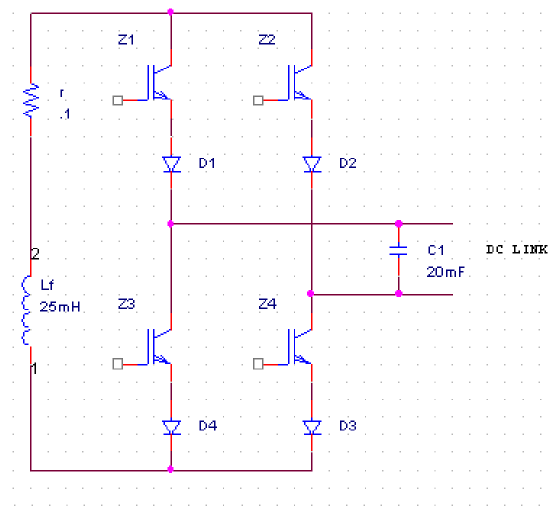
- The objective of this project is to develop an active power filter (APF) to replace the bulky DC link capacitor.
- The APF is expected to
  - Imitate what a DC link capacitor does
  - Be much smaller size than the DC link capacitor
  - Be an enabler for higher temperature operation
- FY09: Develop new topologies and designs to reduce the efficiency problems associated with the high frequency switching and high inductor current the present APF designs require.

Milestones

FY08			FY09		
October to January	**February to July**	**August to September**	**October to February**	**March to June**	**July to September**
Establish the performance requirements for an active filter	Simulate an active filter that can replace a dc link capacitor in a traction inverter	Assess the simulation results, loss calculations, and comparisons against baseline technology	Analyze methods to reduce the frequency and operating current of active filter to improve the performance	New control methods simulation and evaluation	Build a benchtop active filter for a 55 kW inverter

Approach

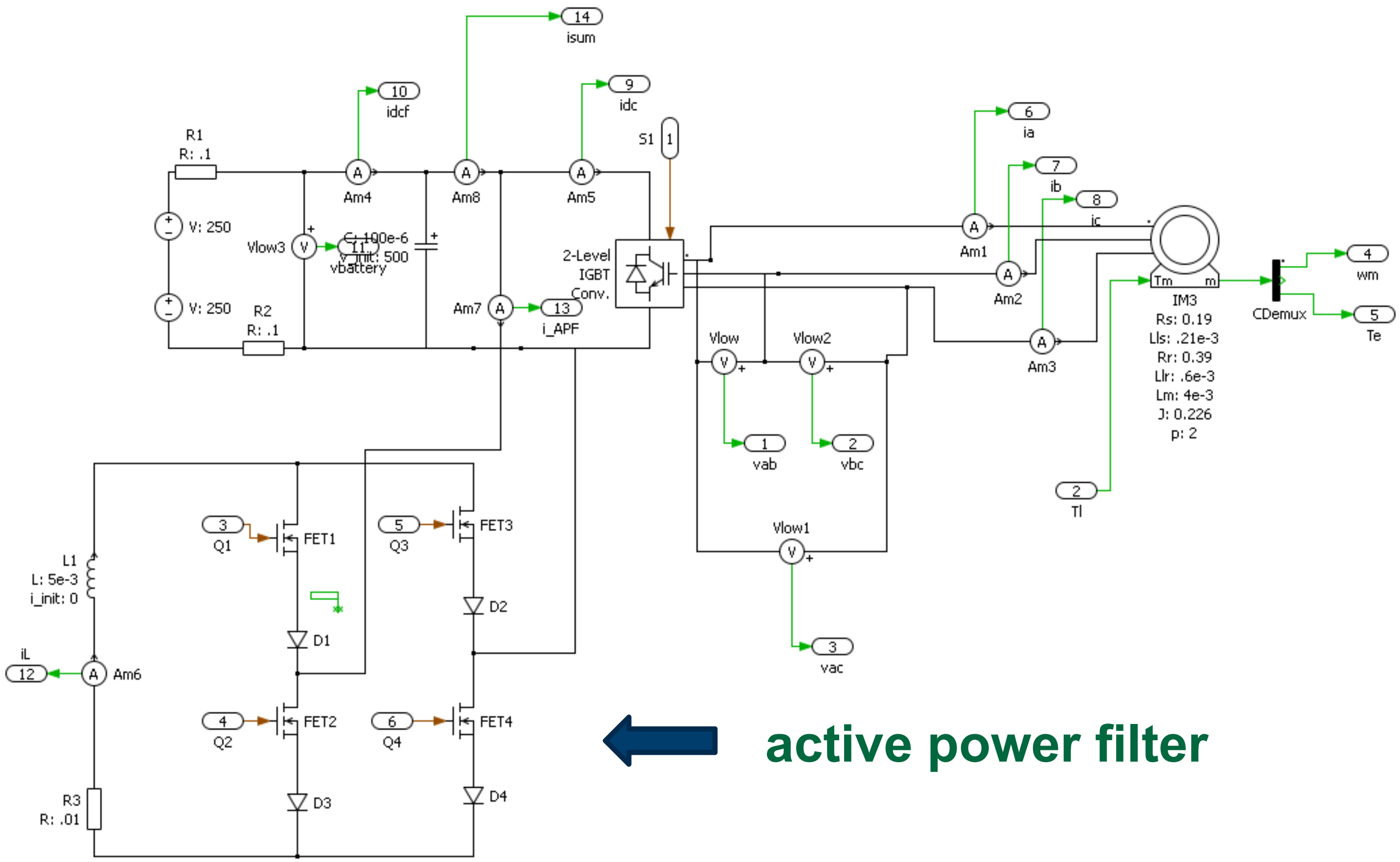
- An active filter with a much smaller capacitor (1/10th-1/20th of the Camry capacitor) and inductor can be used in the DC link together with semiconductor switches to replace the DC link capacitor.



- Impacts
  - Reduced size and cost
  - May provide more cost-effective solution for high temperature operation

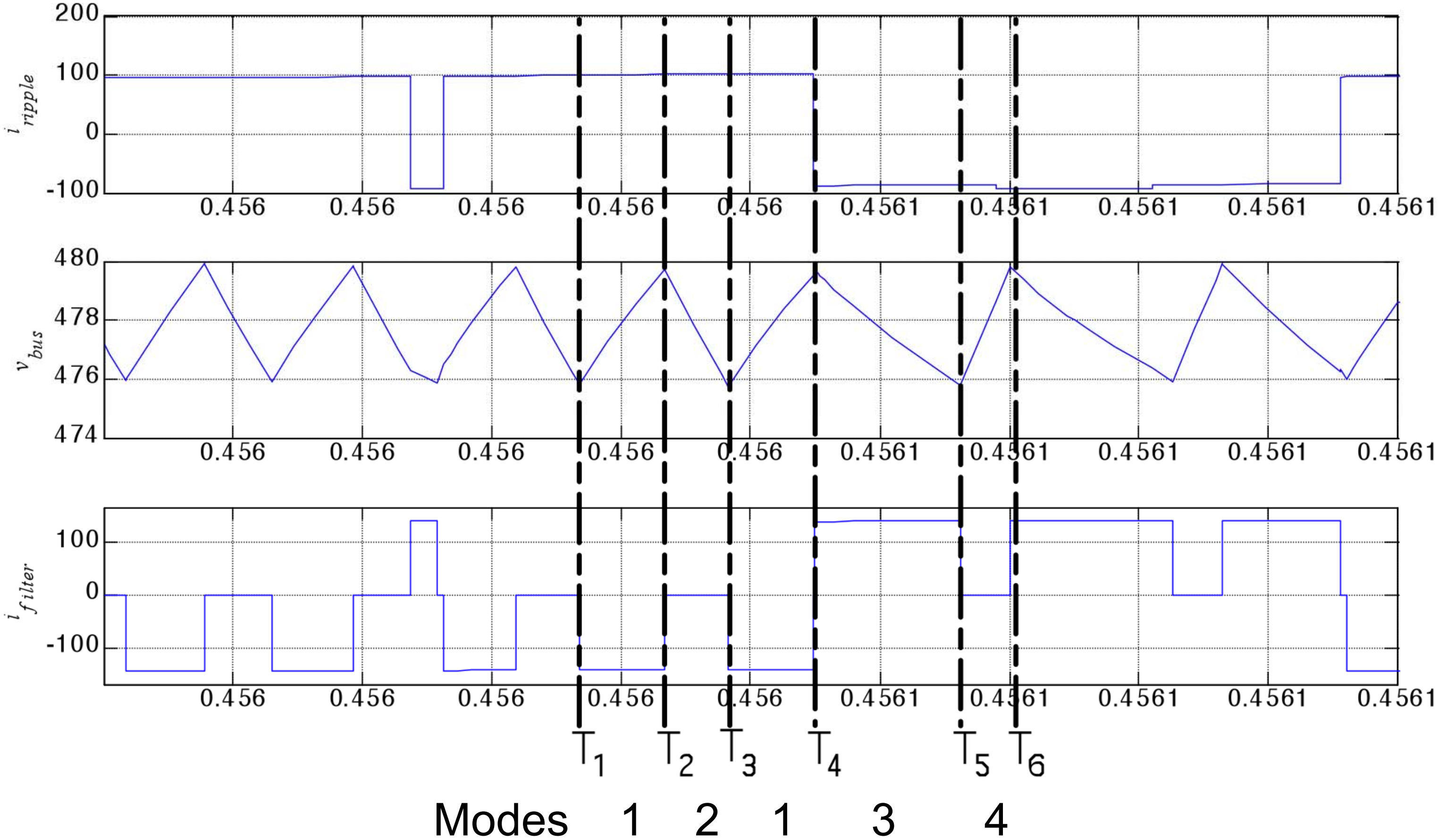
Accomplishments

A Matlab/Simulink simulation model of a traction drive system was used to establish the performance requirements for an active power filter.

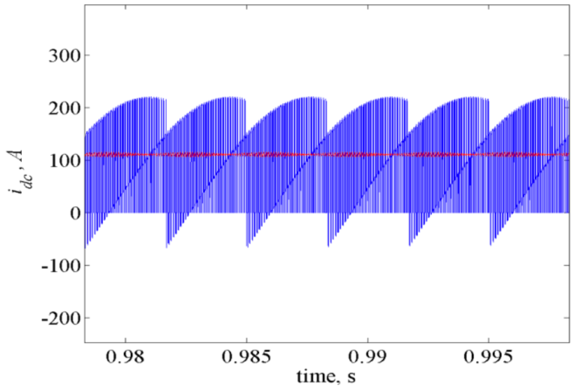


active power filter

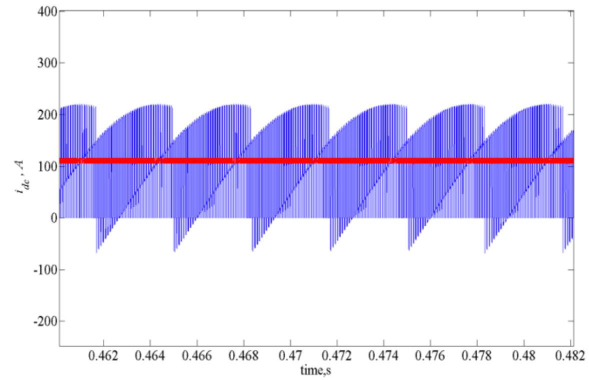
Operation Waveforms



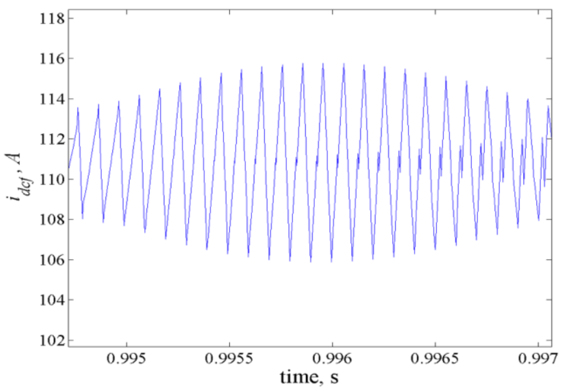
Simulated Operation Waveforms

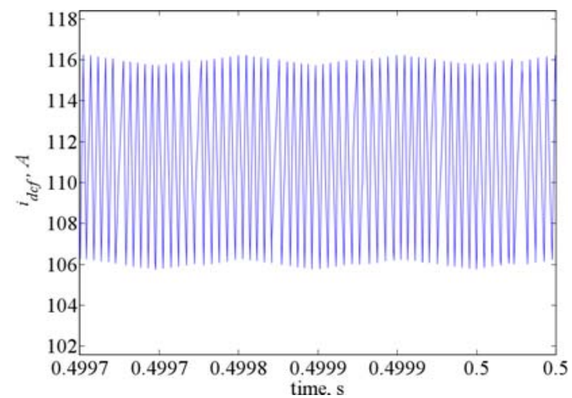


DC Link Current

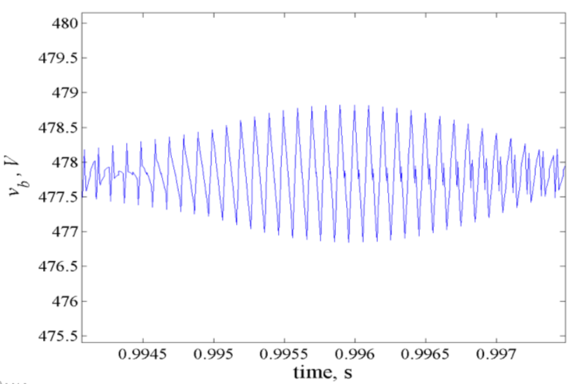


Case 1- w/ capacitor

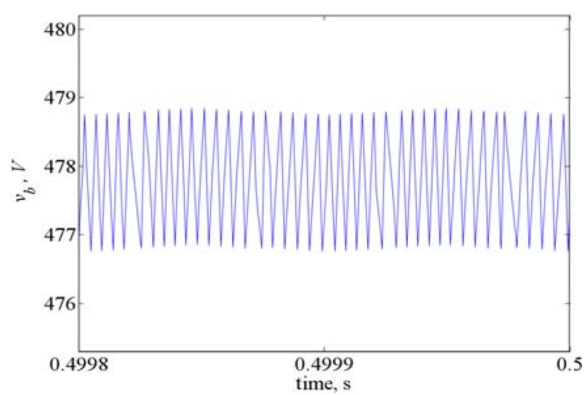




Case 2 – w/ APF



DC Link Voltage



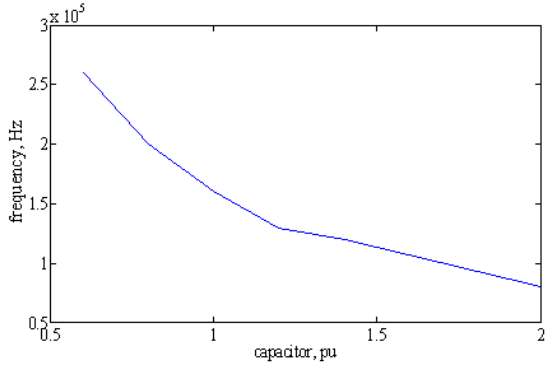
Comparison – APF vs Capacitor

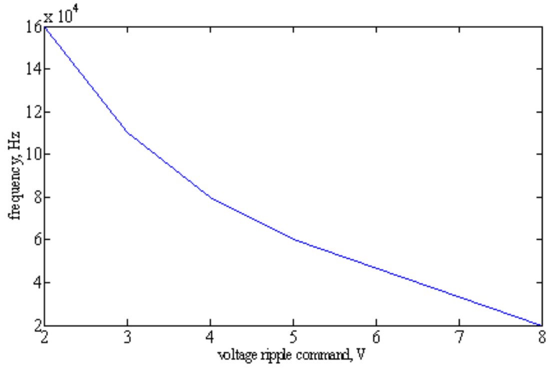
	Case 1 (capacitor)	Case 2 (APF)
DC Link Capacitor	2200µF	100µF
APF Inductor		25mH
APF Switching frequency		130kHz*
Extra Components		4 switches and 4 diodes (could be 4 reverse blocking IGBTs)+inductor
APF Inductor Current		100A* dc
Peak-to-peak voltage ripple	2V (0.4% of DC voltage)	2V (0.4% of DC voltage)
Peak-to-peak current ripple	10A (4.5% of the unfiltered ripple current)	10A (4.5% of the unfiltered ripple current)
DC link voltage	500V	500V
Output Power	30kW	30kW

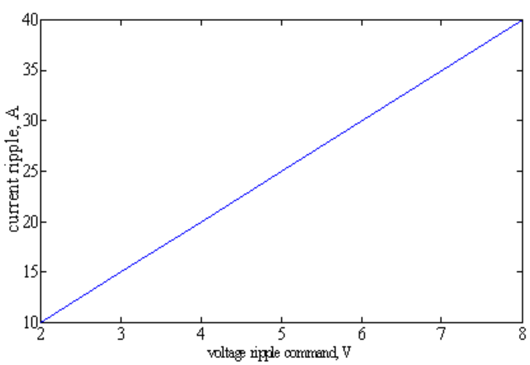
*At lower output power lower switching frequency and lower inductor current will be used.

Parametric Study

- Switching frequency is inversely proportional with the smoothing capacitor size and the DC link voltage ripple hysteresis band limits
- The DC link voltage ripple hysteresis band limits are directly proportional with the amount of DC current ripple







Efficiency is a problem…

- A 100A - 5mH inductor has an internal resistance of 0.01Ω* and a 2.5mH inductor has half of that value
- Typical losses in the inductor for 100A
  - 5mH inductor,100W (0.33% for 30kW)
  - 2.5mH, 50W (0.17% for 30kW)
- The inductor current varies with the output power
- Major losses occur in the devices (IGBTs 1427W – Diodes 460W)

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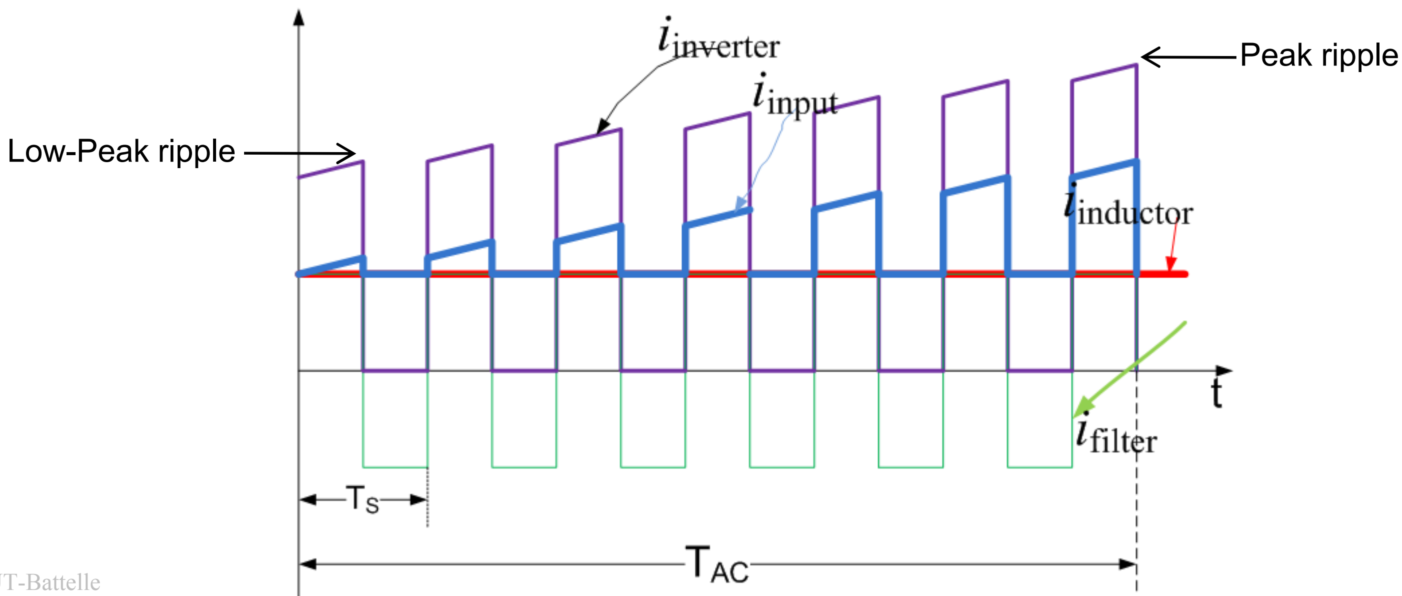
Improved APF

- A new control method with
  - Reduced APF switching frequency – the APF can be switched at the inverter switching frequency
  - Reduced inductor current – half of what the original APF control needs
  - Slight increase in the DC-link capacitance
- Impact on APF losses compared to the original method
  - Reduction in switching losses to less than 20%
  - Reduction in conduction losses to less than 25%

Comparison

	Active power filter (APF)	Improved APF
Principle	Increase the ripple frequency to reduce the smoothing capacitor	Compensate part of the ripple current
Inductor current	Higher than half the peak ripple (140A)	Higher than half the low-peak ripple (75A)
Operating frequency	10x inverter frequency	Inverter frequency
Capacitor size	Small (100μF)	Small (>100μF, <500μF)



Future Work

- Investigate topologies that will reduce the filter inductance requirements and improve the APF efficiency
- Demonstrate the improvements in the topology
- Demonstrate the successful operation of the APF replacing the DC link capacitor
- Develop a topology that is expected to
  - weigh half as much and
  - occupy less than half the space, when compared to the Camry DC link capacitor.

Summary

- **The APF functions as expected but there are some practical barriers that need to be overcome.**
  - **Device losses can be reduced by**
    - **Using less switches and diodes or using a *different topology***
    - **Reducing the inductor current**
    - **Reducing switching frequency**
  - **Inductance value and associated inductor size**
    - **Inductance value determines the stiffness of the dc current**
      - **Low inductance causes low frequency voltage ripple**
    - **An optimum inductance value is required**
- **A new APF control method has been developed that can reduce the losses on the APF and the size of the inductor with a slight increase in the capacitance.**