U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Integration of Novel Flux Coupling Motor and Current Source Inverter

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Project ID: APE034

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Overview

Timeline

- Start: October 2010
- End: September 2015
- 36% complete

Budget

- Total project funding
  - DOE share – 100%
- Funding received in FY12
  - $550K

Barriers

- **Barriers addressed**
  - **High permanent magnet (PM) cost for motor**
  - **Bulky and costly DC link capacitors for VSI**
  - **Bulky and costly DC link inductor for CSI**

VT Program Targets addressed

- **DOE 2020 Drive System Power Density Targets**
  - 1.4 kW/kg
  - 4 kW/l
- **DOE 2015 Drive System Cost Target**
  - -- $12/kW

Partners

- Work with SMC vendor on optional core material
- ORNL Team Members: John Hsu, Lixin Tang, Randy Wiles, Gui-Jia Su

Relevance

Objectives: To integrate a non permanent magnet (PM) electric machine and a current source inverter (CSI)

- **minimizing capacitors in inverters**
- **eliminating rare earth materials used in traditional traction motors**
- **eliminating the DC link inductor in the CSI through utilization of the leakage flux linkage in the motor**

Meet the DOE 2020 drive system targets of
1.4 kW/kg, 4.0 kW/L, and the DOE 2015 cost target of $12/kW

Milestones

FY11

- Perform electromagnetic computation and finite element analysis (FEA) toward a design suitable for a proof-of-concept prototype and conduct tests.
- Go/No Go decision: The feasibility for integration will be judged by sufficient leakage inductance for the CSI and the blocking of the AC flux going into the rotor of the motor.

FY12

- Optimize design for prototype motor and prototype inverter.
- Go/No Go decision: Determine if the optimized motor and inverter designs can meet the objectives.

FY13

- New motor core and coil design and simulations.
- Improved system control study.
- Partial component tests.
- Go/No Go decision: If simulation and partial component tests show that the cost of system and the performance are better than those of the separated old arrangement.

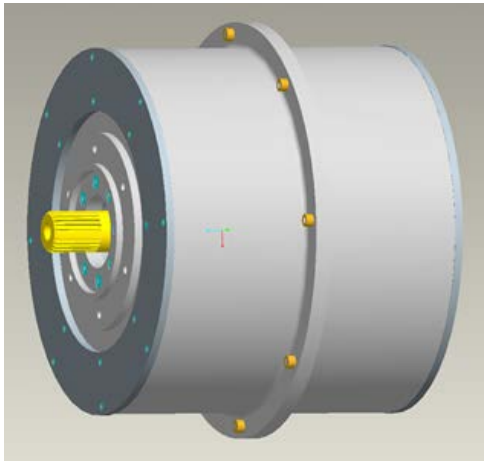
Approach/Strategy

- This project builds upon previous R&D accomplishments
  - ORNL CSI research has demonstrated capacitance reductions of 90%
  - ORNL Novel Flux Coupling Machine Without Permanent Magnets provides IPM like performance using no PMs
- Approach integrates the two technologies and uses inductance from the motor to replace the CSI inductor
  - Reduces weight and volume (inductor largest and heaviest component in CSI)
  - Reduces cost
- This totally new concept involves technical challenges in ability to manipulate and successfully separate the motor coil flux components

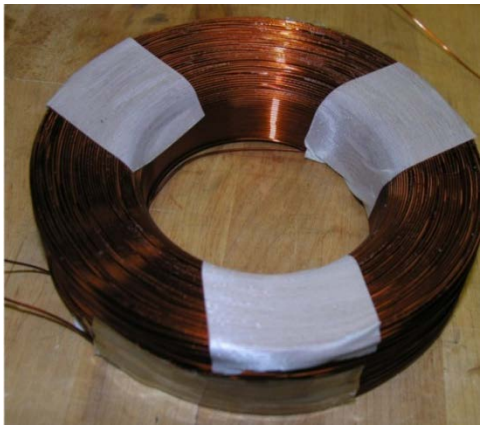
Description of Technology/Approach

- **The concept depends on the ability to utilize the excitation coil in the motor to function in two roles. In addition to providing motor excitation it will also function as an inductor for the CSI.**

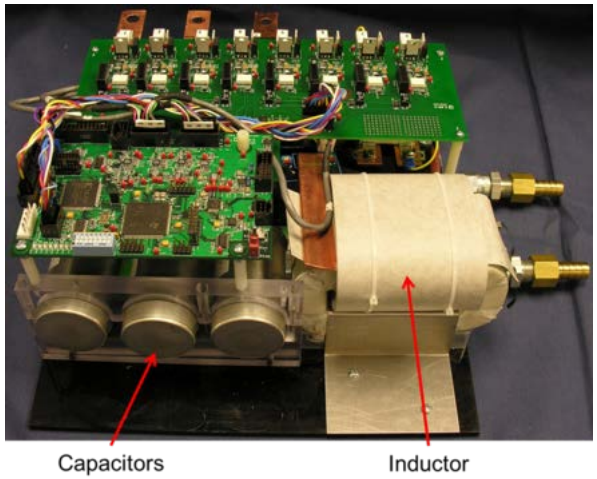
Novel Flux Coupling Motor



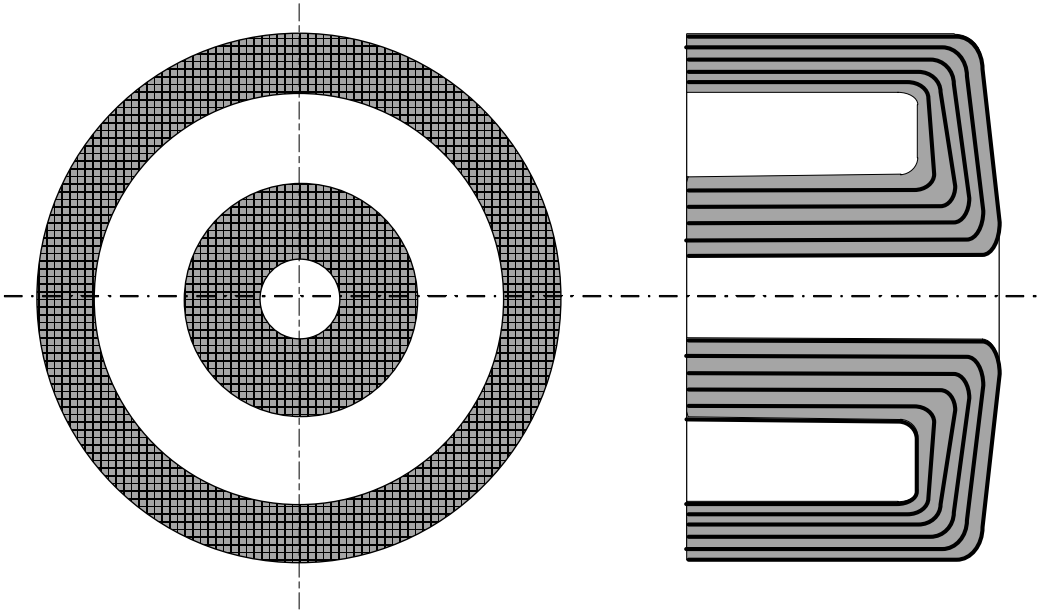
Stationary excitation coil within the NFC



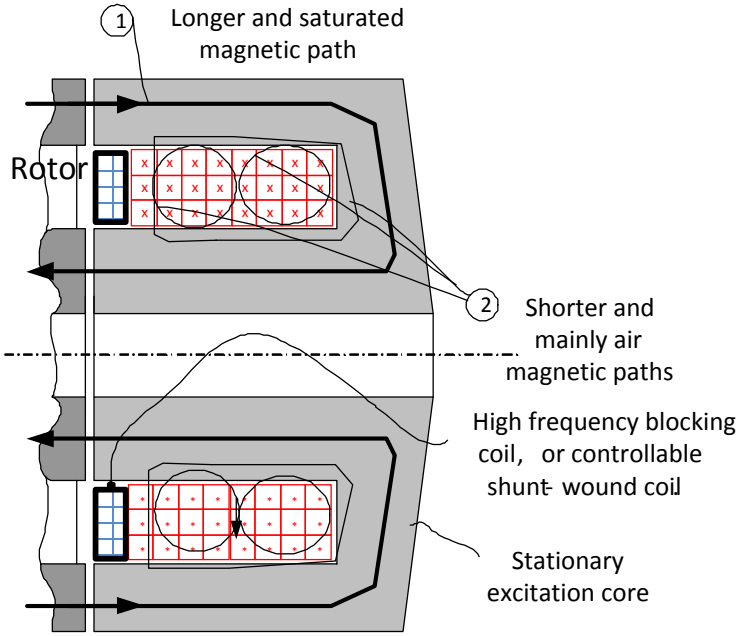
Current Source Inverter



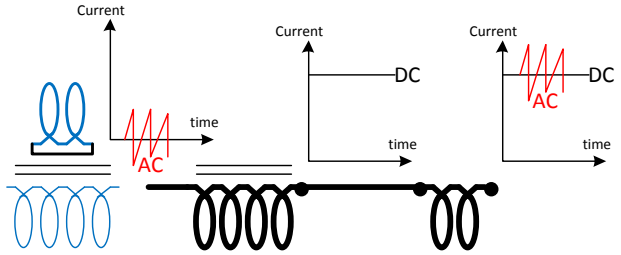
Example for Blocking High Frequency Flux



Insulated iron wires compressed with insulated soft magnetic powders



Blocking high frequency flux going into motor rotor is an on-going research work.



Shunt wound coil acts as a high frequency blocking coil for preventing flux going into rotor.

Iron path inductor sees most DC flux due to shunt wound coil blocking.

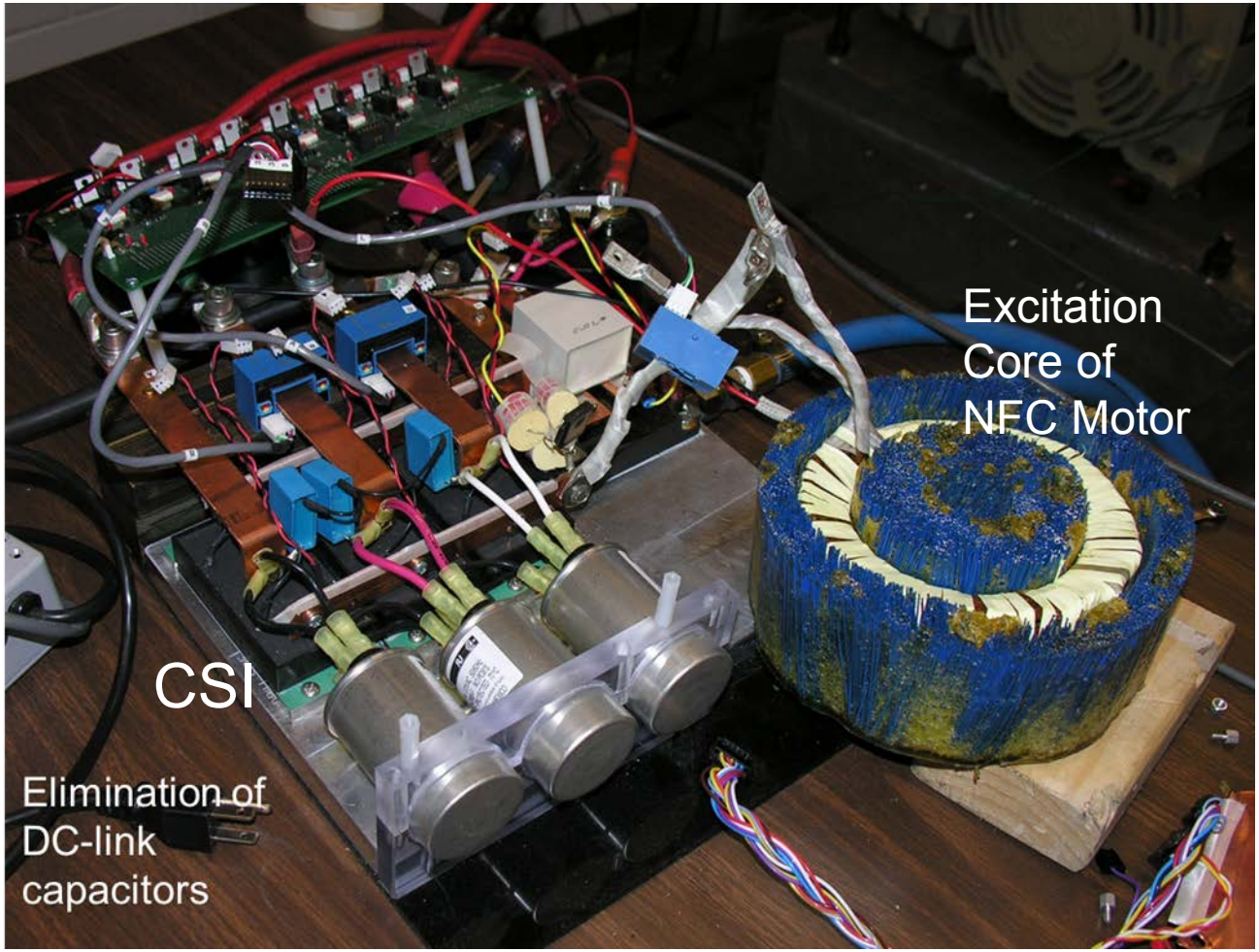
Leakage inductor carries most AC flux.

Accomplishments to Date

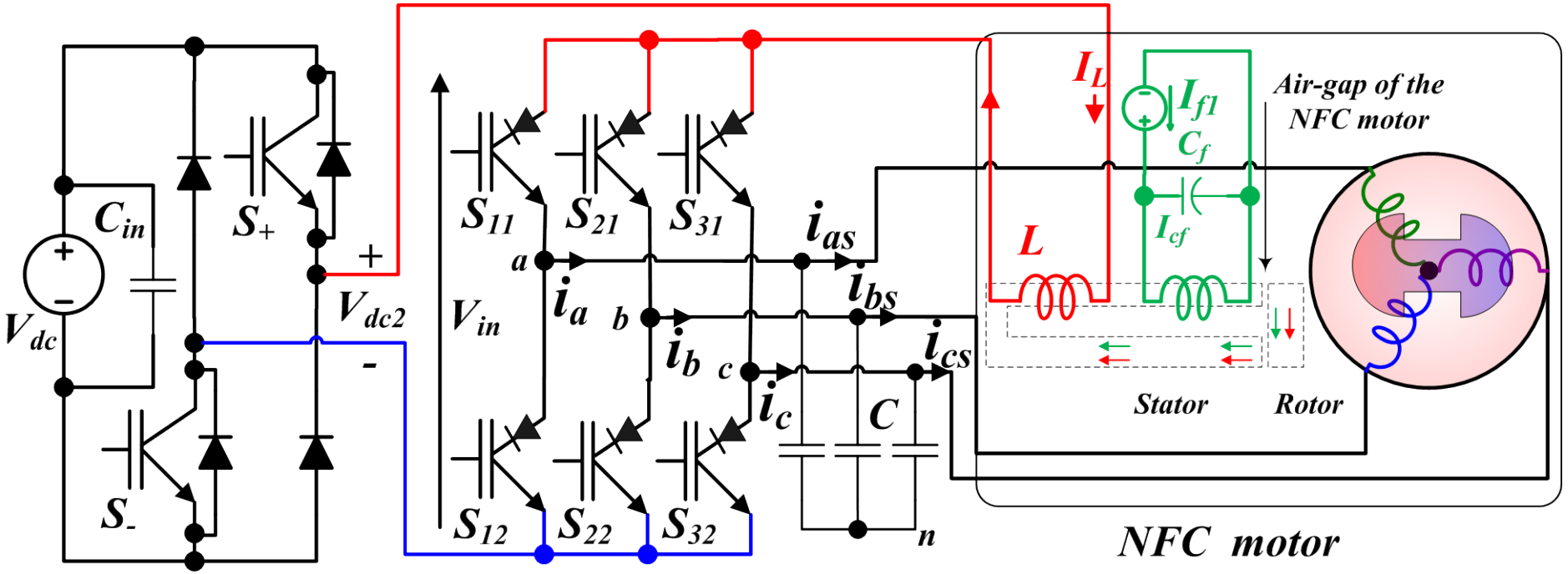
In 2011, we

- Completed the FEA simulations of the NFC motor and locked-rotor tests,
- Designed and fabricated a iron-wire excitation core that can take high frequency for the integration project,
- Tested the prototype core with inverter, and
- Validated the integration concept.
- Initial tests showed poor coil efficiency leading to lower than desired overall efficiency.

Accomplishments to Date - Experimental setup of integration of NFC motor and CSI

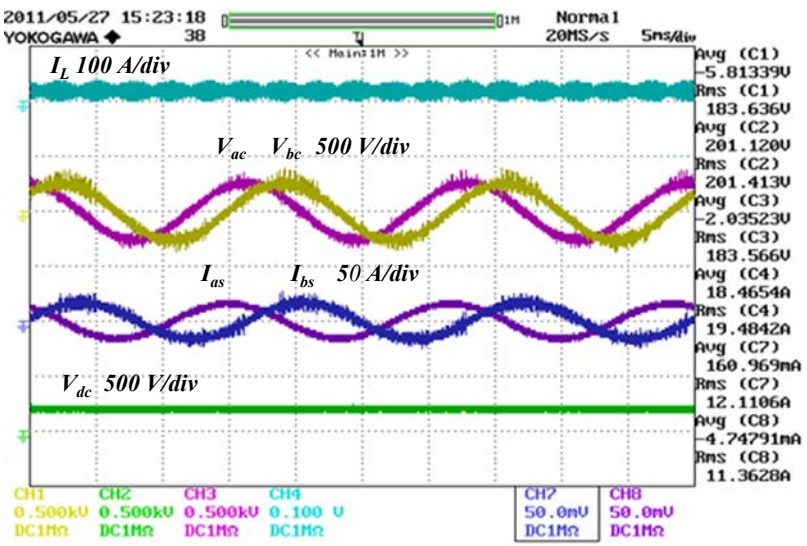


The Integrated System
- Locations of V_{dc2} and V_{dc}

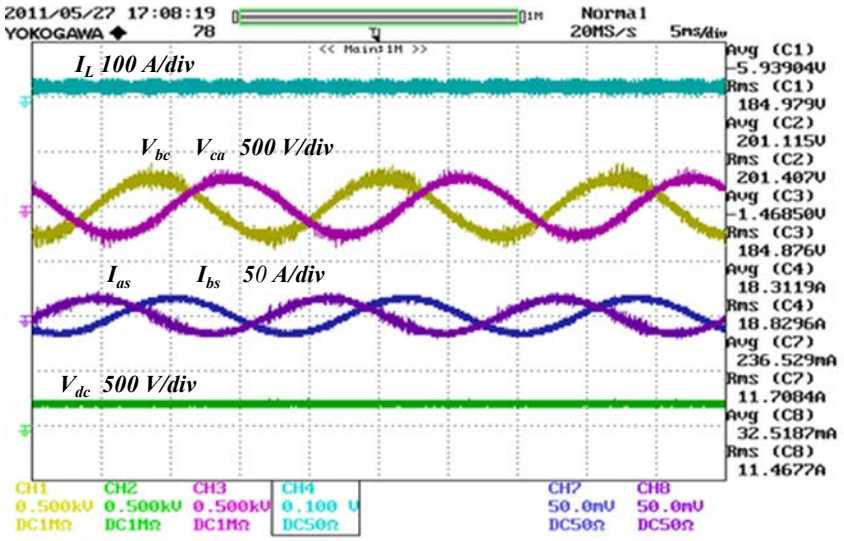


Accomplishments to Date

Tested Input current (100 A/div), two output voltages (500V/div), two output currents (50A/div) and input voltage (500 V/div)

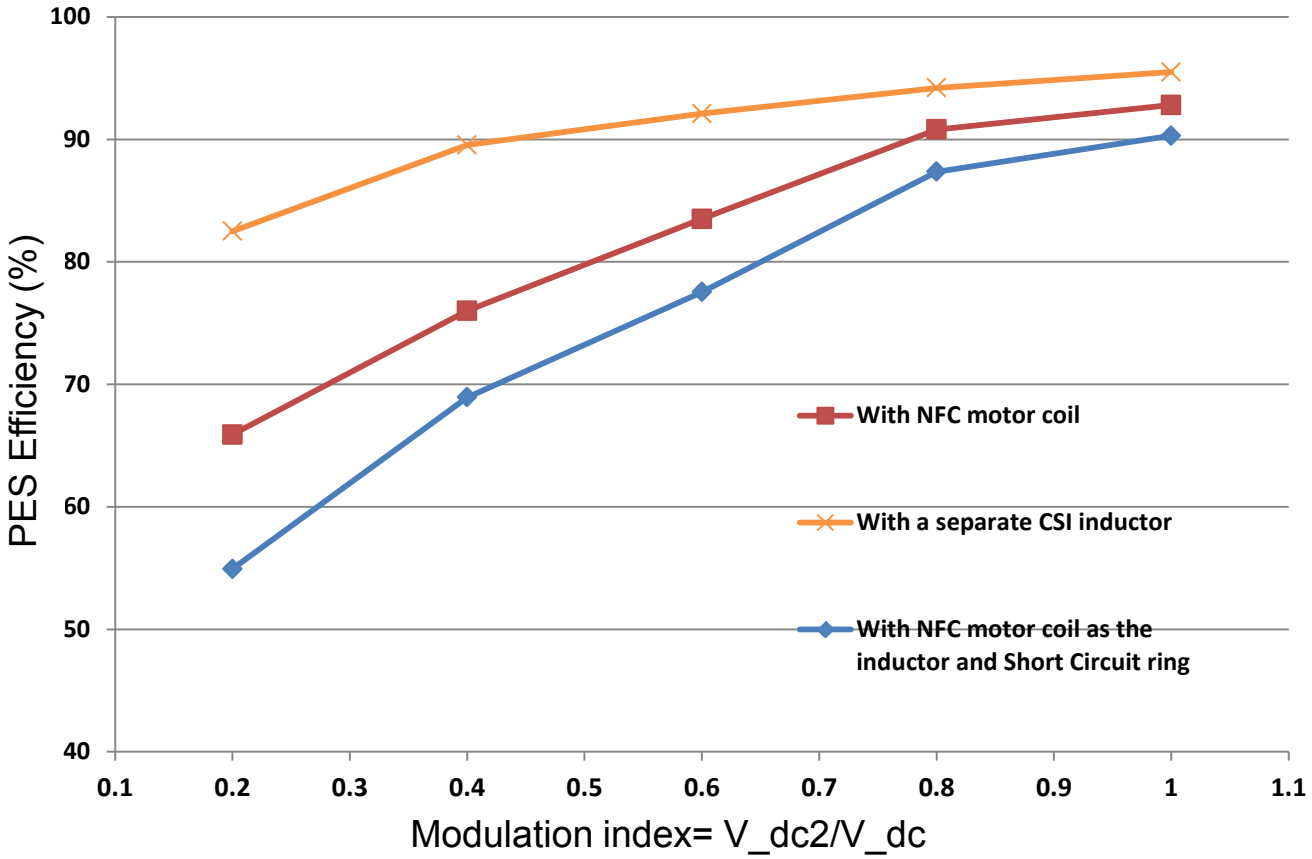


With the NFC-Motor excitation coil inductor



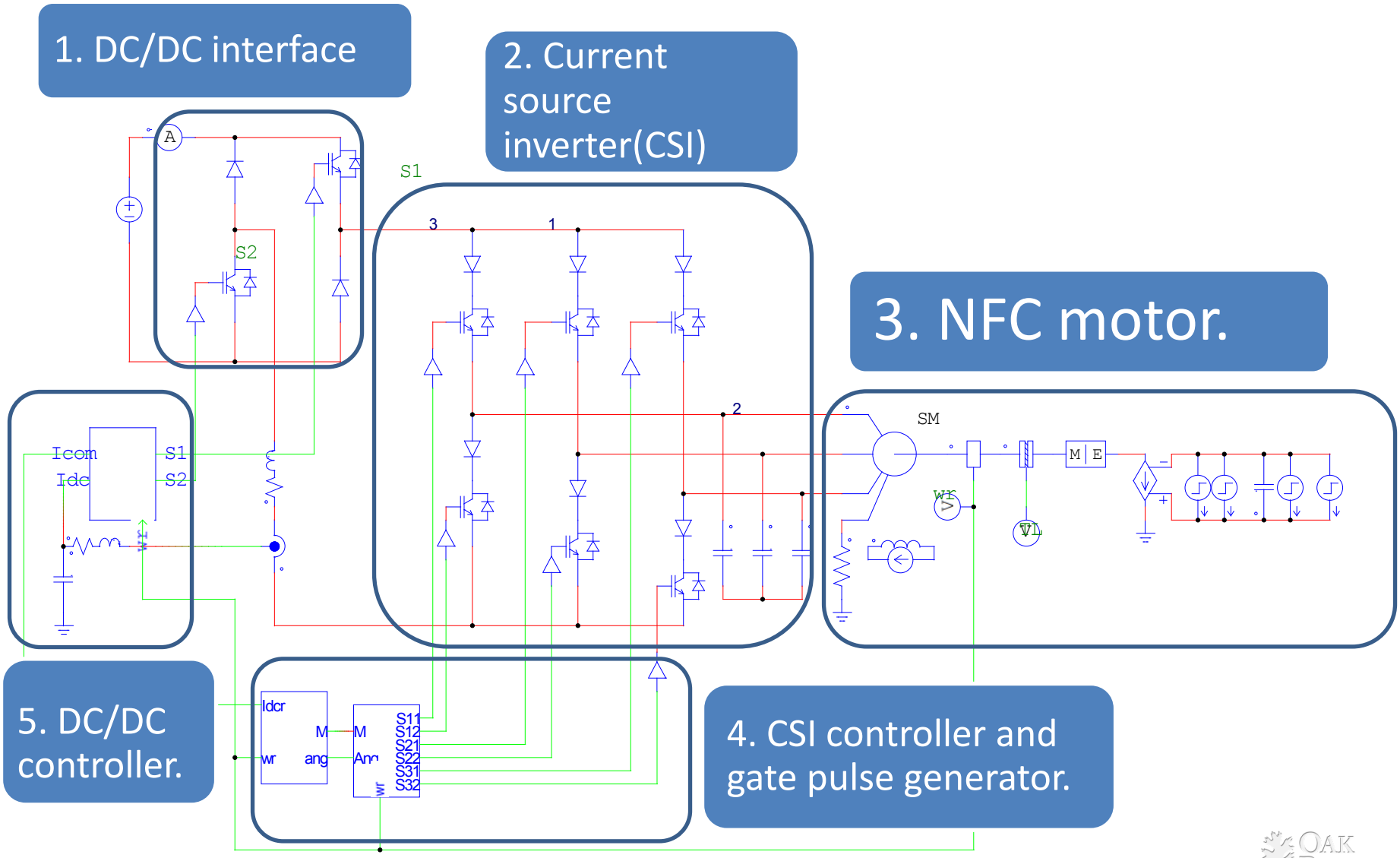
With a separate CSI inductor

Accomplishments to Date - Power electronic system (excluding load) efficiency with different DC bus inductors



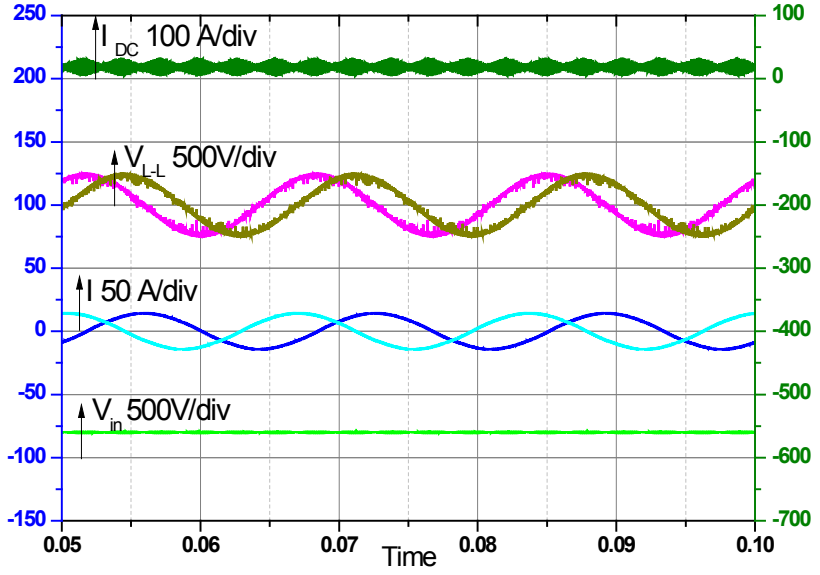
Accomplishments in FY12

Diagram of the simulation model in PSIM

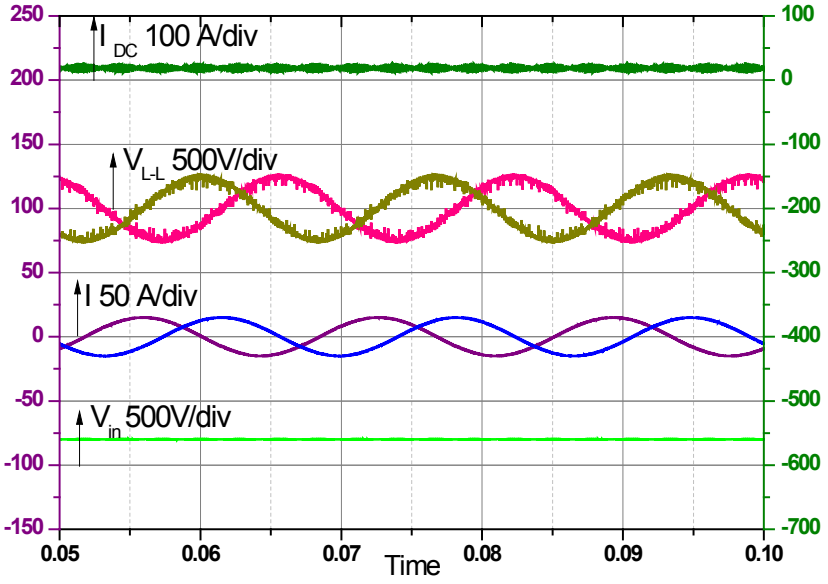


Accomplishments in FY12

Simulated Input current (100 A/div), two output voltages (500V/div), two output currents (50A/div) and input voltage (500 V/div)



With the NFC-Motor excitation coil inductor



With a separate CSI inductor

Collaborations

Depending on success, in FY 12 discussions will be held with soft magnetic composite manufacturers for excitation core materials.

Future Work

FY13

- Motor core and coil simulations and partial component tests.

FY14

- Prototype design and fabrication of the newly designed integrated system.

FY15

- Test the prototype and report the results.

Summary

- Previous R&D has demonstrated;
  - CSI reduces bulk capacitance requirement by 90%; inductor in CSI is heaviest, largest single component.
  - Novel flux coupling motor yields IPM-like performance using no PMs
- This project integrates the two technologies and uses the motor coil to replace the CSI inductor.
- Concept expects to meet DOE 2020 system weight and volume targets and 2015 system cost target.
- Initial calculations indicate that the excitation core of the novel flux coupling motor can produce sufficiently high inductance to meet the inverter's PWM and boosting needs.