High Power Density Integrated Traction Machine Drive

Fred Wang
Oak Ridge National Laboratory

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Project ID: APE024

Overview

Timeline

- Start Date: Jan. 2010
- End Date: Sept. 2012
- 10% Complete

Budget

- DOE Share – 100%
- FY10 received: $389K
- FY11 requested: $500K

Barriers

- Barriers:
  - Simultaneously achieve high performance and fault tolerance while meeting high power density targets.
  - Ability to use low cost devices (Si) with acceptable high-temperature performance and reliability.
- Target: Power density >4 kW/L, and efficiency > 94%, 150 ˚C ambient and 200 ˚C junction temperatures

Partners

- University of Wisconsin
- University of Tennessee

Objective

- Develop a reliable, fault-tolerant, integrated modular motor drive (IMMD) that is capable of operating at 200˚C junction and 150˚C ambient temperatures.
- FY10
  - Design a demonstrator version of the integrated modular motor drive (IMMD) with fault-tolerant controller using the most promising configuration to verify performance characteristics including power density and fault tolerance
  - Evaluate Si IGBT and suitable packaging at 200˚C considering device characteristics, loss and cooling, as well as reliability

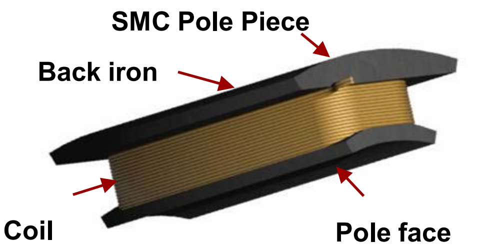
Milestone

- **August 2010:** Complete the design of next-generation low-power (10 kW) demonstrator IMMD motor; Characterize the Si IGBT operation at 200˚C junction temperature, and finish the layout and cooling design.
- *Go/No Go* – Design reviews to evaluate performance and fault tolerance capability, and to determine if prototype machine are ready for construction.

Approach/Strategy

Integrated Modular Motor Drive (IMMD) Concept

Machine Pole



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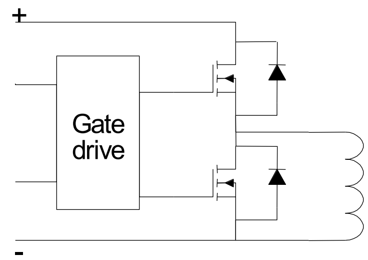
Power Electronics



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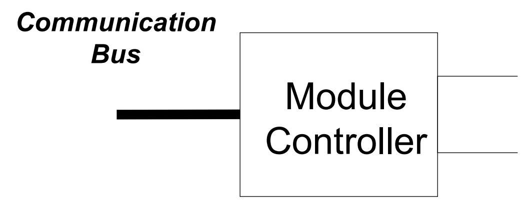
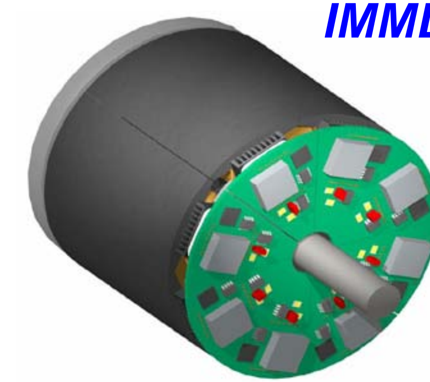
Controller



Modular Pole-Drive Unit

IMMD



Each modular pole-drive unit performs as an independent building block in the motor drive stator configuration

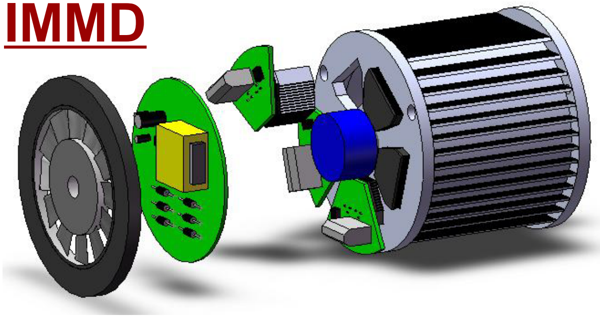
Approach/Strategy (cont'd)

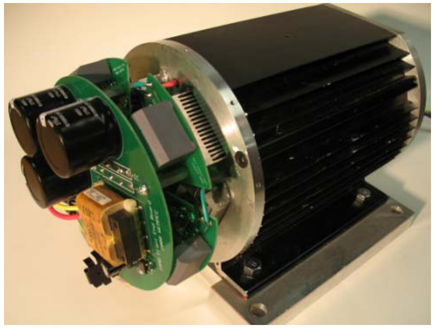
Meet the cost and power density target by

- modularizing both the machine and power electronics and then integrating them together into a single combined machine-plus-drive structure
- extending Si device operation to higher temperatures and utilizing the advanced packaging approaches

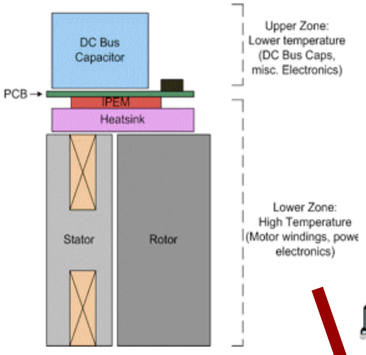
Previous Accomplishments

Demonstrator 5-Phase low power IMMD

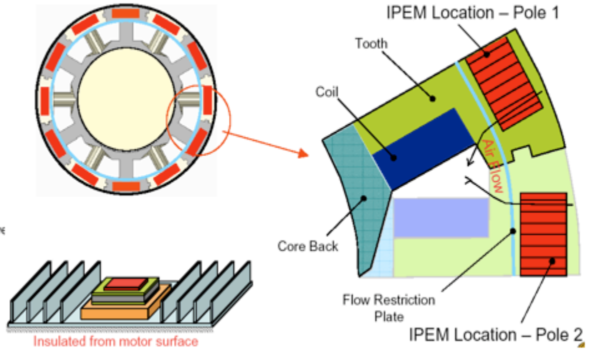




Proposed Zonal Thermal Design

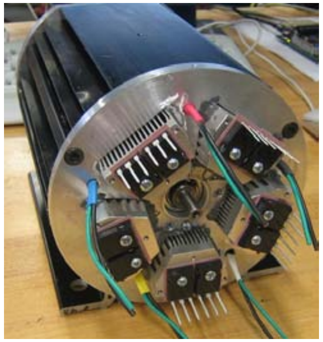


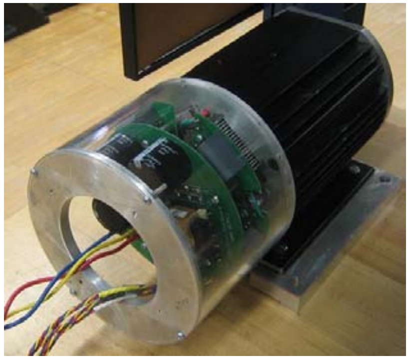
IMMD Thermal Analysis Model

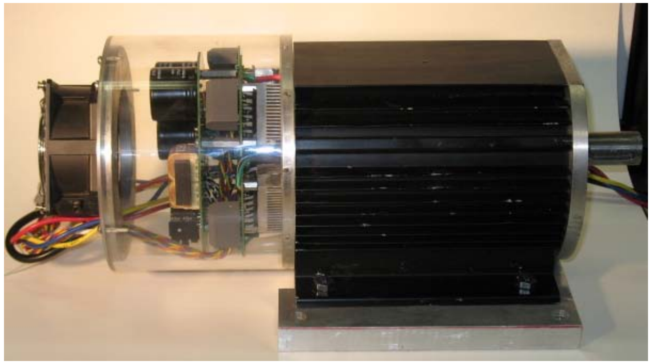


To

Integrated modular 5-phase motor drive







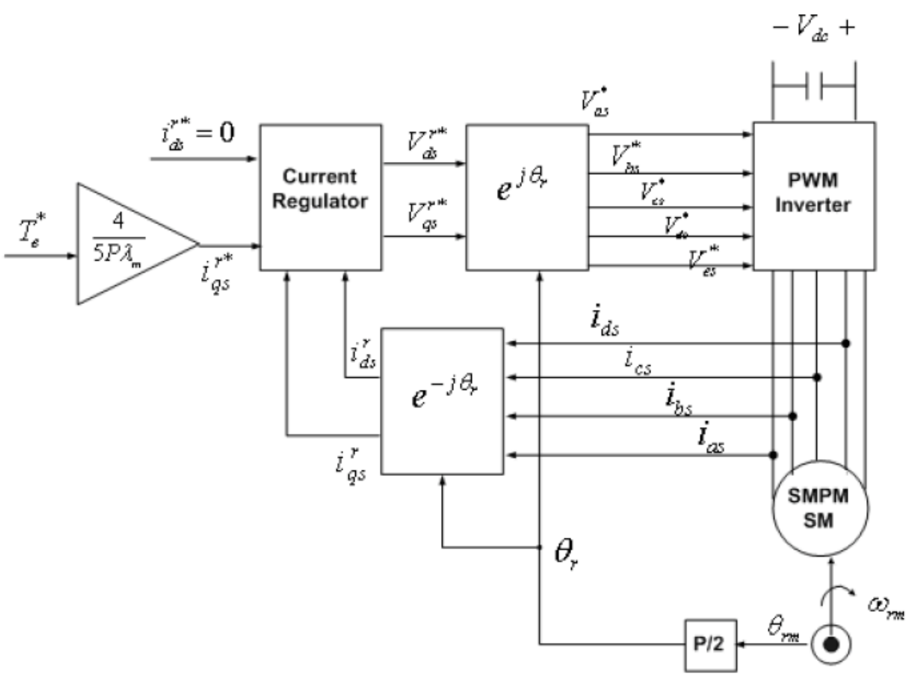
FY10 Technical Accomplishments

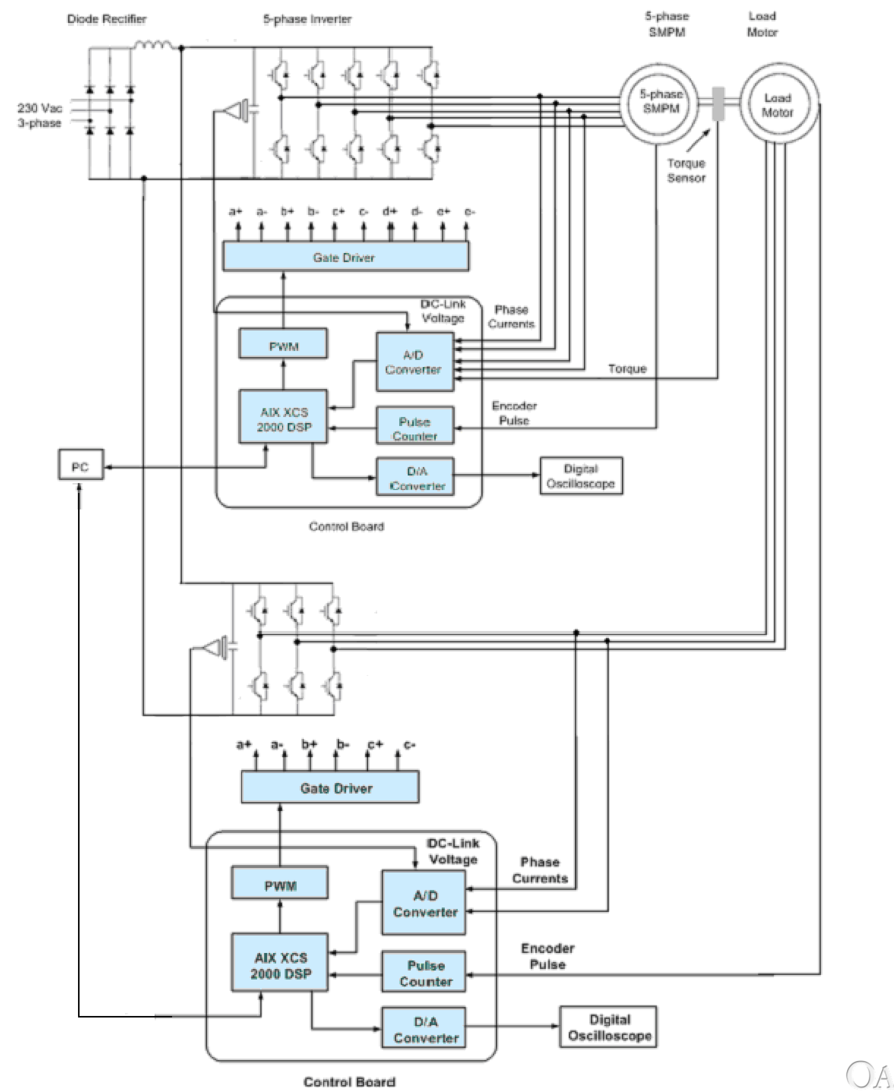
IMMD System:

- 5-phase demonstrator IMMD used as starting point for new investigation
- Vector control algorithm adopted for torque controller
  - Synchronous frame current regulator
  - Encoder provides rotor position feedback
  - Decoupling techniques introduced for improved dynamic performance
- Simulation used to explore predicted IMMD drive performance with vector controller
- Controller hardware configuration defined using AIX DSP-based controller

FY10 Technical Accomplishments (cont'd)

IMMD Controller





FY10 Technical Accomplishments (cont'd)

Simulation Results

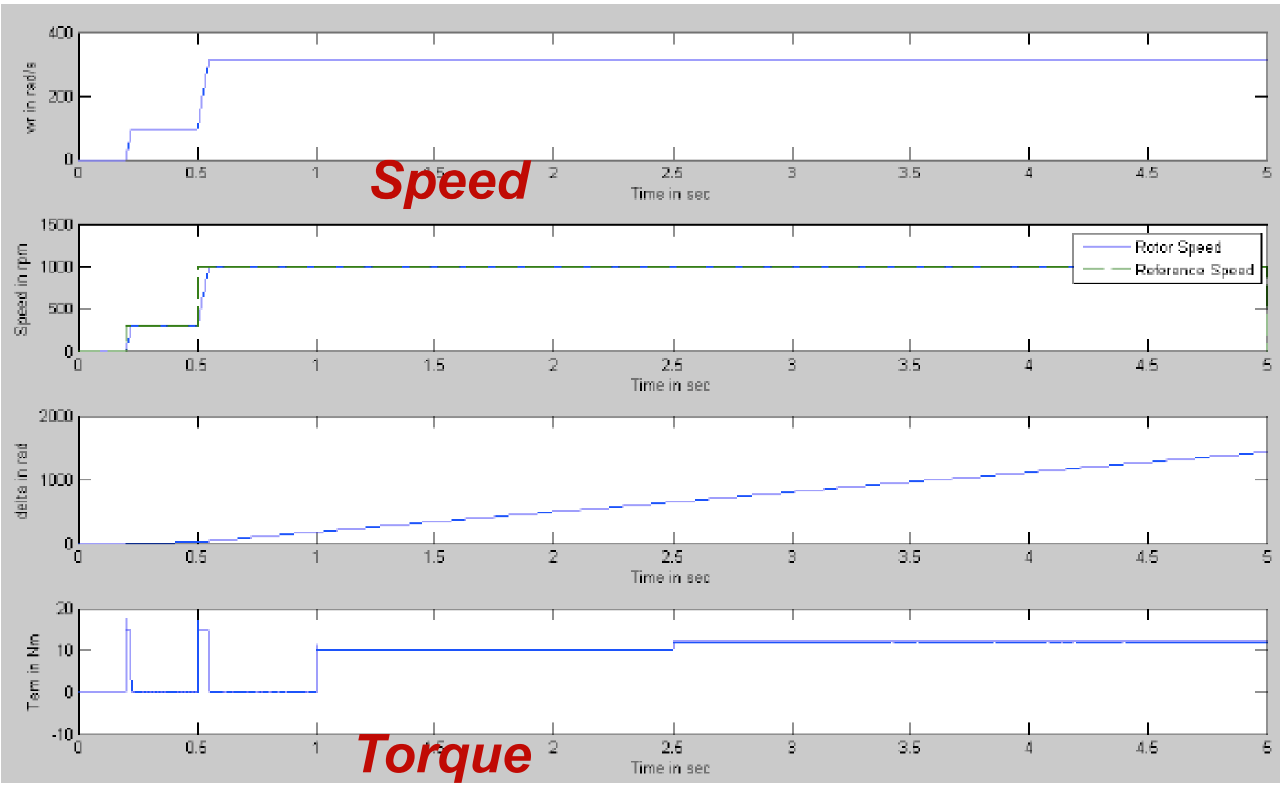


Fig. 14(b) wr, delta, and Tem waveforms under step change in speed reference and load torque:
300 rpm @ 0.2 sec and 1000 rpm @ 0.5 sec. 10 Nm @ 1 sec and 12 Nm @ 2.5 sec.

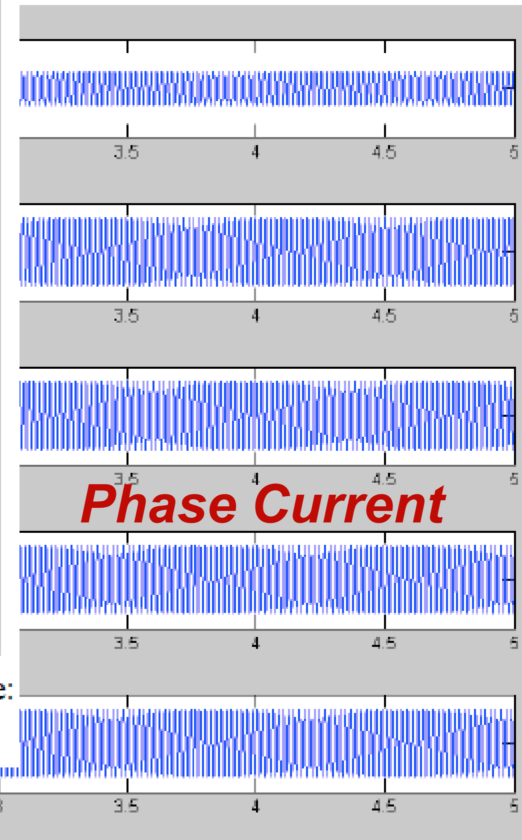
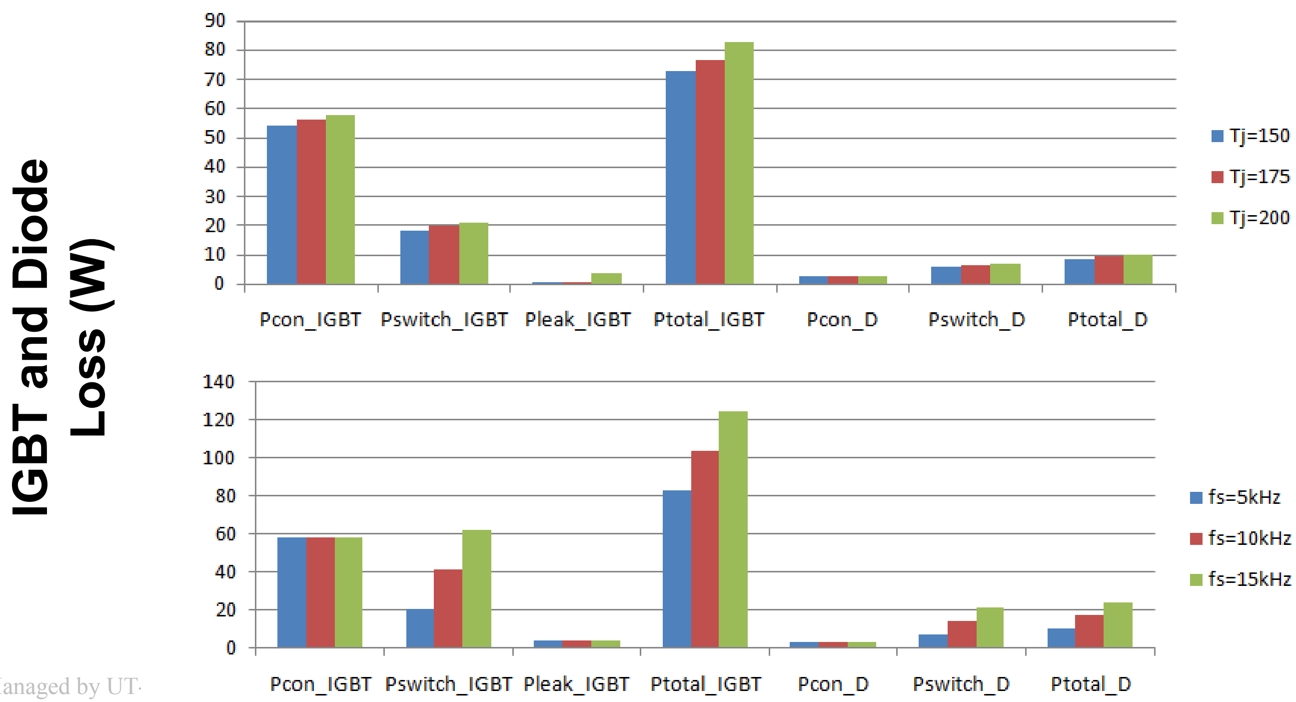


Fig. 14(d) ia, ib, ic, id, and ie under step change in speed reference and load torque:
300 rpm @ 0.2 sec and 1000 rpm @ 0.5 sec. 10 Nm @ 1 sec and 12 Nm @ 2.5 sec.

FY10 Technical Accomplishments (cont'd)

Device Evaluation

- **Baseline devices for evaluations selected (IKW40N120H3 – Trench Fieldstop IGBT)**
- **Loss calculations show the loss increase due to elevated temperature manageable**



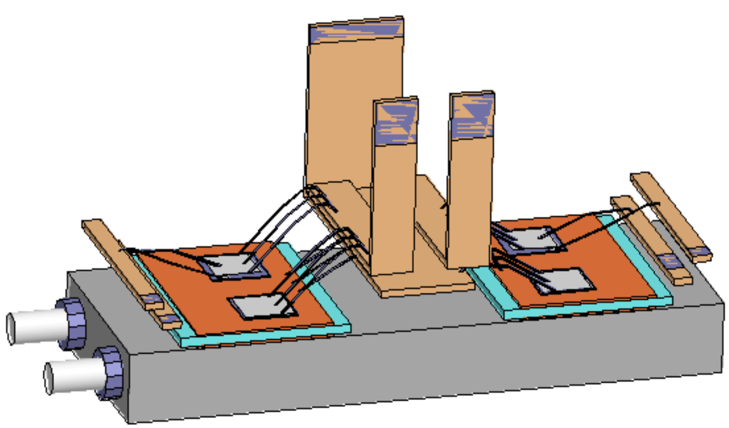
When f_s=5 kHz,
η=98.37%, T_j=150 ˚C;
η=98.28%, T_j=175 ˚C;
η=98.14%, T_j=200 ˚C.

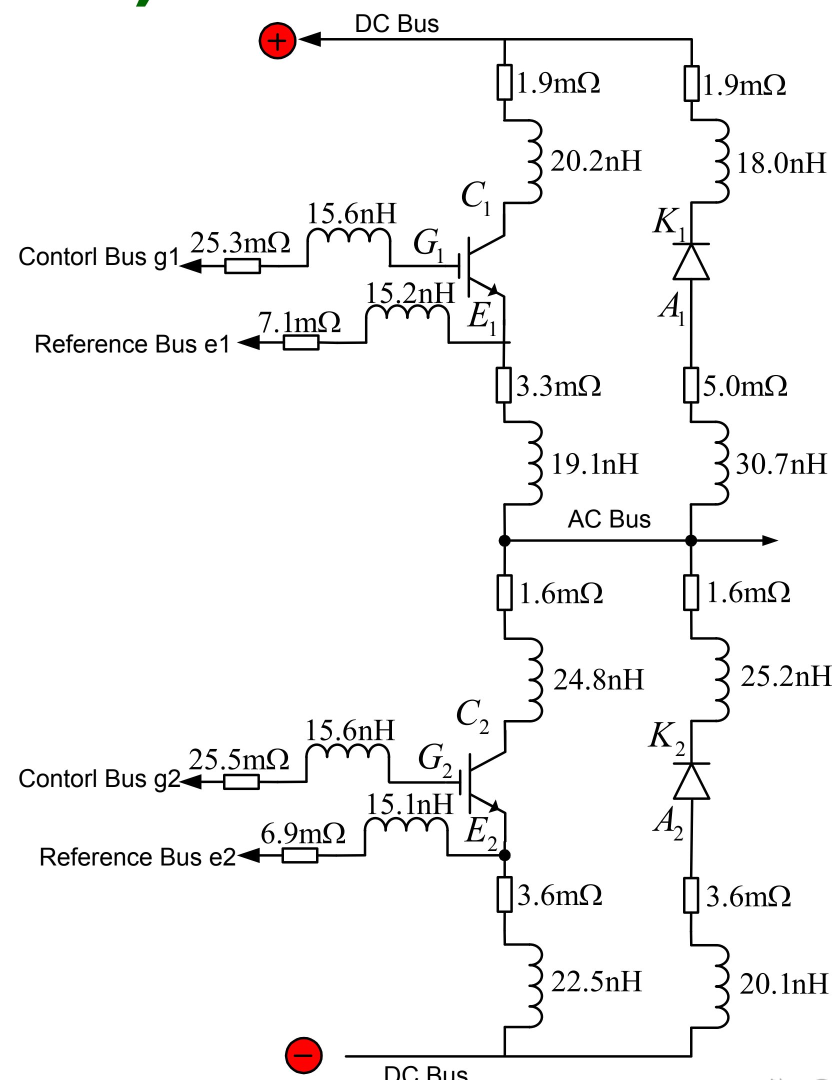
When T_j=200 ˚C,
η=98.14%, f_s=5kHz;
η=97.58%, f_s=10kHz;
η=97.03%, f_s=15kHz.

FY10 Technical Accomplishments (cont'd)

Device Packaging

- **Baseline packaging structures and materials selected**
- **Phase-leg layout designed**
- **Baseline cooling system designed**





Collaboration

- **Partners**
  - University of Wisconsin (Academic): Subcontractor, design and develop integrated modular motor drive system
  - University of Tennessee (Academic): Subcontractor, design and develop power modules based on Si devices operating at 150˚C ambient and 200˚C junction temperatures

Future Work – FY10

- Design next-generation 10 kW demonstrator IMMD motor
- Design hardware and software of the controller for demonstrator IMMD
- Characterize and test Si IGBT and diode module at 200˚C
- Select IGBT/diode dies and design the high temperature packaging for 10 kW phase-leg power module to be used for full power (55 kW peak) IMMD

Future Work – FY11 and beyond

- Build and test 10 kW demonstrator IMMD to evaluate drive system performance and fault tolerance
- Develop the 10 kW phase-leg power modules needed for implementing the full power IMMD. The modules should be based on low cost Si and can operate in ambient temperatures of 150˚C, with junction temperatures up to 200˚C.
- Scale up the power level of the IMMD technology and combine with the high temperature modules to achieve high-density integrated traction motor drive.

Summary

A high-density integrated motor drive is being developed that will feature:

- Modular power electronics and motor integrated in a single structure with fault tolerance
- High temperature capability based on low cost Si devices and novel packaging, capable of operating at 150˚C ambient and 200˚C junction temperatures with 105˚C oil cooling
- Power density and efficiency meeting DOE 2020 targets