Electrical Machinery Introduction And Overview

Advanced Power Electronics and Electrical Machines Quarterly Review

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OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

2010 FreedomCAR Partnership Goals

Develop by 2010 an integrated electronics system that costs no more than $12/kW peak and can deliver at least 55 kW of power for 18 seconds and 30 kW of continuous power. Additionally, the propulsion system will have an operational lifetime of 15 years.

FreedomCAR Goal	
Peak Power	**55 kW for 18 seconds**
Continuous Power	**30 kW**
Lifetime	**> 15 years or 150,000 miles**
Cost	**< $12/peak kW (< $660)**

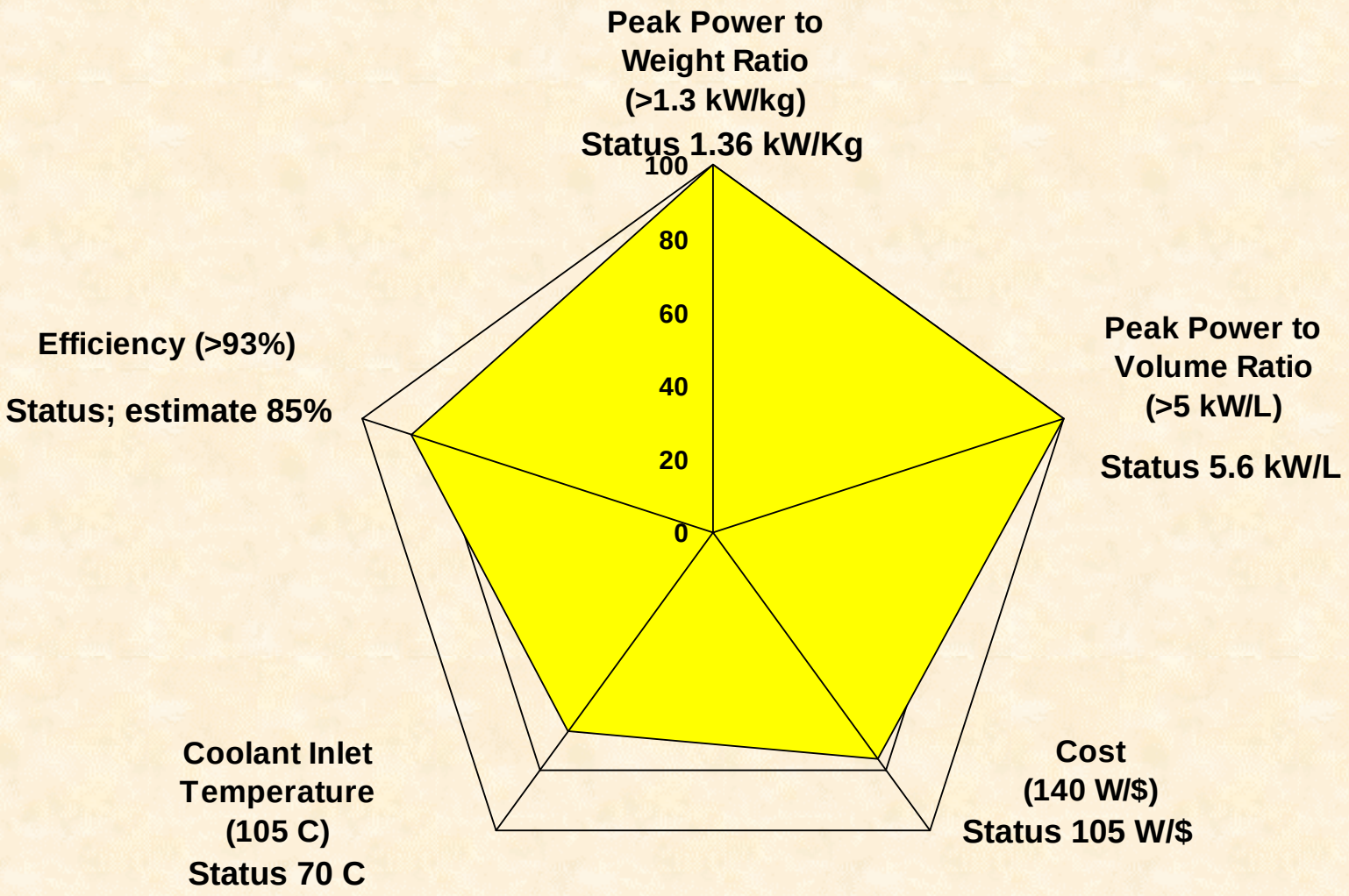
2010 FreedomCAR Technical Targets

Target Parameter	System Technical Targets[1]	Motor Technical Targets[1]	Power Electronic Technical Targets[1]
Peak Power to Weight Ratio	> 1.2 kW/kg (< 46 kg)	> 1.3 kW/kg (< 42.3 kg)	> 12 kW/kg (< 4.6 kg)
Peak Power to Volume Ratio	> 3.5 kW/liter (< 16 liters)	> 5 kW/L (< 11 liters)	> 12 kW/L (< 4.6 liters)
Cost	> 83 W/$ (<$660)	> 140 W/$ (<$393)	> 200 W/$ (< $275)
Efficiency (10 to 100% speed at 20% rated torque)	> 90%	> 93%	> 97%
Lifetime	15 Years	15 Years	15 Years
Coolant Inlet Temperature[2]	105°C	105°C	105°C

[1]Technical targets are interdependent and must be satisfied simultaneously

[2] The minimum cooling temperature difference target is 20 °C for the inverter, and it may be higher for other components

Electrical Machine Status and Targets



Technology Choices: Challenges and Approaches

Simultaneous Achievement is Required

Challenges	Approaches				
Temperature Capability of Power Electronics	**SiC Technologies** Modeling (ORNL) SiC hybrid inverter (Semikron/Cree) All SiC (RS)	**Two-Phase Cooling** Spray Cooling (OSR) Jet Impingement (RS) VIBE Technology (GT) Modeling (NREL)	**Ceramic or Glass Capacitors** Glass Ceramic (PS)	**Film Capacitors** Polymer Film (SNL) Film on foil (ANL)	**Thermal Resistance** Modeling (NREL) (Semikron)
Cost-Effective Size Reduction of Motors	**Magnetic Materials** Bonded Magnets (AMES)	**Advanced Motor Designs** Reluctance IPM (ORNL) Motor RFP (ORNL) Flux Weakening/CPSR Study (ORNL) Benchmarking (ORNL)	**Material Fabrication Technologies** Motor RFP (ORNL) Benchmarking (ORNL)	**Interior PM Motor** Reluctance IPM (ORNL) Motor RFP (ORNL) Benchmarking (ORNL)	**Thermal Management** Floating Loop (ORNL) Motor slinger/jacket cooling (ORNL)
Weight and Volume of Power Electronics	**Advanced Topologies** Integrated inverter (ORNL) Dual converter (ORNL) DC/DC Converter (Ballard) SoC (AIEC)	**Z-Source Inverter** (MSU)	**Advanced Packaging** (Semikron) DC/DC Converter (Ballard) SoC (AIEC)	**DC/DC Converter** (Ballard) Dual converter (ORNL)	**System On a Chip** (AIEC)

Electrical Machine Project Purpose and Rationale

AOP Task	Title	Purpose/Rationale
3.1	Flux weakening, flux enhancement, & CPSR enhancement techniques	Improve flux control models and explore fundamental flux strategies that have the greatest potential to enhance traction motor performance characteristics (CPSR, power density, etc.)
3.2	Electric motor research & development	Develop motor designs, build motors, and evaluate motors that take advantage of the state-of-the-art flux control strategies in order to meet FreedomCAR performance targets (peak power to weight ratio, efficiency, etc.)
3.3	Advanced traction motor development RFP	Design, fabricate, assemble, and evaluate an advanced traction motor suitable for U.S. industry adoption and commercial production in hybrid electric vehicles.
DOE Contract	Bonded PM for electric machines	Design PM alloys that are useful up to 200°C. Develop improved processing methods to produce spherical magnet powders with enhanced loading and corrosion resistance for molding into bonded isotropic magnets for electric machines.

Electrical Machine Project Summary

AOP Task Number	Title	PI	Participants	Budget
3.1	Flux weakening, flux enhancement, & CPSR enhancement techniques	John McKeever	Milton Bailey Pedro Otaduy Sam Nelson Jack Lawler Tom Jahns Gerald Callison	$670K
3.2	Electric motor research & development	John Hsu	Randy Wiles Curt Ayers Chester Coomer Mike Jenkins John McKeever Pedro Otaduy Phil Jalloulk S.T. Lee	$580K
3.3	Advanced traction motor development RFP	John Hsu	Laura Marlino Shannon Bridges Milton Bailey John McKeever Richard Smith	$705K
DOE Contract	Bonded PMs for electric machines	Iver Anderson	Bill McCallum Matt Kramer	$325K

Electrical Machine Research and Development

Support Projects	Applied Research and Commercial Development – Confirmation of Specific Performance Targets and Tradeoffs (commercialization in 2007 to 2010)	Fundamental Research and Technology Development – Scope Range of Performance Targets and Tradeoffs (commercialization in 2010 to 2015)	Basic Research and Science – Validation of Performance Target Opportunities (commercialization in 2015 to 2025)

3.3 Advance Traction Motor Development RFP ($705K), John Hsu

IPM Reluctance Motor with Brushless Field Excitation, FY04 John Hsu

Benchmarking of Competitive Products, FY05 Bob Stauton

HEV Paramentric Study, FY04 Sam Nelson

3.2 Electric Motor Research and Development ($580K), John Hsu

- Design, simulate, fabricate, and test a reluctance interior permanent magnet with brushless field excitation machine
- Complete conceptual design for a hybrid secondary-uncluttered PM machine

3.1 Flux Weakening and CPSR Enhancement Techniques ($670K), John McKeever

- Voltage control (dc-dc boost converter study and evaluation), McKeever
- Direct flux control (flux weakening study and evaluation), Otaduy
- Inverter control (minimum current control for motors with concentrated windings), Lawler
- Inductance control (evaluate motors with concentrated windings), Bailey
- Reluctance control (evaluate reluctance contribution to PM motor performance), Otaduy

Bonded Magnets for Electric Motors ($325K), Iver Anderson

- Develop an alloy with increased remanence and energy product for 200°C operation
- Test alloy powders to verify magnetic properties and refine composition
- Modify fluidized bed process to enhance surface coating and adherence properties
- Develop bonded magnet samples
- Develop an insert molding process
- Enhance the fluidized bed coating process for large scale operation

Electrical Machine Project Barriers and Risk

AOP Task Number	Title	Barriers and Risk
3.1	Flux weakening, flux enhancement, & CPSR enhancement techniques	Cost effective method for coil switching. Limited number of flux control methods: 1) field excitation, 2) coil switching, 3) magnet temperature, 4) shunt the flux, and 5) mechanical.
3.2	Electric motor research & development	Back emf at high speed operation requires high voltage or field weakening strategies which will affect the final system cost.
3.3	Advanced traction motor development RFP	Preliminary discussions with motor manufacturers indicate that the motor power density goals and temperature requirements are difficult targets to attain simultaneously.
DOE Contract	Bonded PMs for electric machines	Alloy must have high magnetic strength and stability. Translate alloy from ribbon to droplet solidification. Robust process for more resistant particulate.

Electrical Machine Project Highlights and Status

AOP Task Number	Title	Highlights and Status
3.1	Flux weakening, flux enhancement, & CPSR enhancement techniques	Minimum current control. DMIC theory for PM machines is extended to reluctance machines using continuous current conduction.
3.2	Electric motor research & development	The reluctance interior-permanent-magnet motor with brushless field excitation combines the magnetic flux from the 1) PM's, 2) reluctance, and 3) the brushless field coil excitation.
3.3	Advanced traction motor development RFP	Proposal almost ready to send to DOE/ORO for final approval. Approximately 60 names from 40 companies have been identified as potential bidders.
DOE Contract	Bonded PMs for electric machines	Gas atomized Zr-stabilized near-final alloy. Near-final alloy improved for flake particulate trial. Industrial partner team secured for bonded flake trial.