U.S. DEPARTMENT OF ENERGY

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

Converter Topology for Wired Onboard Battery Chargers

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Overview

Timeline

- Start – FY11
- Finish – FY13
- 50% complete

Budget

- Total project funding
  – DOE share – 100%
- Funding for FY11
  – $537K
- Funding for FY12
  – $415K

Barriers

- Reducing onboard battery charger cost, weight, and volume
- Achieving high efficiency

Partners

- **ORNL team member:** Lixin Tang, Cliff White
- ORNL vehicle systems group

Objectives

- **Develop a 5 kW integrated wired battery charger that fully utilizes the existing onboard power electronics components to reduce the cost, volume and weight and simultaneously provide galvanic isolation and the capability of charging fully depleted batteries**
- **The goal is to reduce the weight, volume, and cost of the plug-in HEV charger by 70%, compared to that of a standalone charger**

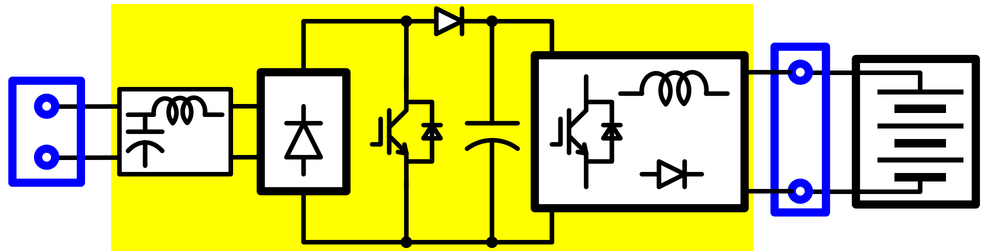
- **FY11:** Perform a circuit simulation study and generate a converter design for a 5 kW integrated wired charger
- **FY12:** Design, build, and test a 5 kW isolation converter (a part of an integrated wired charger)

Milestones

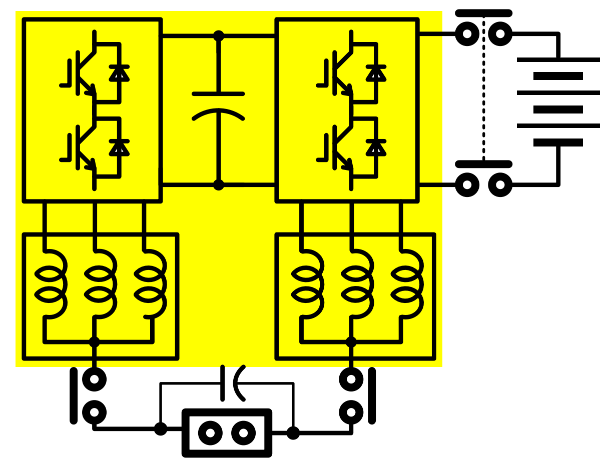
Month/Year	Milestone or Go/No-Go Decision
Sept-2011	Milestone: Complete the simulation study on selected converter topologies for wired and wireless charger applications. Go/No-Go Decision: If simulation results show potential for meeting cost, weight, and volume goals with superior efficiency, proceed to prototype development in FY12.
Sept-2012	Milestone: Complete testing a 5 kW isolation converter. Go/No-Go Decision: If converter test results meet efficiency target of 97 %, proceed to build and test a 5 kW charger in FY13.

The Problem and Approach

- An on-board standalone battery charger
  - Adds a significant cost (projected at $300~400)
  - Is typically unidirectional (can only charge the battery but not capable of V2G support)



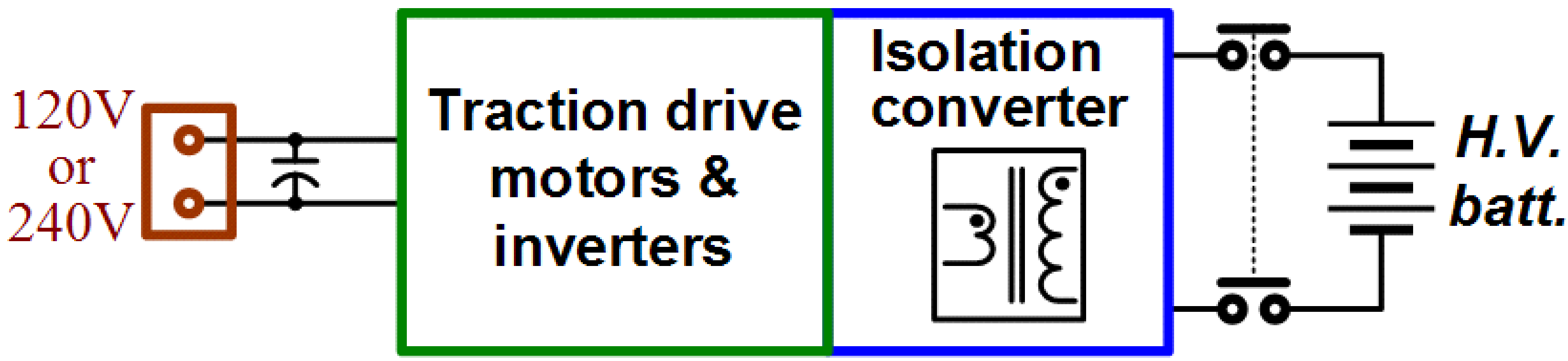
- The approach of using the on-board traction drive inverters and motors for charging the battery overcomes the issues with standalone battery chargers but
  - difficult to provide galvanic isolation to address safety concerns
  - cannot charge "dead" batteries



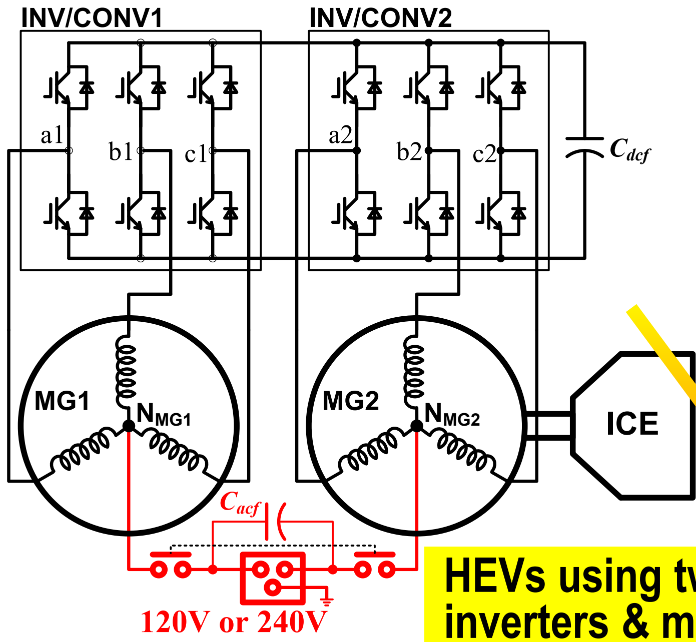
- ***Approach***: Using the existing on-board power electronics components to reduce cost and accomplish galvanic isolation

Description of Technology/Approach (1)

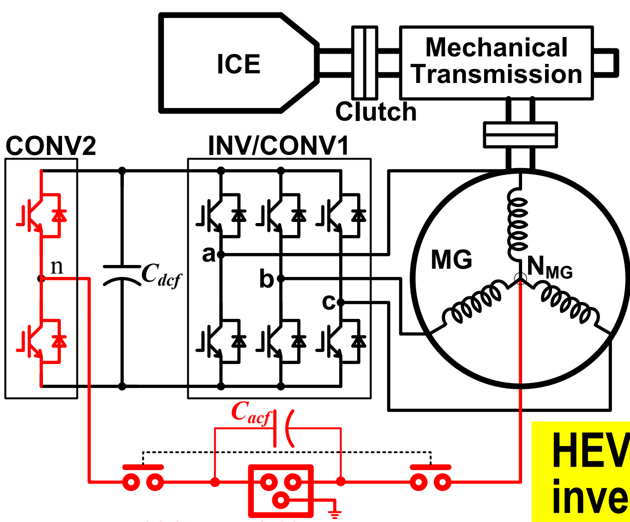
- Utilize the traction drive inverters and motors as part of the charger converter
- Provide galvanic isolation and capability for charging fully depleted batteries
- Use soft switching for electromagnetic interference (EMI) reduction and efficiency improvement
- Provide level 1 & 2 charging rates



Description of Technology/Approach (2)

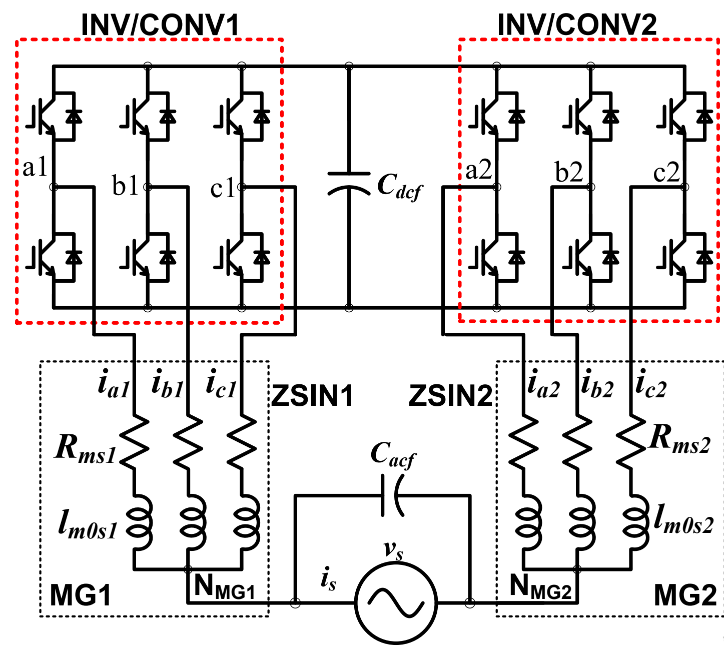


HEVs using two inverters & motors



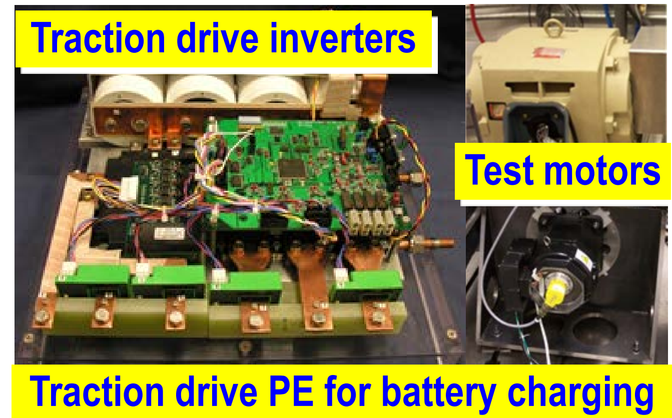
HEVs using single inverter & motor

- **Utilize the traction drive inverters and motors as part of the charger converter**
  - **Three phase inverters as a single phase converter**
  - **Motor zero sequence impedance network (ZSIN) as filter inductor**



Technical Accomplishments – Summary

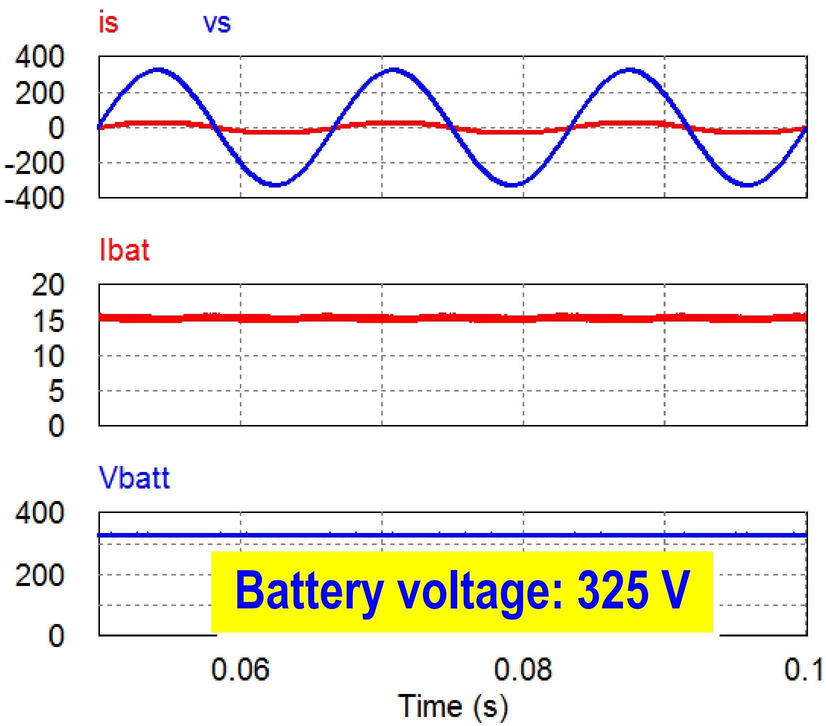
- Built upon a previous project that demonstrated an integrated charger (no galvanic isolation) with:
  - 90% cost reduction compared to a standalone charger
  - high efficiencies of 93~97% (SOA: 84~93%)
  - charging, mobile power generation, and vehicle-to-grid operations

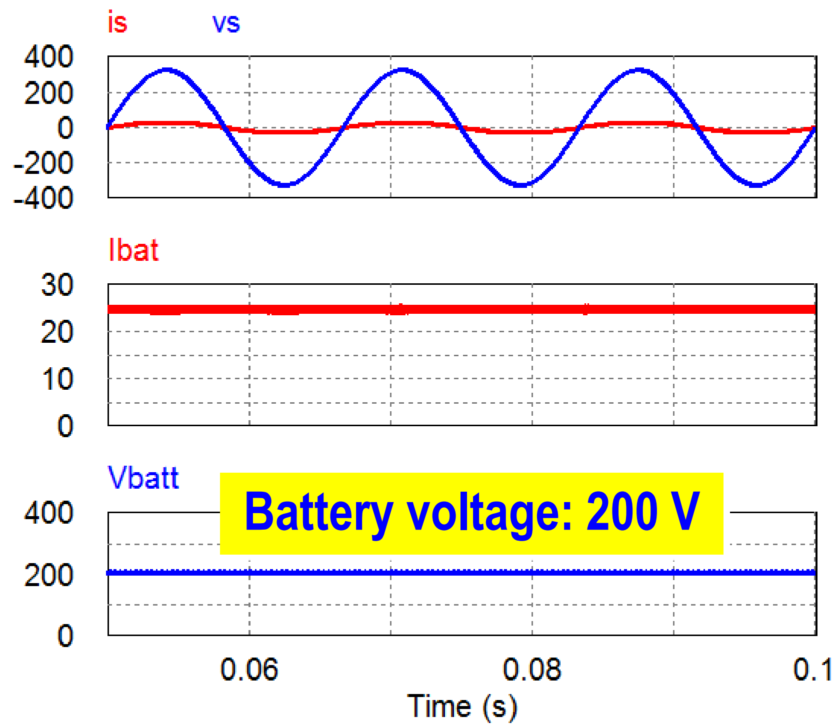


- FY11 simulation results confirmed the new topology
  - can achieve the goal of reducing cost, weight, and volume by 70 %
  - can meet galvanic isolation requirements
  - can charge at nominal and fully depleted battery voltage levels
  - has high power factor and low current THD
- FY12
  - Completed hardware design for a 5 kW isolation converter
  - Partial completion of major component assembly and tests

Technical Accomplishments – FY11

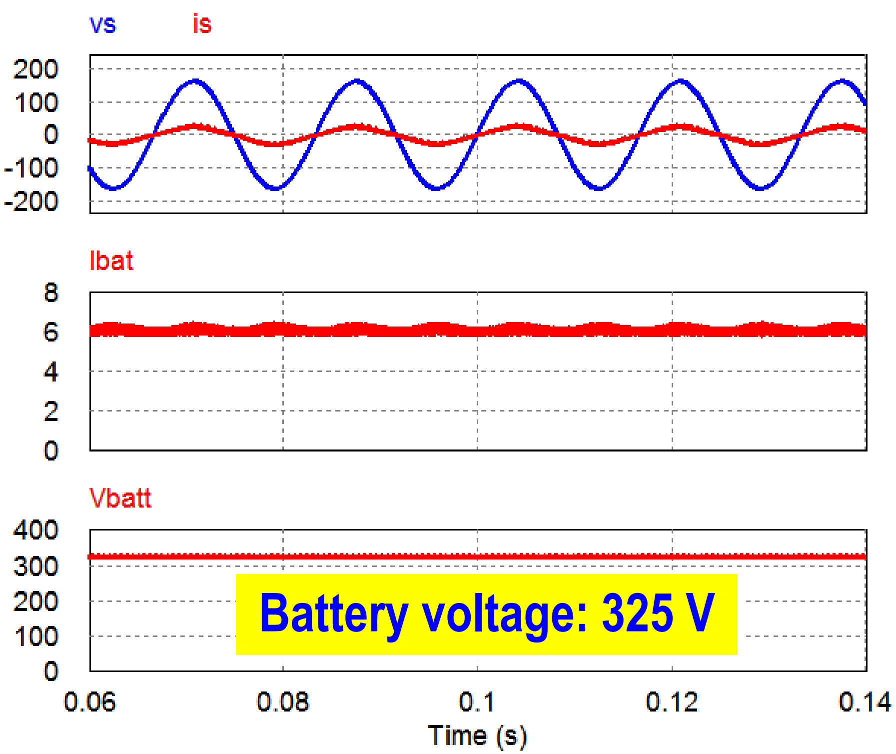
- Simulation results for charging at 5 kW from 240 V input; showing
  - capability for charging at nominal and fully depleted battery voltage levels
  - very low total harmonic distortion factors (the input source currents are sinusoid shaped)
  - high power factor (the input source currents are in phase with the source voltages)

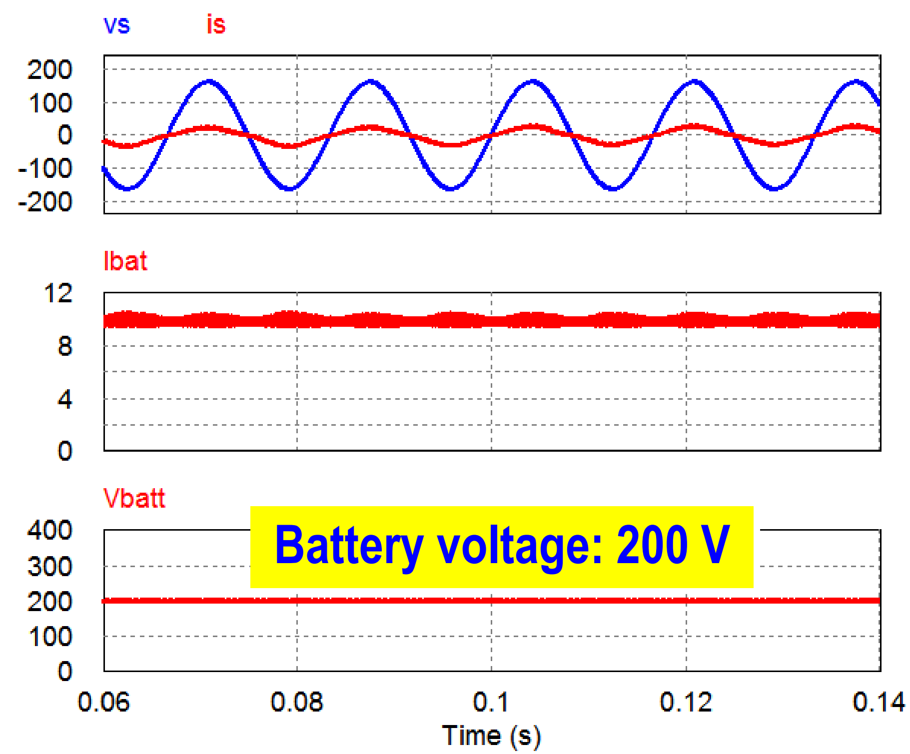




Technical Accomplishments – FY11

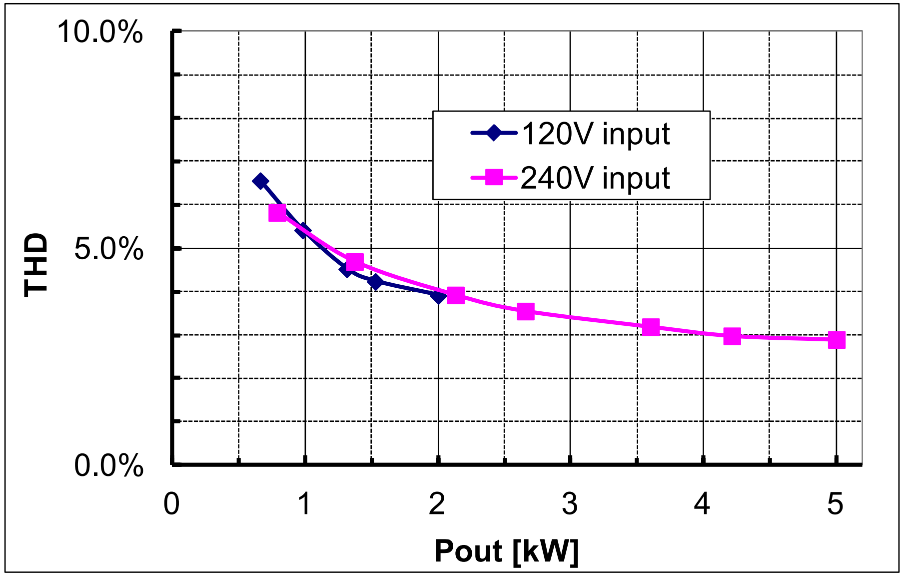
- Simulation results for charging at 2 kW from 120 V input; showing
  - capability for charging at nominal and fully depleted battery voltage levels
  - very low total harmonic distortion factors (the input source currents are sinusoid shaped)
  - high power factor (the input source currents are in phase with the source voltages)



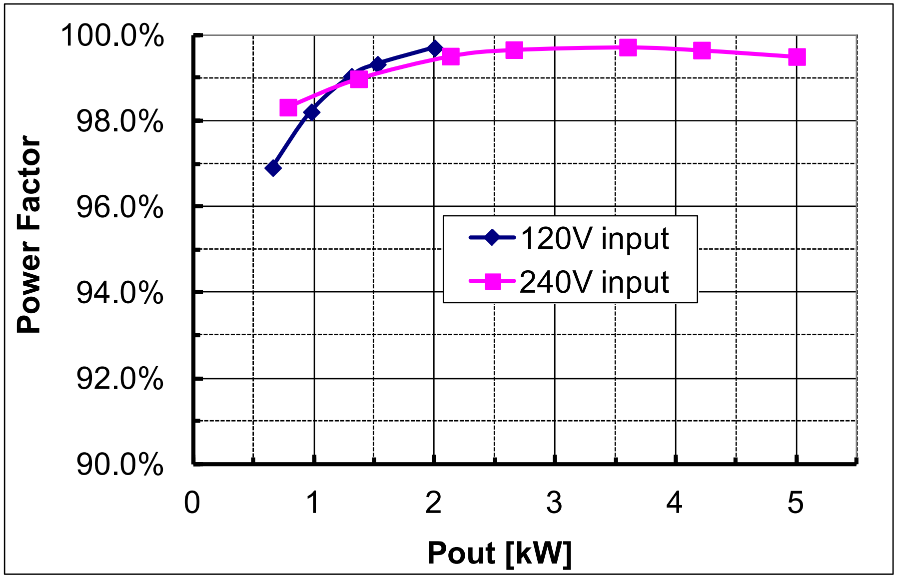


Technical Accomplishments – FY11

- **THDs are in the range of 2.8~6.6% and lower than 5% when charging rates are over 1 kW.**
- **Power factors are in the range of 97~99.6% and greater than 98% when charging rates are over 1 kW.**



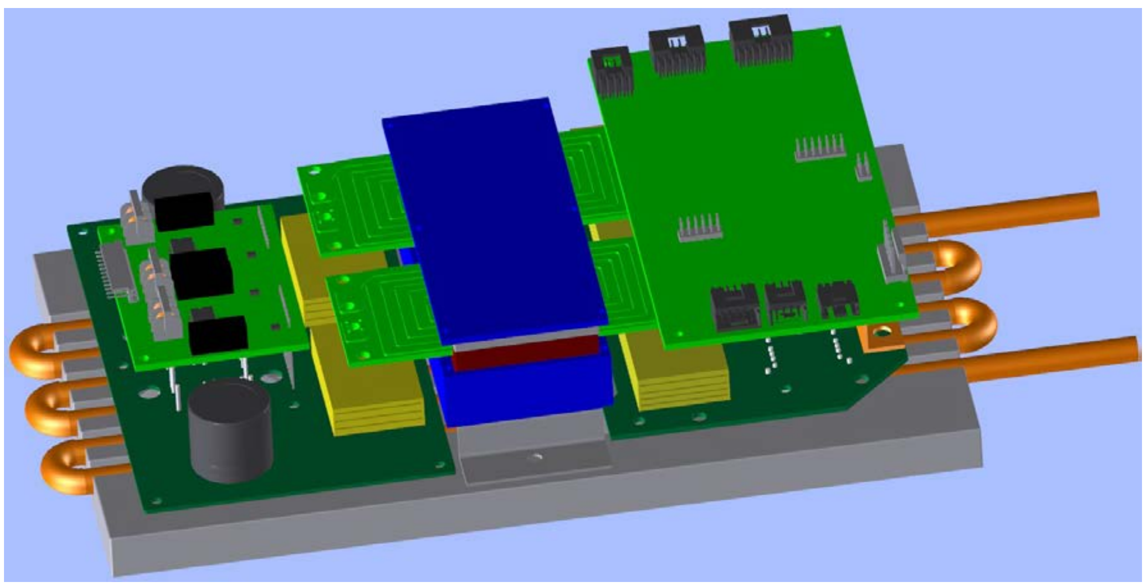
THD vs. charging power



Power factor vs. charging power

Technical Accomplishments – FY12

- Completed hardware design for a 5 kW isolation converter using
  - Planar transformer with PCB windings for compactness and easy automated assembly
  - Heavy copper PCB for power connections
  - CoolMOS MOSFETs for low conduction loss
  - Soft switching for low switching loss and EMI

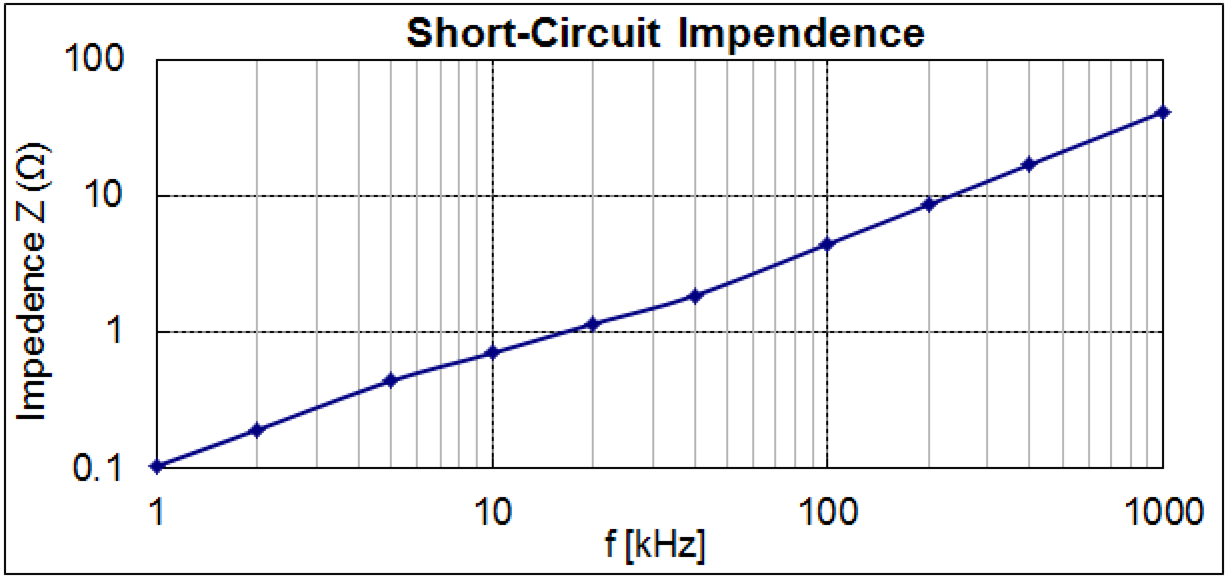


Hardware design for a 5 kW isolation converter

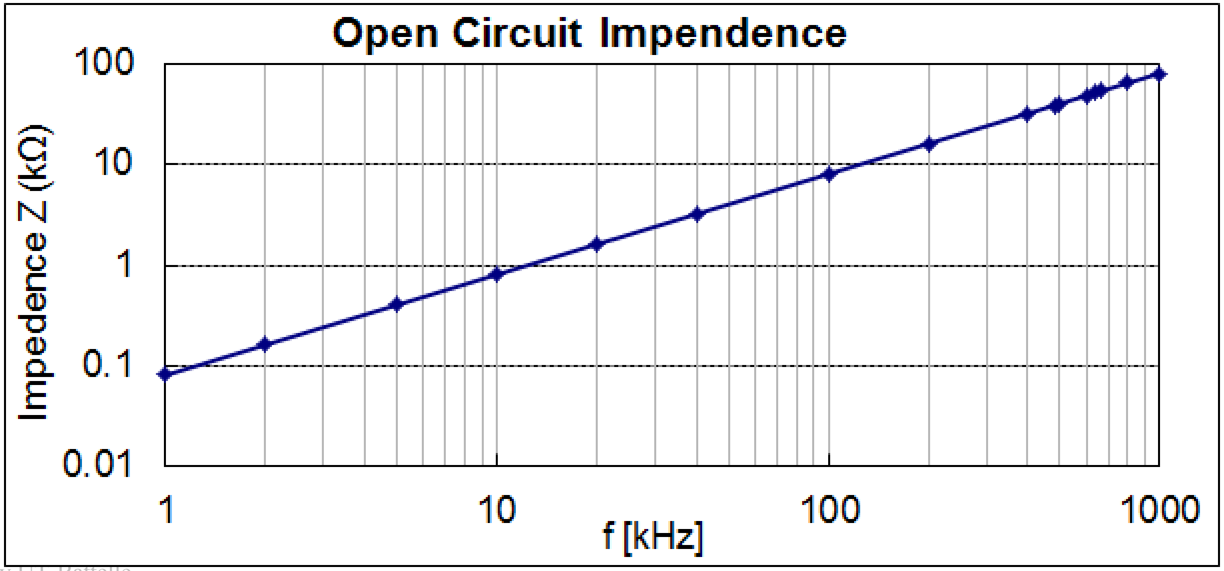
Planar transformer assembly

Technical Accomplishments – FY12

- **Transformer tests**



Secondary short-circuited



Open secondary

Collaborations

- ORNL vehicle system group
  - Vehicle system requirements

Future Work

- Remainder of FY12
  - Complete fabrication of a 5 kW isolation converter
  - Develop digital control algorithms and implement with a TI dsp
  - Test and characterize the 5 kW isolation converter

- FY13
  - Employing the isolation converter built in FY 12, design, build and test a 5 kW integrated charger prototype

Summary

- The integrated wired charger can significantly reduce cost, weight, and volume by minimizing additional components through utilization of on-board power electronics components and can
  - Provide galvanic isolation
  - Charge from 120V and 240V outlets
  - Charge fully depleted batteries
  - Provide V2G support
  - Improve efficiency

- Good progress on design and test of a 5 kW prototype