U.S. DEPARTMENT OF ENERGY

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

A New Class of Switched Reluctance Motors

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May 21, 2009

Project ID: apep_02_burress

Overview

Timeline

- Start: FY09
- Finish: FY12
- 15% Complete

Budget

- Total project funding
  - DOE: 100%
- Funding Received in FY08
  - $0K
- Funding Received in FY09
  - $569K
- Funding Requested for FY10
  - $486K

Barriers

- Barriers
  - Minimizing flux leakage
  - Reducing acoustic noise and torque ripple
  - Minimizing phase conductor count
- VTP 2015 Targets
  - Motor power density:
    - Between 5 kW/L and 7.5 kW/L
  - Motor specific power:
    - Between 1 kW/kg and 2.2 kW/kg
  - Motor cost:
    - Between $6/kW and $8/kW

Partners

- University of Tennessee

Objectives

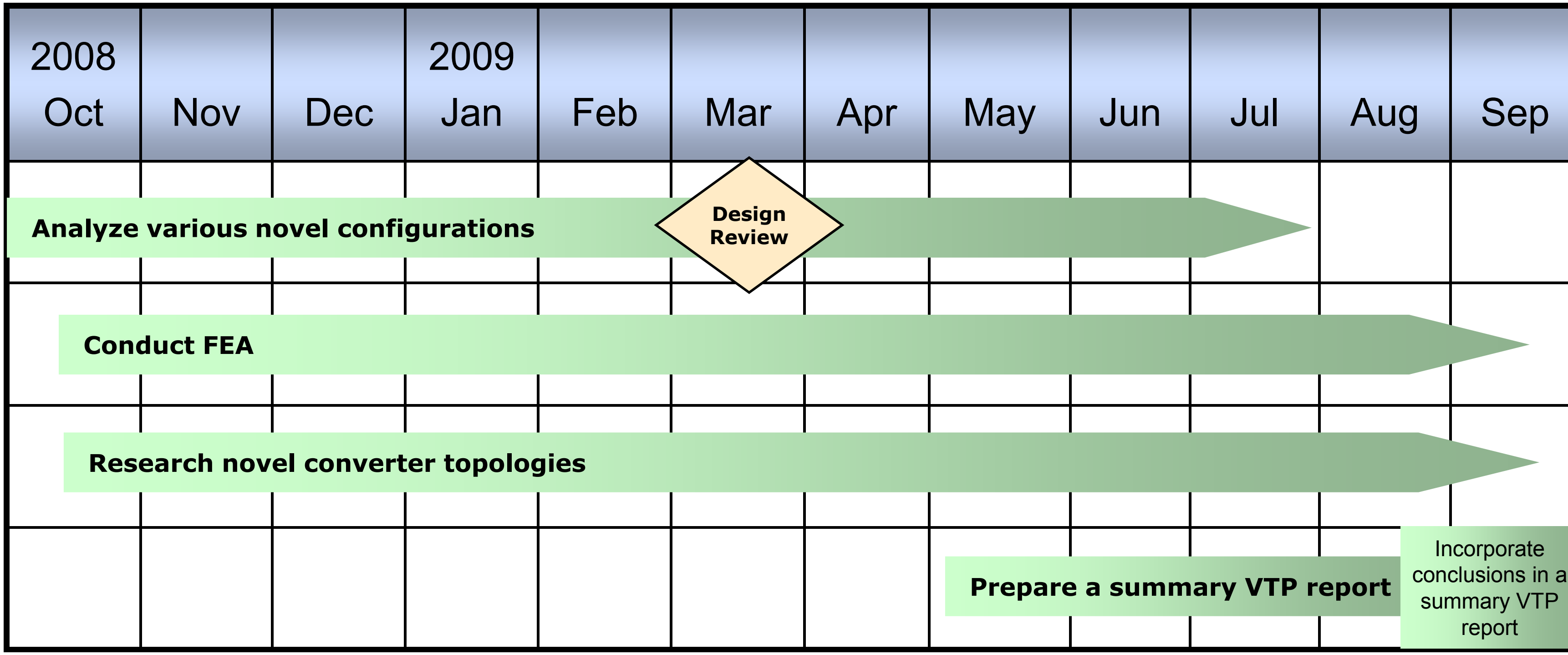
- **Address need for HEV motors <u>without permanent magnets</u> by investigating various unconventional Switched Reluctance Motor designs with emphasis on improving:**
  - Motor characteristics
    - Increase power density significantly above that of conventional SR topologies
    - Increase SR specific power
    - Decrease torque ripple
    - Reduce cost (in comparison to permanent magnet machines)
    - Reduce core losses
  - Converter design
    - Reduced cost (component count)
    - Increase power density

- **Explore potential to remove boost converter or reduce battery voltage**

- **Seek to provide initial quantitative results showing that estimated characteristics of the proposed design reach the following targets:**
  - Power density between 5 kW/L and 7.5 kW/L
  - Specific power between 1 kW/kg and 2.2 kW/kg
  - Motor cost between $6/kW and $8/kW

- **FY09 Objective: Determine preferred embodiment and associated preliminary control algorithm**

Milestones



Decision point discussion: Select preferred design, based on simulation results and assess if benefits justify proceeding into next year

Approach

- **Select preferred embodiment of novel switched reluctance machine**
  - Analyze basic feasibility of various novel switched reluctance machine designs
  - Conduct finite element analysis (FEA) to obtain motor characteristics
  - Develop preliminary novel control schemes
  - Simulate final design(s) with basic dynamic model
    - Obtain estimated capabilities of torque and power as a function of speed
  - Choose preferred embodiment based on preliminary cost assessments, FEA, and dynamic simulation results
- **Perform detailed design and simulation of selected embodiment**
  - Conduct structural, thermal, and acoustic noise modeling
    - Adjust preferred embodiment as necessary
    - Investigate potential to apply air-gap enhancements
  - Carry out comprehensive dynamic simulations
    - Refine novel control algorithm and investigate potential to apply other novel control techniques
    - Obtain accurate capabilities of torque and power as a function of speed
  - Research novel inverter topologies
    - Explore use of unique novel SRM characteristics to improve upon conventional converter topologies
    - Study ways to reduce chip count, increase specific power, and power density
- **Build and test prototype of preferred embodiment**
  - Determine power density, specific power, and cost based on results from dynamometer tests
- **Transfer technology to industry**

Technical Accomplishments (1)

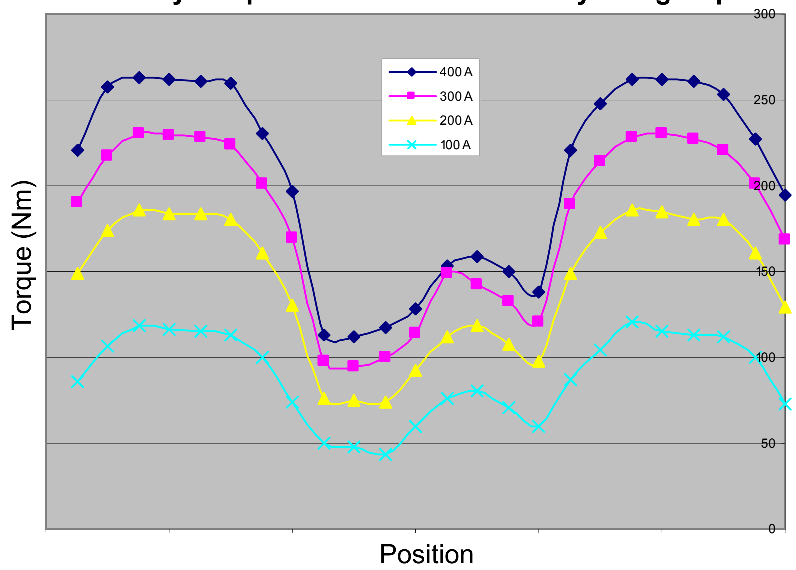
- Feasibility of several designs based on unconventional concept already verified through extensive FEA simulations with improvements upon
  - Manufacturing and material costs
  - Peak-torque
  - Torque-ripple
  - CPSR (constant power speed ratio)
  - Mass and volume

- Encouraging results
  - Capabilities of conventional SR machine surpassed while maintaining low manufacturing cost
  - Capability to attain extremely low torque ripple
  - Still much room for design refinement
  - Several more novel geometries to be analyzed

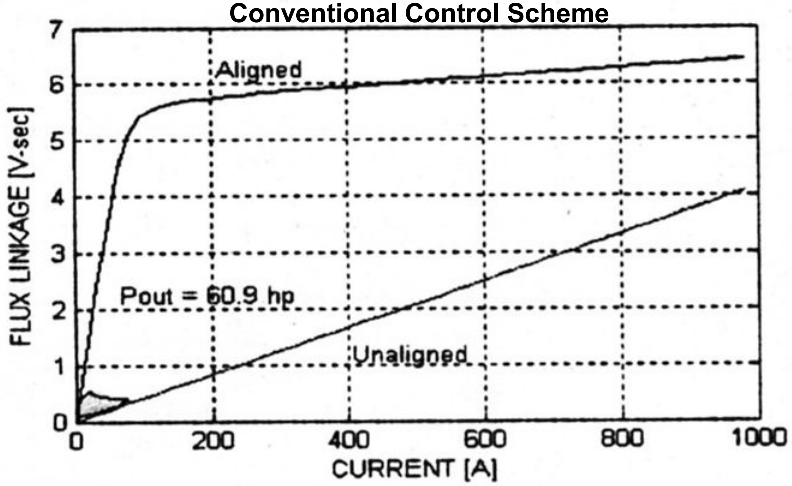
Technical Accomplishments (2)

- **Various hardware solutions developed**
  - Unconventional stator and rotor designs
- **Software solutions being developed to be incorporated into final design**
  - Continuous conduction
  - Torque ripple reduction
  - Acoustic noise reduction

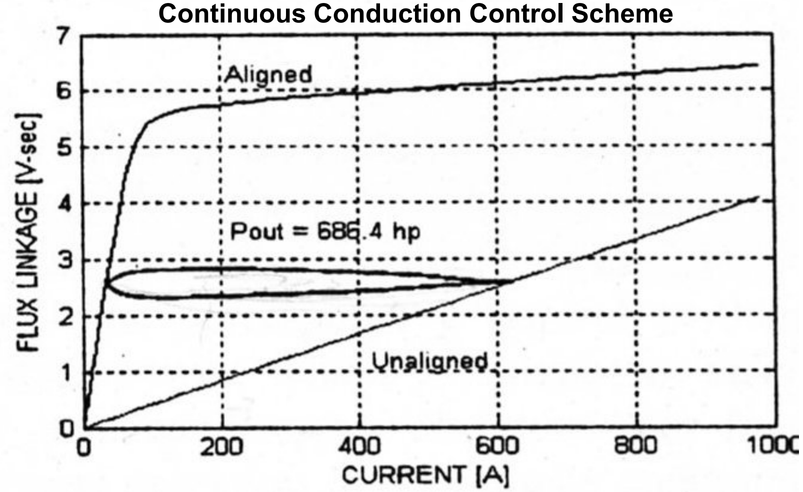
Preliminary Torque Profile For One of Many Design Options



Conventional Control Scheme

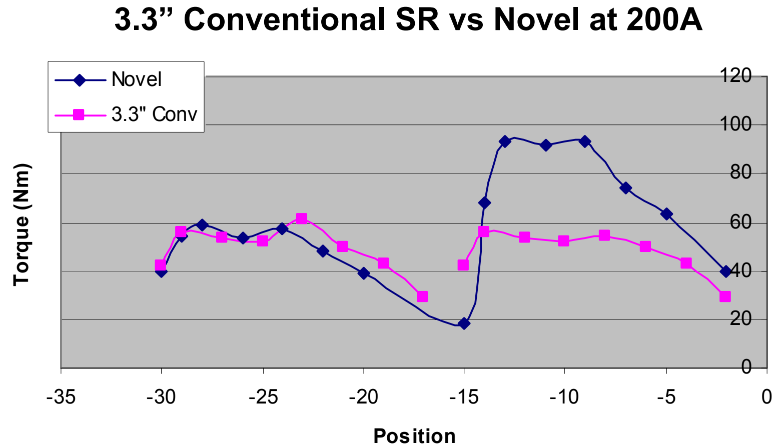


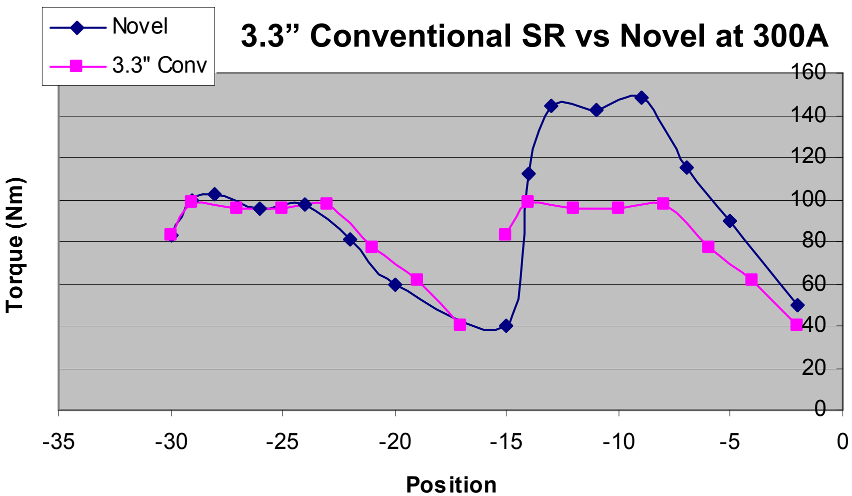
Continuous Conduction Control Scheme

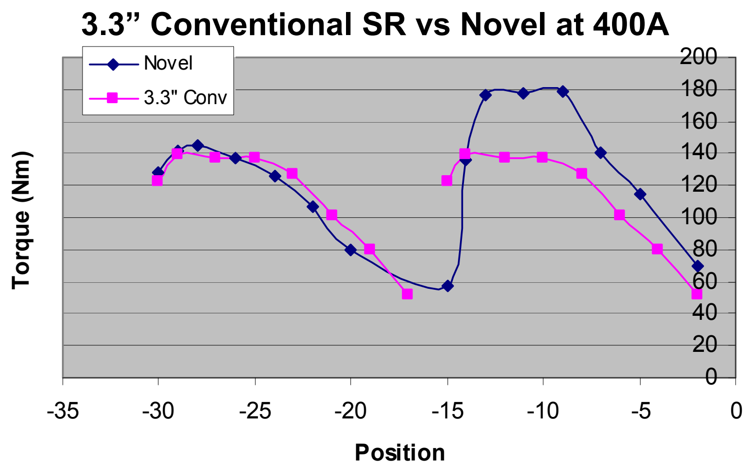


Technical Accomplishments (3)

- **Novel concept applied to conventional 12-8 SRM**
  - Same stator and winding properties
  - Direct comparisons made with conventional SRM
- **Instantaneous peak torque improvement:**
  - 70% at 200 A
  - 49% at 300 A
  - 30% at 400 A







Future Work

- FY09
  - Further studies upon additional geometries to be conducted
  - Universal dynamic simulator to be developed to determine estimated power densities and speed capabilities
  - Choose at least one preferred embodiment
- FY10
  - Develop control algorithm
  - Fully verify and finalize novel design

Summary

- Novel hardware and software solutions developed to address
  - Material and manufacturing costs of PM machines
  - Torque ripple and acoustic noise of conventional SRM
  - Need for high-speed machines with low power density
  - High core losses of conventional SRM

- Preliminary simulation results reveal promising outlook
  - Capabilities of conventional SRM torque/current matched, with considerable reduction in torque ripple
  - Ability to choose between various trade-off characteristics (e.g. peak torque vs torque ripple) through design parameters
  - Some geometries under consideration offer the opportunity to apply continuous conduction