2011 DOE Vehicle Technologies Program Review

Advanced Integrated Electric Traction System

Greg S. Smith
General Motors
May 11, 2011

Project ID # APE014

Overview

Timeline

- Start - October 2007
- Finish – May 2011
- 97% Complete

Barriers

- Cost
- Weight
- Performance and Lifetime

Budget

- Total project funding
  - DOE - $7.9M
  - GM - $13.5M
- Funding received in FY08, FY09, FY10, and FY11
  - GM - $7.0M
  - National Labs - $0.7M

Partners

- Ames Laboratory, Arnold Magnetics, AVX, DuPont, Infineon, Semikron, NREL, and Oak Ridge National Laboratory

Relevance - Project Objective

Overall FY08-FY11

- Develop and demonstrate advanced technologies for an integrated ETS capable of 55kW peak power for 18 seconds and 30kW of continuous power.
- The ETS is to cost no more than $660 (55kW at $12/kW) to produce in quantities of 100,000 units per year, should have a total weight less than 46kg, and have a volume less than 16 liters with a nominal 105°C coolant and >93% efficiency.
- The cost target for the optional Bi-Directional AC/DC Converter is $375.

May ’10 to May ’11

- Complete Build and Test

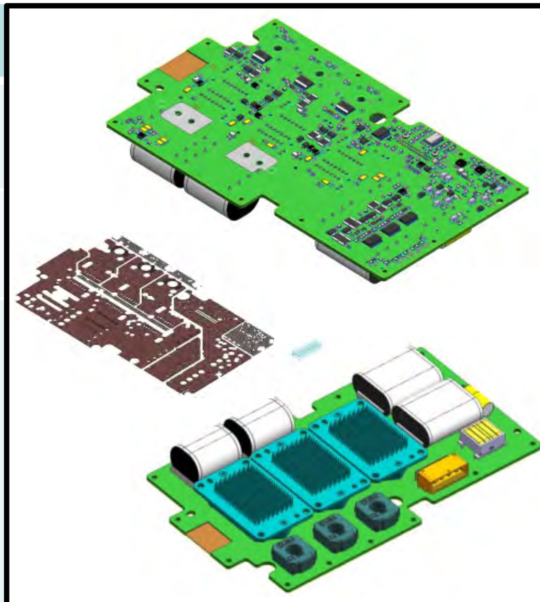
GM

Milestone

Timing	Milestone
April 2010	Environmental Test Setup –Design and fabricate fixtures for chamber setup.
June 2010	Complete AIETS Build.
October 2010	Electrical Verification - Electrical testing of Electric Traction System to requirements this includes a bench, dyne, and EMC radiated and conductive.
March 2011	Final Test Report – Documentation of all Electric Traction System test data generated
May 2011	Project Completion

Approach

Description	Reason
Develop accurate system specifications.	Reduce cost and increase reliability of system.
Motor - increase power density using multi-phase topology.	Reduce cost, less material needed for same power.
Board centric power electronics – heavy copper board (power and signal) with surface mount and press fit parts only.	Increase flexibility to adapt to vehicle applications, simplify manufacturing process, while improving electrical performance. Entire inverter on circuit board, up integration of bulk capacitor, elimination of lead free solder joint with press fit pins, and reduced inductance.
Power module – improve design, with new switches with on-chip current and temperature sense, reduced packaging inductance, and improved joint technology.	Integrate/increase functionality to reduce cost and increase reliability. Increase system protection for over current and temperature. Improve joining technologies to allow >175C junction temperature and will allow in the future increasing to >200C. Enable packaging to support future GaN/SiC switches.
Dc bus capacitor – eliminating housing, minimizing potting and bus structure	Reduce cost by eliminate non value added material and increase flexibility of scaling capacitance to system needs.



Heavy Layer Circuit Card Technology

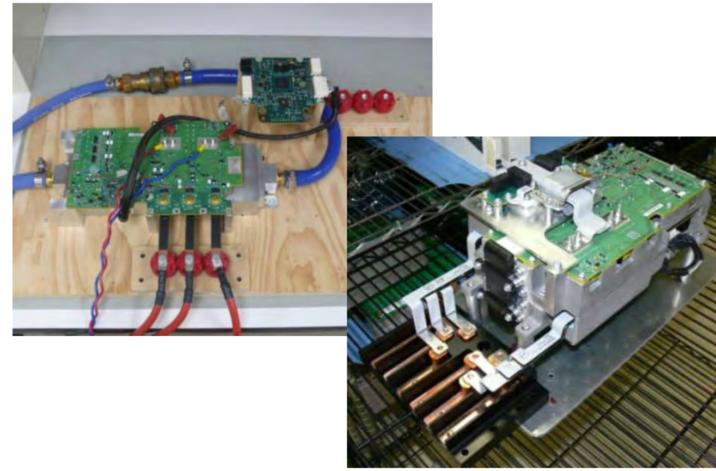
Strategy

- Use results of Phase I technology investigations and assessments and execute Phase II Development/Demonstration
- Phase II Development/Demonstration (8/08 – 5/11)
  - Develop detailed design of an Advanced Integrated ETS
    - Ensure compatibility with all vehicle requirements
    - Simplify and integrate ETS to meet technical targets
    - Work closely with suppliers and leverage National Lab materials, packaging, and analysis work
    - Applying learning from GM's electrification experience
    - Verify component technologies and document
  - Build Advanced Integrated ETS and characterize
    - Prove the viability of the technologies through 7 tests designed to assess hardware performance for temperature, vibration, and EMC

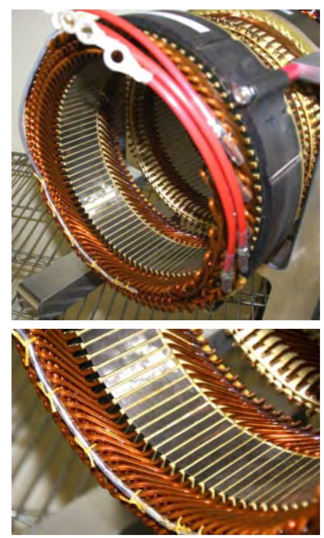
GM

Accomplishment - Build

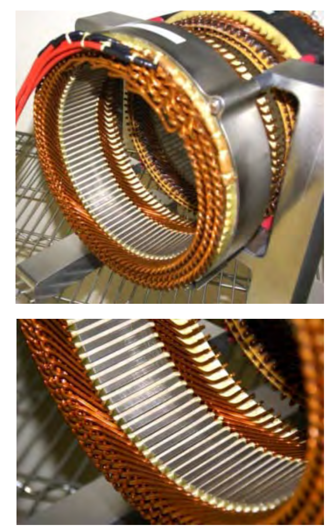
- Inverter
  - Two open units for electrical evaluation and controls development
  - Ten complete units for ESS, EMI, ETS
- Motor
  - Three axial inserted
  - Two radial inserted



Axial Inserted



Radial Inserted



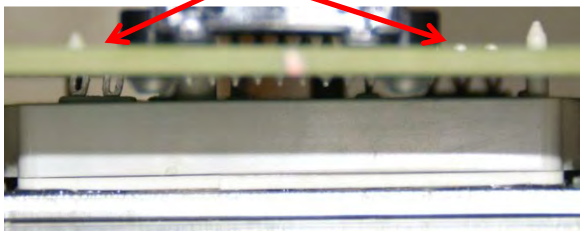
Accomplishment – General Learning's

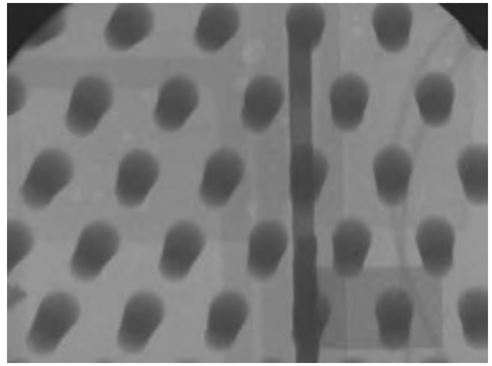
Every new technology/component when placed into a system create new engineering problems that must be addressed

- Interfaces and component tolerances drove significant engineering effort
- Variability of prototype component parts make it highly difficult to understand integration issues, especially when dealing with systems that are highly integrated
- Component builds need to be off of tooling, even though costly, to minimize process variables
- Manufacturing process learning's will be placed back into design tools

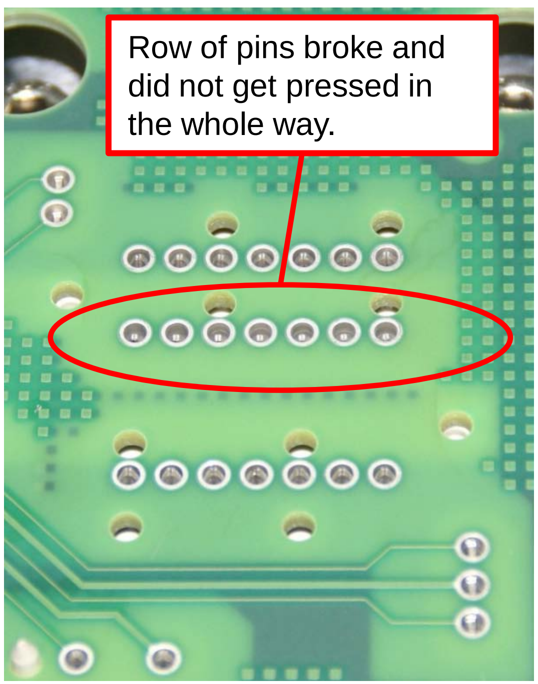
Accomplishment – Power Module Learning's

Pin engagement uneven due to pin xy location on dbc.





Light spots are solder voids under die

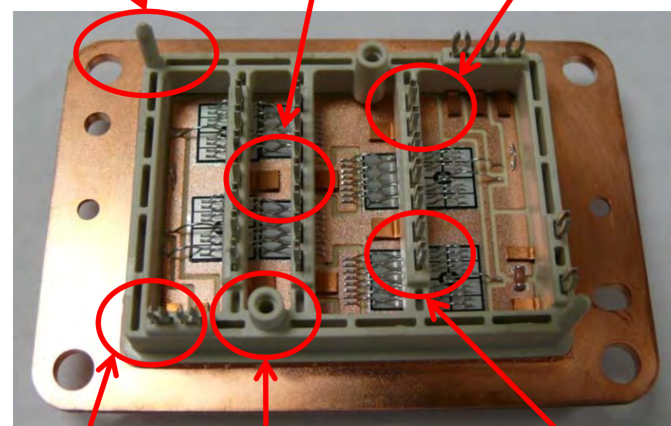


Row of pins broke and did not get pressed in the whole way.

Spacing between ultrasonic welds needs to be increase in production.

1. Must be able to align substrate to heatsink.
2. Plastic frame to substrate and heatsink.

Plastic must provide alignment and significant structure for press fit pin.



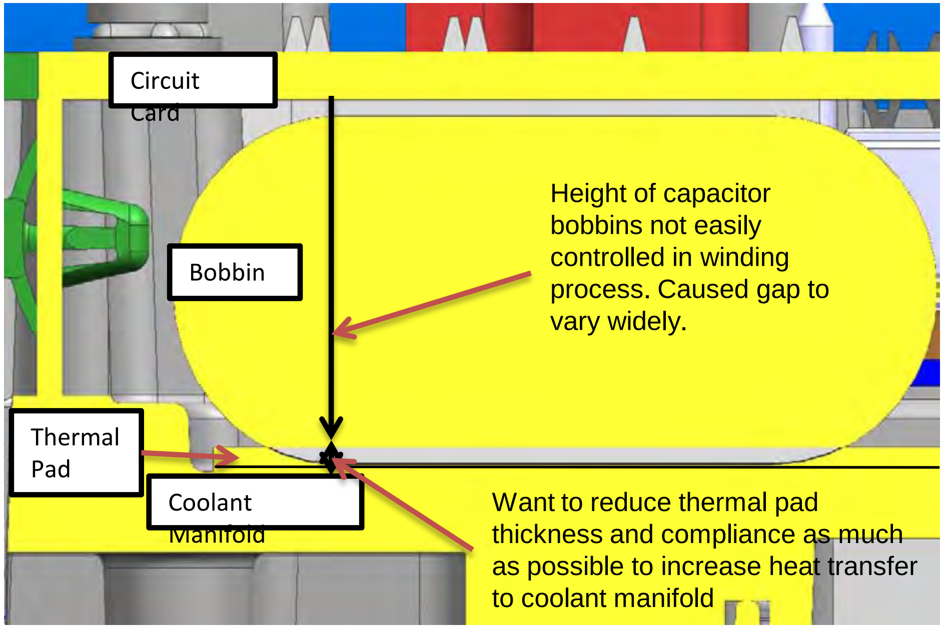
Plastic needs to take mechanical load when installing gate drive not ultrasonic weld. As you press on Pin it should transfer load to plastic.

Height reduced to eliminate interference with board

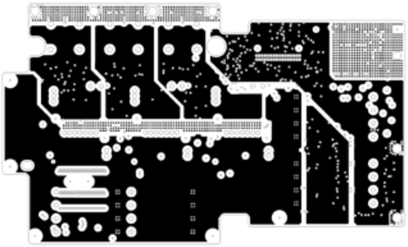
Eliminate cantilever of pins

Accomplishment – Capacitor & Heavy Copper Board Learning’s

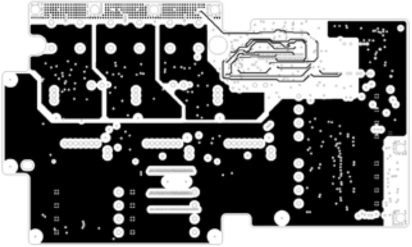
- Capacitor
  - Variation in bobbin diameter greater than expected
  - Soldering of capacitor to heavy copper board difficult
- Heavy Copper Board
  - Few manufactures available
  - Cannot use fine pitch devices
  - Difficult to solder devices
  - Aspect ratio requires larger diameter via’s
  - Need to reduce gate drive component count to reduce infringing on bus heavy copper layers
  - Decouple gate drive ground plane



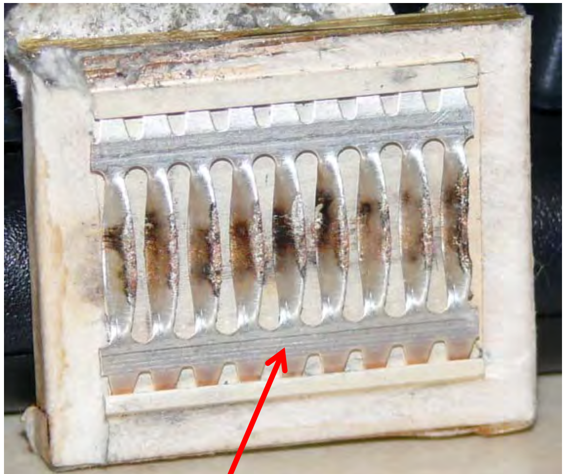
Gate Drive Board DC +



Gate Drive Board DC -

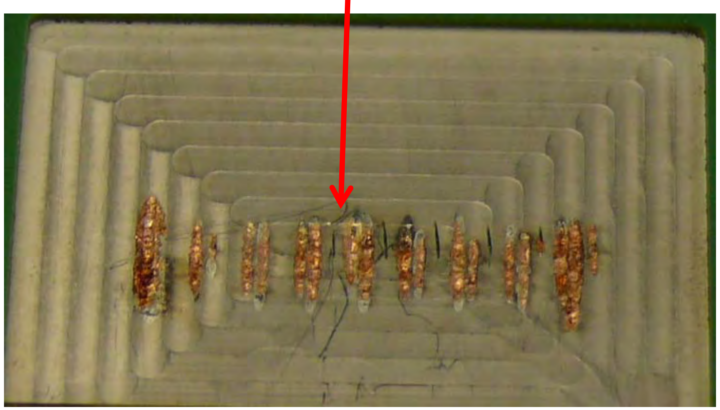


Accomplishment – DC Bridge Learning's



Damage resulting from poor louver contact

Lack of compression in louvered contact led to arcing between circuit card and busbar contact

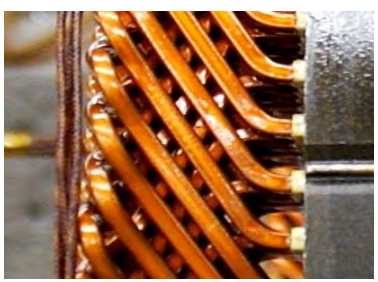


Contact compression needs to be 0.3 to 0.5mm for high current.

Accomplishment – Motor Design Learning's

A leakage inductance of 125uH was determined by comparing test and simulation results which is significantly higher than the original assumption in the simulation model of 60uH.

- Much longer end turns than expected due to current manufacturing process capability
  - +4mm on crown end side
  - +5mm on weld end side



Crown end

Weld end

Accomplishment – Motor Build Learning's

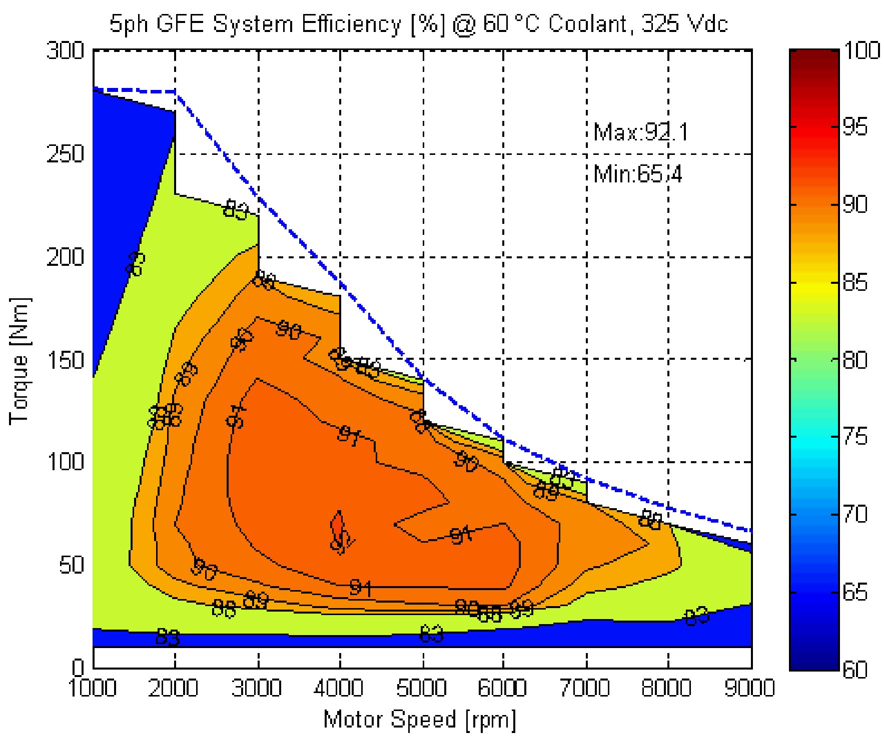
5-Phase Stator :
- 90 slots
- 6 conductors per slot
- Longer span
- Deeper slots
- Slot width is narrow
- Thin conductor
- Slot liner thickness is thin

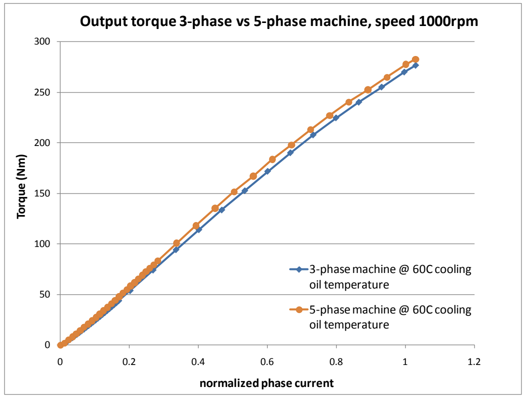
- 5-Phase Challenges
  - Longer span ➔ Leads to higher spring back rate
  - Longer span ➔ Leads to longer endturns length
  - Longer span ➔ Severe coils forming ➔ Tougher to manufacture
  - Thinner conductor (under preformed crown end) ➔ Harder controlling final designed shape and conductor relaxation due to pre-stress is much greater
  - 6 conductors / 3 layers ➔ Harder controlling the spacing / clearance between conductors
  - 6 conductors / 3 layers ➔ Difficult for welding due to spacing between them
  - 6 conductors / 3 layers ➔ Difficult to control coils O.D & I.D
  - 6 conductors + thin liners ➔ Difficult to control coils + liners axially during insertion due to sliding
  - 90 slots + 6 conductors/slot ➔ Result more coils to work with
- Axial Inserted Unique
  - 6 conductors per slot ➔ Leads to complicated and expensive weld-end twisting tools
- Radial Inserted Unique
  - Open slot ☐Leads difficult to insert conductors + slot liners radially due to friction while positioning conductors + slot liners axially
  - Open slot ☐Additional coils retaining processes such as lacing cords (both ends) must be used to restrain coils inside open slots during and after insertion

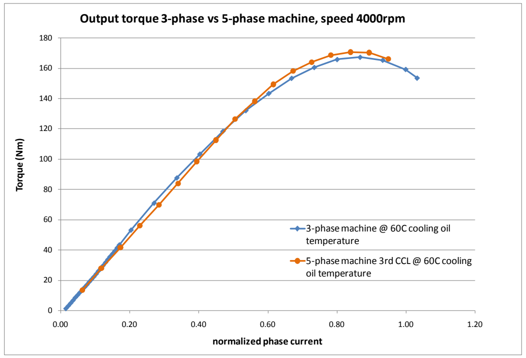
- Process development needed for AUTOMOTIC forming/inserting/twisting/trimming/welding/ lacing procuring tools
- Additional development to optimize the coils design for friendly manufacturing

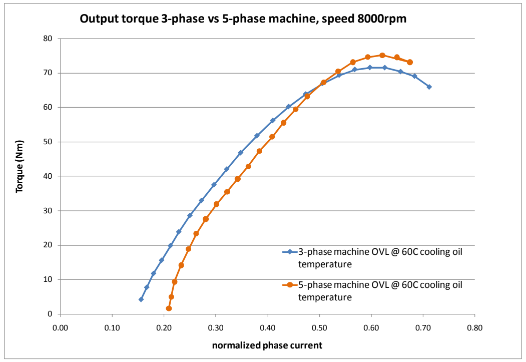
Accomplishment – ETS Dyne Testing

- Dyne testing
  - Peak torque requirement is fulfilled > 270Nm
  - Torque per Ampere is slightly higher for 5-phase than 3-phase machine.
  - The max torque gain compared to 3-phase is lower than expected due to higher end turn leakage inductance.
  - Efficiency Max 92.1



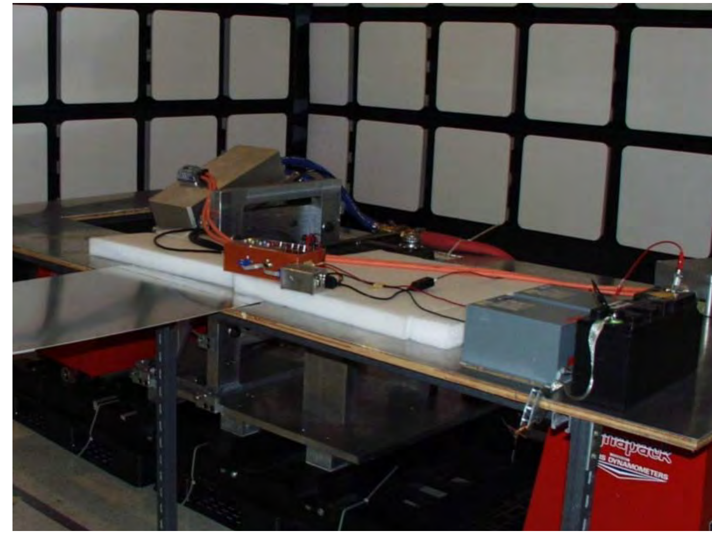


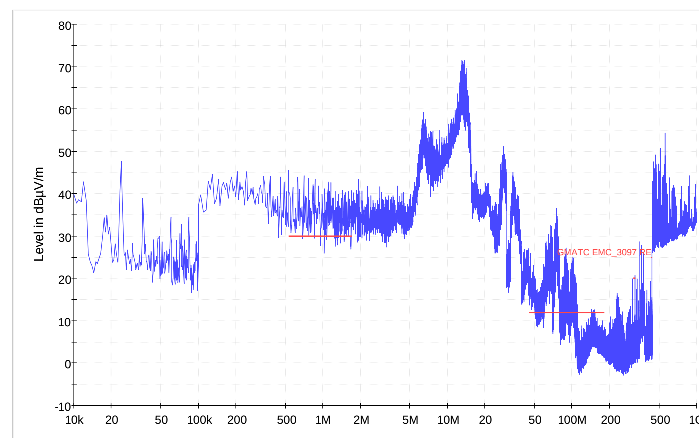




Accomplishment – ETS EMI Testing

- Determine the Radiated and Conducted Emissions of the 5-phase AIETS. The following tests were completed:
  - RE GMW 3097 – AIETS in wakeup and drive modes
  - CE GMW 3097 – LISN on 12 V + and 12 V return lines
  - CE with current probe – Measure common mode current on all external cables.
- Bia's supply needs to be re-laid out to meet GM EMI requirements

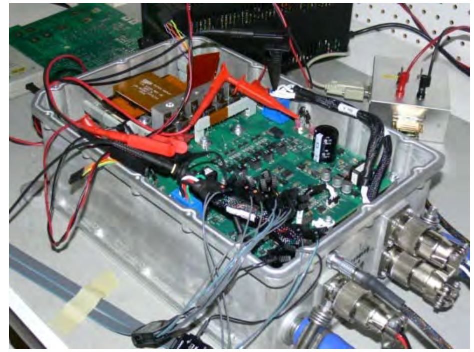


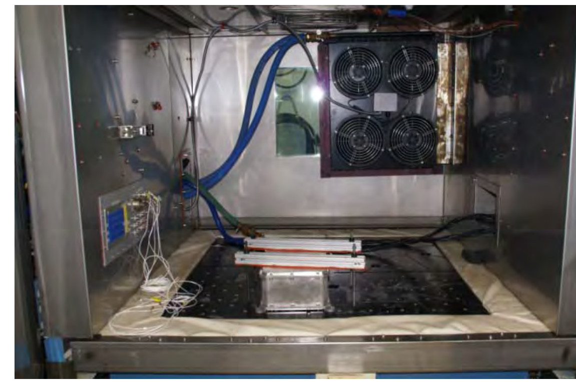


RE DOE 5-PHASE AIETS
300 HVDC & 12V - ENABLED
DRIVE MODE-ENABLED; 1KRPM
08MAR11

Accomplishment - Charger

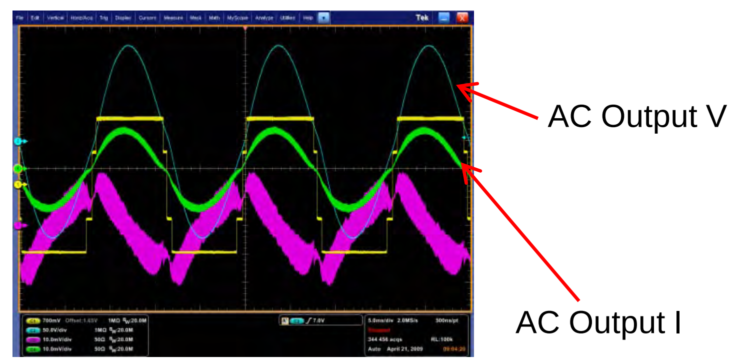
- Units built
- Testing
  - Electric Power Take-off
  - Charging
  - ESS
- Established collaboration with EPRI for battery to grid





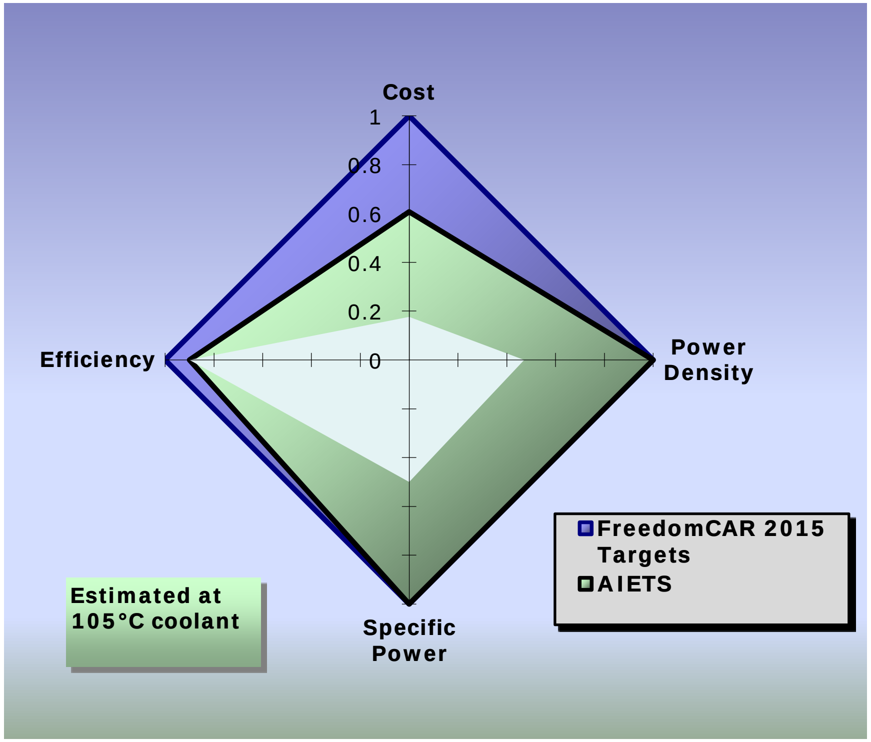
Charging Mode

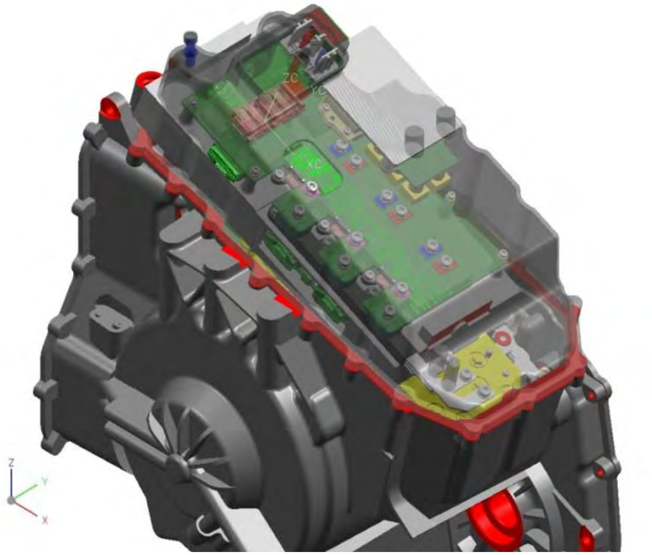
EPTO Mode



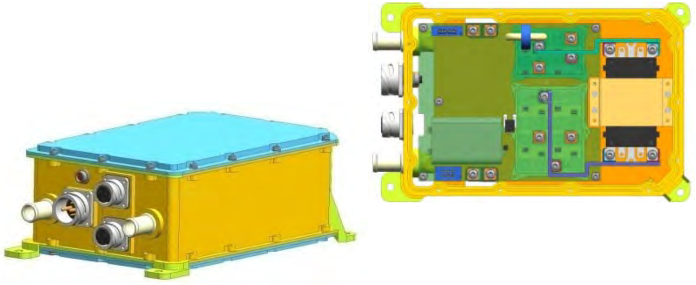
Accomplishments - Program

- **Technologies assessed : 29**
- **Configurations/Types: 36**
  - **Topologies, bus, EMI filtering, components, and concepts**
- **Patents: 31**
- **Compatibility with vehicle production**





Integrated Motor and Inverter



Charger

Collaboration

- AIETS GMATC
  - Systems
  - Motor
    - Magnets: Arnold Magnetics, (S/C) Hitachi Metals, TDK, Chevron Mining
    - Lab Support: Ames (materials)
    - Materials: Mitsui-High-tec, L.H. Carbide, Hoganas, Tempel, & IAP
  - Inverter
    - Power Module: Infineon &Semikron
    - Capacitor: AVX (S/C)
    - LAB Support: ORNL & NREL (materials, joining tech., switches)
    - Materials: DuPont, Kyocera, Murata, &Curamik
  - Charger
    - Power Module: IXYS, Teledyne
    - Capacitor: ASC
    - Applications/Usage: EPRI

GM, Suppliers, and National Labs cooperation has been of great benefit to the program and has provided input into other existing Vehicle Technologies projects.

Proposed Future Work

- FY11
  - Complete characterization testing of ETS and Charger
  - Verification Tests with Government Lab
  - Issue final report

Summary

General Motors is applying a systems approach to the ETS and how it is used in vehicle applications

- Relevance
  - Meet DOE 2015 targets
- Approach/Strategy for Deployment
  - Proper requirements, improve power density through topology, board centric design, and automotive regimented development
- Technical Accomplishments and Progress
  - Completed build
  - Testing
    - ESS
    - Dyne
    - EMI
- Collaborations and Coordination with Other Institutions
  - Extensive work being done with suppliers and National Labs that also has provided input into other existing Vehicle Technologies projects
- Future Work
  - Witness testing

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